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Research Article

Properties of briquettes and pellets of pine needles from Hattiban Community Forest, Kathmandu, Nepal

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Abstract

Biomass is the most utilized primary energy source in context of Nepal. Briquetting of pine needles can be an option for natural resource management. This research work was carried out to quantify the amount of pine needles during the fall season and to study the combustion properties, performance and emission of the briquette produced. The study was carried out in Hattiban Community Forest of Kathmandu district. In order to quantify the pine needle, simple random sampling was used. The average weight of needles in field was observed to be 751g m^{-2}. Altogether, four types of briquettes and two types of pellets were produced using different binders and various briquetting technologies. Proximate analysis was carried out following the Japanese Industrial Standards (JIS 8812) and the calorific value test was done using Toshniwal Digital Bomb Calorimeter. The result from the proximate analysis showed higher (32.93%) amount of ash content of beehive briquette. Calorific value test of the fuel showed that high pressure pellets had the higher heating value (5555.1 kcal kg^{-1}) and beehive had the lower heating value (3801.4076 kcal kg^{-1}). The water boiling test reveals that thermal efficiency of the stove was highest (39.1%) when operated with high pressure pellet and low (24.76%) for charcoal pellets. Except high pressure pellets, other briquettes and pellets exceeded the safe limit of carbon monoxide and particulate matter emission given by National Indoor Air Quality Standard. Fuel characteristics like high thermal efficiency, high calorific value and proximate value obtained from present analysis shows pine needles can be used as appropriate and sustainable source of energy.

Keywords: Biomass, Briquetting, Calorific value, Proximate analysis, Pine needles

Introduction

Biomass is considered to be one of the key renewable energy resources, which are indigenous and often cheap, both at small and large scale. Among the renewable energy sources which will ultimately replace the use of fossil fuels over time, the largest contribution, especially in the short to medium term, is expected to come from biomass. In developing countries, over 2.5 billion people still rely on biomass for cooking. Biomass accounts for more than 90% of household energy consumption in many countries (IEA, 2006). In the last three decades, global energy consumption has almost doubled due to global economic growth, continued urbanization as well as the increased demand on mobility and other energy dependent services (Gadonneix et al., 2012). In Nepal, traditional or biomass source of energy has the greatest share in the current energy scenario. Pine needles have traditionally been used as direct fuel as well as for their gasification into producer gas to cater the rural energy needs. However, direct combustion of biomass has negative implications due to the intrinsic properties such as low density, low calorific value in a unit volume and high moisture, etc. Therefor, it is important to develop strategies to convert biomass to secondary fuels having better characteristics in comparison to the parent material (Kaur et al., 2017). The increasing availability of biomass, combined with the current development of technologies to use it efficiently with low range of emissions, promise for making biomass fuel a more attractive option. Compacting biomass waste into briquettes increase the bulk density of biomass, thus storage, transportation and handling costs reduce by almost 10 times, making it much easier to store and transport than loose biomass waste. These energy sources are available indigenously and are known as alternative sources of energy. This form of energy is clean or inexhaustible and can decrease the environmental pollution, but is still under-utilized due to the handling, transportation, storage and combustion issues (Matiru, 2007). Briquette could be made of different shapes and sizes depending on the mold and are normally cylindrical or rectangular in shape (Garriot, 2004). Briquettes do not contain any sulphur, so they are immeasurably cleaner than the other fuel alternatives, especially coal. Briquettes have several

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advantages over fuel-wood in terms of greater heat intensity, uniform and ideal physical dimensions, and combustion characteristics result in more efficient energy conversion (Kaliyan et al., 2009). Pine needles cover large portions of the Himalayan region and being loose forest residue, it is totally waste material. People frequently use kerosene, which is expensive and highly damaging to health and the environment, as a cooking and backup lighting source. There are numerous ways to resolve these problems, of which briquetting and/or pelletizing biomass are the most commonly utilized technologies (Vance, 2009). Briquettes produced from waste; through a simple process are a good source of energy and environment friendly and alternative energy for replacing fossil fuels (Roy et al., 2015). During the energy crisis, use of pine needle for making briquette and pellets could be proper utilization of waste for solving energy problem with an alternative source of energy. Therefore, the present study was carried out with the aim of determining energy efficiency of briquettes and pellets made from the pine needles, quantifying the amount of pine needles produced in the study area and evaluating performance and emission of briquettes and pellets.

Materials and Methods

Study Area

The study was carried out in Hattiban Community Forest which has an area of 39.734 ha (Fig. 1). It is located at south west corner of Kathmandu Valley, approximately 6 km away from Pharping. It lies at geographical coordinated between 27°38'1.37"N latitude and 85°15'49.00"E longitude. The forest is homogenously dominated by *Pinus roxburgii*.

Methods

For the quantification of pine needle litter simple random sampling was performed. Sampling plots were obtained using 0.01% sampling intensity as recommended by community forestry inventory guideline 2004. The briquette production process involves the collection of raw materials, grinding, mixing and densification. In this study, both brown briquettes and carbonized (black) briquettes were produced. Three types of brown briquettes were produced, i.e. in low compaction (using paper as a binder) and under high pressure using the screw extruder briquetting machine. Two kinds of low compaction briquette were produced using different ratio of pine needle powder and paper. Both were produced using 70% pine needle powder and 30% paper binder. Similarly, beehive briquette was produced using mixture of pine needles and clay in 60:40 ratios. Charcoal pellet was the mixture of pine needle char (95%) and CMC (carboxy methyl cellulose) 5%. High pressure pellet was the mixture of pine needles (70%) and wood shavings (30%) and the screw extruder briquette was produced without using any binder. The pine needle briquette sample was analyzed in the laboratory of Center for Energy and Environment Nepal (CEEN). Proximate analyses of the samples were carried out following the procedures of the Japanese Industrial Standard (JIS, 8812). It was performed to determine the percentage of volatile matter (% VM), ash content (% AC), moisture content (% MC) and fixed

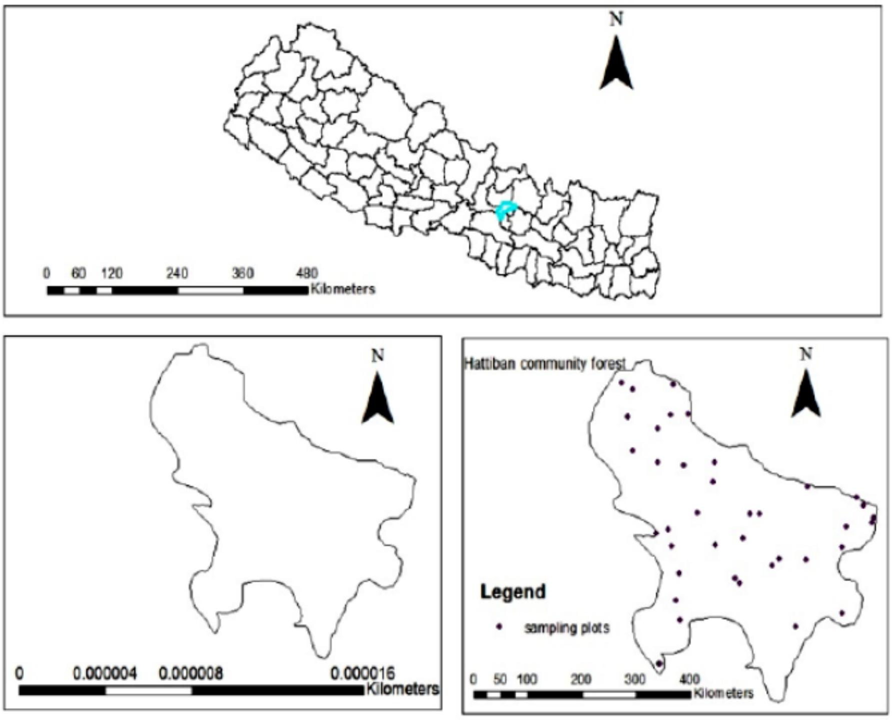


Figure 1 Location of Hattiban Community Forest and sampling points

carbon content (% FC) of the briquettes sample. Calorific value of the different biomass and briquettes samples were determined using Toshniwal Digital Bomb Calorimeter with the digital differential temperature or firing unit. Water Boiling Test was carried out to compare the cooking efficiency of the briquettes. The water boiling test was conducted as per the standard method described by Aprovecho (Water Boiling Test version 4.2.4) through Agni stove with some modifications. During this test, fuel characteristics like thermal efficiency, specific fuel consumption, boiling time, ignition time and burning rate was calculated. Also, carbon monoxide (CO), particulate matter ($PM_{2.5}$, PM_{10}) and carbon dioxide (CO_2) emission test from the combustion of fuel were also performed. Flame temperature was recorded using Fluke data logger during the water boiling test. CO emission was measured by the Fluke CO meter as described in Water Boiling Test Version 4.2.4. Similarly, Air Visual's new Node device based on laser sensor technology was used to measure $PM_{2.5}$ and CO_2 concentration. The data obtained from the field study as well as experimental analysis were analyzed using MS Excel.

Results and Discussion

Pine needles quantification

The amount of needles varied between 0.585 kg m^{-2} and 1.220 kg m^{-2} with an average weight of 0.751 kg m^{-2}. The amount of the litter in the periphery was found to be lower than that of the core part. It was due to human disturbance, as people used to come there for picnic and litter collection in the peripheral area, while the central part was relatively undisturbed. According to Bhattarai et al. (2009), in Nepal, pine forest occupies 382,944.80 hectares area. The present results show that the total litter fall in the study area during the fall season may reach up to 7.84 tons ha^{-1}. Taking this as a reference and the pine forest area (382,944.80 ha) of Nepal, around 3002287.232 tons pine needle will be available.

Proximate analyses of biomass and fuels

The results show moisture content in the range of 5.6% to 26%. Volatile matter content varied between 25.79% and 71.85 %. Ash content of beehive briquette was found to be highest (32.93%) followed by charcoal pellet (21.87%), screw extruder briquette (5.33%) and circular briquettes (5.33%). Fixed carbon content of charcoal pellet was (36.1%) followed by beehive (23.96%), screw extruder briquette (23.02%), high pressure pellet (16.89%), circular briquette (15.77%) and square briquette (12.93%) (Table 1).

Moisture content

The moisture content of the pine needle was found to be 8.41% (data not shown) which is within the acceptable working moisture content of 8-12% (Eriksson & Prior, 1990). The moisture content obtained in the present research is safe for briquette production. The moisture content of the pine needles in the present study is 8.46% which is lower than the value, i.e. 9.76%, reported by Pandey and Dhakal (2013), *Eupatorium adenophorum* (9.22%)and *Lantana camera* (12.12%) (Pandey & Regmi, 2013).

Volatile matter content

Volatile matter content of the biomass and fuel sample was high and signifies easy ignition of the briquette and proportionate increase in flame length as suggested by Loo et al. (2008). High volatile matter content indicates easy ignition of fuel (Bisht et al., 2014). Biomass typically has high (up to 80%) volatile matter content (Efomah & Gbabo, 2015). Pine needles briquette contains volatile content of nearly 70% which indicates easy ignition of the briquette. Volatile matter of the pine char (44.6%) was much lower than that of the pine needles (71.14%). Paper has the highest volatile matter content (75.26%) than other biomass and fuel sample. Since high volatile matter or high percentage of volatile matter indicates higher ignition rate of the fuel, briquettes will volatize and burn as gas in combustion chambers. In the present study beehive has lowest volatile matter content and high pressure pellets has highest volatile matter content (Table 1).

Ash content

High ash content decreases the burning rate and reduces the heating value of fuel. The tolerance level of ash content for fuel is below 4% (Okolo et al., 2016). The low ash content indicates that it is suitable for thermal utilization. Higher ash content in a fuel usually leads to lower calorific value (Loo et al., 2008). In the present research, ash content of the biomass and fuel sample varied from 0.96% to 32.96% (Table 1). Ash content of pine needle char was higher (24.43%) than those of pine needles (2.79%). This implies that during carbonization, most of the ash in biomass remained in char. In general, biomass residues have lower ash content, except for rice husk with about 20% ash (NAEES, 2010). Higher ash content indicates more mineral matter present in the fuel. It usually leads to lower calorific value

Table 1 Proximate analysis of biomass sample

Sample name	% MC	% VMC	% AC	% FC
Rectangular Briquette	26.00	56.48	4.59	12.93
Square briquette	13.49	65.81	4.93	15.77
Beehive	17.32	25.79	32.93	23.96
Charcoal pellet	10.58	31.45	21.87	36.1
Screw extruder	5.60	66.05	5.33	23.02
High pressure pellet	10.30	71.85	0.96	16.89

Note: MC = Moisture content, VMC = Volatile matter content, AC = Ash content, FC = Fixed carbon of fuel, while low ash content makes it suitable for thermal utilization (Van Loo & Koppejan, 2008). The present results show the mean ash content of pine needle briquette (PNB) is 11.76%, which is lower than coal with mean ash content 33.47% (Singh et al., 1996). The low values of ash content obtained could be due to the high heating value of the briquettes.

Fixed carbon content

In terms of fixed carbon, charcoal pellet and beehive have the highest percentage of fix carbon respectively accounting 36.1% and 23.96% (Table 1). The increase in fixed carbon in compared to the overall constituents is most likely due to the concentration of binder in the briquette preparation. Zubairu and Gana et al. (2014) showed that fixed carbon of briquettes made from agro-waste increased with increasing binder concentration. This trend was further observed in the work of Wang et al. (2017). Fixed carbon content (17.66%) of pine needles is also higher than that of raw biomass, i.e. *Eupatorium adenophorum* (15.27%), water hyacinth (13.11%) and rice straw (12.67%). Pandey and Regmi (2013), and Pandey and Dhakal (2013) have reported that the fixed carbon of pine needle and pine char is 15.83% and 69.15%, respectively. This value seems almost similar in this study and slightly lower than the fixed carbon content of rice husk determined by Sengar et al. (2012) and Ghimire and Shrestha (2014), i.e. 16.76% and 15.26%, respectively. But, it is slightly lower than the fixed carbon of *Mikania micrantha* biomass (Singh & Poudel, 2013). Fixed carbon content (26.87%) of pine char is higher than rice husk char (12.3%), but lower than the *Mikania micrantha* (35.45%) (Singh & Poudel, 2013). The higher the value of fixed carbon, the quality of bio-briquettes gets better because the amount of fixed carbon acts as a major generator of heat during combustion.

Calorific value of biomass and fuels

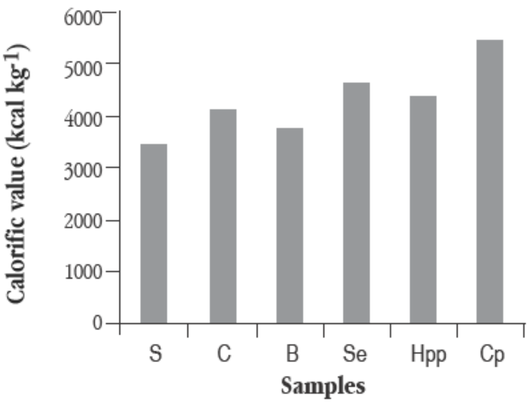
The results show highest calorific value (6643.49 kcal kg^{-1}) of pine needles char followed by pine needles (5027.06 kcal kg^{-1}) and paper (3662.49 kcal kg^{-1}). Among different fuel samples prepared, charcoal pellet has highest calorific value (5482.99 kcal kg^{-1}) followed by screw extruder briquette (4662.73 kcal kg^{-1}), high pressure pellet (4416.85 kcal kg^{-1}), circular briquette with 50% paper binder (4157.943 kcal kg^{-1}), square (3462.4585 kcal kg^{-1}) and beehive briquette (3801.4076 kcal kg^{-1}) (Fig. 2).

In the present set of experiments, the calorific value of raw pine needles was found to be 5027.06 kcal kg^{-1}, which is higher than rice-husk, saw-dust and *Mikania micrantha* briquettes (Pandey & Dhakal, 2011). This means that with the same amount of fuel, more energy can be generated by using the pine needles biomass. This value is higher than the calorific value of pine needles (4795 kcal kg^{-1}) as reported by Bisht et al. (2014).

Among the briquettes, screw briquette made from 100% grinded pine needles found to have higher calorific value (4662.73 kcal kg^{-1}) than the raw pine needles. This is because of the higher density of the screw extruder briquette (1.5 g cm^{-3}). Moreover, during briquetting, layer of carbonized material covers the briquette adding additional calorific value to the briquette. The energy/volume ratio of the fuel increases with its density (Bhattacharya et al., 1990). In addition, the amount of inorganic matter in biomass also affects its ultimate calorific value (Strehler, 2000). Also, the energy content (5482.99 kcal kg^{-1}) of the screw extruder briquette is higher than other low compression square briquettes (4157.94 kcal kg^{-1}) and circular briquettes (3462.45 kcal kg^{-1}) with 50% paper binder. Calorific value decreases with the increase in moisture content of fuel (Bajracharya et al., 2016).

Density

Briquettes produced using screw extruder technologies have a higher density of 1.5 g cm^{-3}, whereas other briquettes have densities lower than 0.28 g cm^{-3} to 0.63 g cm^{-3}. Density of screw extruder briquette was found to be highest in compared to other briquette, as it was made using tapered die screw extruder



S = Square, C = Circular, B = Beehive, Se = Screw extruder
Hpp = High pressure pellet, CP = Charcoal pellet

Figure 2 Calorific value of different briquettes briquette machine. The higher thickness observed in the 100% briquettes might be expected with its homogenous nature, which might have enabled those materials to structure a stronger bond, making more dense. Furthermore, the more stable briquettes contrasted with the individuals from those two other mixtures. Briquettes with high density are also favoured due to enhanced features for transport, storage and handling (Bhattacharya et al., 1990).

Thermal efficiency

The thermal efficiency of the stove was highest (39.1%) when operated with high pressure pellet followed by beehive (37.8%), screw extruder briquette (28.2%), low compaction circular briquette (27.5%), square briquettes (25.2%) and charcoal pellet (24.7%).

The preliminary water boiling test of pine needle beehive briquette showed average thermal efficiency of 27.01% (Pandey & Dhakal, 2013), fuel-wood 15.55% (Singh et al., 2001) which is lower than the value obtained in the present study (Fig. 3). Charcoal pellet showed lowest (24.76%) cooking efficiency which may be due to slow burning of pellet and low height of flames. High pressure pellet found to have the highest efficiency (39.1%) which might be due to use of improved cooking stove during water boiling test.

Boiling time

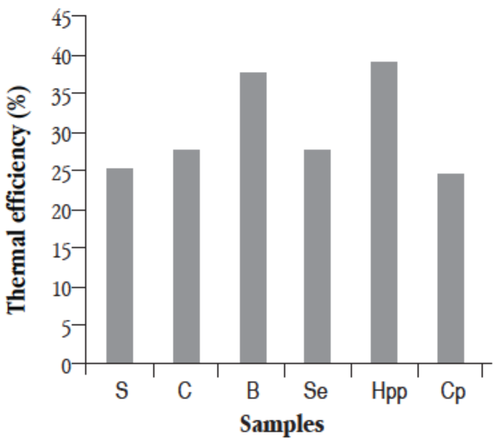
Charcoal pellet took highest (25 min) time to boil the water, followed by beehive briquette (22 min), square briquette with 50% paper binder (20 min), circular briquette (18 min), high pressure pellet (17 min) and screw extruder briquette (16 min). It was observed that despite having high calorific value of charcoal pellet, it took highest time (25 min) to boil the water. It is because of high (27.58%) moisture content causing slow boiling of water. According to Sivakumar et al. (2011), the moisture content reduce the thermal efficiency and in turn the heat produced is used for heating the wet biomass.

Flame temperature

In this test, maximum temperature of the flame was observed to be 677.4°C for high pressure pellet followed by beehive (582°C), square (589°C), screw briquette (577°C), circular (522.9°C) pellet (449°C). The flame temperature for the circular and square briquettes seems to be almost same and higher than other briquettes and pellets. It is because of the higher volatile content of the two briquettes than the other briquettes. Brown briquettes have higher volatile matter and hence long and higher flame that hit the cooking pot and black briquettes have lower volatile matter content, thus has lower flames. High pressure pellet has highest flame temperature, which may be because of its higher thermal efficiency. In volatile combustion, the flame is higher than the char combustion. Thus, higher temperature is recorded. It may be attributed to the flame not reaching the pot and the briquette need to be raised, so that the flame hit the pot. According to Onuegbu et al. (2011) percentage ash content is one of the factors that affect consumption of fuel briquettes negatively.

Ignition time

The charcoal pellet and high pressure pellet took the longest time (8 min) to ignite, followed by screw extruder briquette (6 min), beehive (7 min), square and circular briquette (1 min) to ignite. Two types of low compression briquettes were found to be easily ignited, unlike charcoal briquettes and pellets. The ignition time of square and circular briquettes decreased with increase in paper binder ratio. As paper contains more volatile matter than pine needles, it happens. In general, higher the volatile matter, easier to light the fuel, as volatile combustion is faster than char combustion. Therefore, increasing concentration of paper binder in the briquette increases its ignitability. In the case of charcoal fuel, pellet took more time to ignite as compared to beehive briquette.



S = Square, C = Circular, B = Beehive, Se = Screw extruder
Hpp = High pressure pellet, CP = Charcoal pellet

Figure 3 Thermal efficiency of different briquettes

Burning rate of pellet was lower (4.6 g min^{-1}) followed by beehive (5.9 g min^{-1}), circular (6.8 g min^{-1}), square (7.8 g min^{-1}), high pressure pellet (8.6 g min^{-1}) and screw extruder briquette (8.9 g $minv^{-1}$). The specific fuel consumption of different fuel samples varied from 0.56 to 1.058.

CO, CO_2 and $PM_{2.5}$ emission

CO emissions were observed as high as 83.2 mg L^{-1} for charcoal pellet combustion. Likewise, $PM_{2.5}$ emissions were observed as high as 263 $\mu g\ m^{-3}$ for screw extruder combustion and CO_2 emissions were observed as high as 790 mg L^{-1} for high pressure pellet combustion. As indicated by the results, CO emission from the six different types of briquettes and pellets were found to be higher than the prescribed level by the National Indoor Air Quality Standards (MoEST, 2009) due to incomplete combustion. The insufficient oxygen in the air/fuel ratio during combustion makes it unable to burn completely. The results from CO fluke meter show harmful level of emission for the briquette. However, the mean values during the test period do not exceed the safe limit, except for the pellet. The safe limit for CO is 35 mg L^{-1} for one hour (MoEST, 2009). Emission from high pressure pellet was found to be comparatively lower than the other fuel samples. It is due to higher efficiency of the pellet with the use of 'Oorja' stove with forced draft which supports excess air supply for better combustion. Moreover, emission from the charcoal pellet (83.2 mg L^{-1}) was found to be higher than other fuel. It is due to slow start up, incomplete combustion and higher emission.

The national ambient air quality standards of Nepal have been taken as emission standard. In the water boiling test, CO_2 emission from the six briquettes and pellets produced has not exceeded the prescribed value given by National Indoor Air Quality Standard (NIAQS), i.e. 1000 mg L^{-1}. Furthermore, carbon dioxide is less toxic than carbon monoxide; therefore, combustion of fuel briquettes is even more suitable for well ventilated indoor applications.

The safe limit for PM_{10} and $PM_{2.5}$ is 200 $\mu g\ m^{-3}$ and 100 $\mu g\ m^{-3}$ per hour, respectively (MoEST, 2009). It has been observed that, except high pressure pellet, the level of PM emission from the remaining fuel sample exceeded the safe limit of $PM_{2.5}$ and PM_{10} prescribed by National Indoor Air Quality Standard (NIAQS). According to Njenga et al. (2012), CO emission from briquette made from saw-dust is 0.45 mg m^{-3} and wood-charcoal is 0.41 mg m^{-3}. An average 24 hours mean $PM_{2.5}$ test conducted by ENPHO as a part of research for AEPC/ESAP showed that the average 24 hours mean $PM_{2.5}$ concentration of pine needle briquettes is 2.127 mg m^{-3}, using the traditional cooking stove. The test of briquettes showed a mean $PM_{2.5}$ concentration to be 0.570 mg m^{-3}. This value is lower than the value obtained from the present analysis.

Conclusion

Quantification of pine needle is one of the best ways to know about the existing available quantity of pine needle on the forest floor during fall season. Following inference can be drawn from the briquettes and pellets produced after mechanical processing pine needles.

- The average weight of pine needle in the study area is 0.751 kg m^{-2}. This data can be used to quantify pine needle in other forest areas of Nepal.
- The density of briquette increase with the increasing amount of paper binder in low compression briquetting process. Among the three binders used, i.e. CMC, paper and clay, CMC shows better binding/gluing effect.
- Proximate analysis shows the pine needle as an excellent raw material for briquetting due to its low ash and moisture content, relatively high carbon and volatile matter content with the higher calorific values, and ability to burn longer with stable and uniform temperatures than fuel-wood suggesting their potential use in place of fossil fuels.
- The water boiling tests shows that bio-briquettes have better combustion and fuel efficiencies with higher combustion gas temperature.
- Ignition time of the low compaction briquette is better than the beehive briquette as they contain more volatile matters (65.81%).
- Except high pressure pellet, emission from other fuel sample exceeded the safe level provided by National Indoor Air Quality Standard (NIAQS), which need further improvement during combustion.
- High pressure pellet shows highest thermal efficiency (39.1%) when tested in 'Oorja' stove. This is obvious as 'Oorja' stove is specially designed to use high pressure pellets with both primary and secondary air supply for combustion.
- Among all briquettes and pellets, the high pressure pellet can be considered as the best fuel for cooking and heating purpose due to its high thermal efficiency (39.1%), high calorific value (4416.85 kcal kg^{-1}), and low CO and $PM_{2.5}$ emission.
- These briquettes demonstrate huge potential for use as an alternative biomass fuel for energy generation.

Recommendation

- Further researches need to be carried out in economic aspect of briquetting and other physical, chemical and combustion properties.
- The research should be further extended using other different binders in different proportion.
- In the present study, the energy efficiency was studied only in 'Agni' stove which is specially designed for beehive briquettes. Further testing of the fuel samples with other different kinds of stoves is necessary for enhancing energy efficiency.
- Out of six different types of briquettes, five briquettes and pellets have higher PM and CO emission than the national standard. Further researchers are suggested to reduce the emission.

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