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Research Article

Design and Development of a Pine Needle Briquetting Machine for the Uttarakhand Region of India

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ABSTRACT

Fossil fuels, a non-renewable source, supply more than 81% of the world's primary energy and contribute heavily to global climate change. This paper represents a strategy to address the administration of forest bio residue in the northern Himalayan district of India. Uttarakhand state, the north part of India, is rich in bio residues such as Pine needles of Chir Pine (Pinus roxburghii). Every year during the summer, there is a forest fire breakout, mainly caused by these dry pine needles, which cover a forest floor and are highly flammable. This forest bio residue is renewable and is a potential energy source for rural livelihoods, which would also generate social business enterprises among the locals. This is an effort to develop a practical manual-operated briquetting machine (BM) capable of fabricating briquettes from forest waste. The primary materials utilized to make briquettes are pine needles and forest waste. The proposed method inculcates principles of compression molding along with necessary optimizations. Briquetting is one of the cheapest ways to harvest the destructive energy of pine needles in a clean and economically viable way. Briquetting machines reduce forest fires by reducing dependency on wood from forests for fuel while simultaneously lowering carbon emissions by using biomass or agricultural waste as alternative fuel sources. This dual benefit protects forests and helps battle climate change and local air pollution, making it a long-term option for environmental protection. The developed BM is one solution that can solve the dual purpose of climate change mitigation and employment. The designed and developed machine fabricates thirty-three briquettes per hour and is currently installed in the Uttarkashi district of Uttarakhand, India.

1. Introduction

The Indian Himalayan Region (IHR) is spreading to 12 states: Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh, Meghalaya, Nagaland, Manipur, Mizoram, Tripura [1]. The Indian piece of the Himalayas covers a territory of around 5 lakh km² (about 16.2% of the nation's free land zone) and structures the northern limit of the country. This contributes to three significant land substances named the Himadri (more prominent Himalaya), Himachal (lesser Himalaya), and the Siwaliks (external Himalaya) [2]. Siwalik range, having an average height of 1500 m - 2000 m, runs across Jammu, Himachal, Uttarakhand, and

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Sikkim. This region has amazingly rich flora and fauna. In recent years, sustainable materials such as forest waste natural fibers have been in high demand for innovative material science and technology development, helping achieve Sustainable Development Goals (SDGs) [3, 4]. Chir Pine is a commonly grown tree in the Himalayan region. Wood as a fuel is getting difficult to get day by day, and women have to go deeper into the forest to:

- To get the wood
- Results in more time spent and more cases of chronic diseases like back pain, joint pain, etc.
- Increased incidences of fracture due to climbing on trees.

Pine trees shed their dry leaves each year in January, February, March, and April. These dry needles have about 70.03% mean volatile matter content, which makes them profoundly inflammable [5]. Throughout the late spring, the residents burn dry and fallen pine leaves accidentally or purposefully, discharging vast volumes of greenhouse gases into the air. A massive amount of pine needles in the outer Himalayan region fall each year on the forest floor, converted into ash due to forest fires, causing discomfort to the earth's atmosphere by releasing carbon dioxide, causing soil disintegration, and loss of soil fertility [6]. In a rough estimate, more than 2–3 million tons of dry and fallen pine needles are delivered in the province of Uttarakhand every year from the aggregate 0.34 million ha reserve forest region [7].

Few non-governmental organizations in the Uttarakhand state have been conscious about adopting ecologically friendly and sustainable activities in this fragile and environmentally sensitive region. They apply strict environmental conservation measures in their day-to-day activities, and practices like composting, organic farming, waste segregation, etc., are all carried out diligently.

Using forest waste briquettes has several environmental benefits over wood burning: Briquettes use forest waste (e.g. pine needles), thus reducing wood harvesting and preserving forest ecosystems. Since briquettes are fabricated from forest waste materials, they emit less carbon dioxide than wood. This lowers carbon emissions and mitigates climate change. The briquettes pollute less than wood burning, improving local air quality and reducing health concerns of local people depending on solid fuel for cooking and heating. Thus, forest waste briquettes are a sustainable alternative to wood burning, preserving forests, neutralizing carbon, and improving air quality.

Additionally, using pine needle briquettes reduces the hazard of bushfires in the forest region and helps achieve efficient self-employment by preventing rural farmers from migrating from the countryside. It was observed from the literature that the already developed BM were for commercial purposes (massive in size, transportation not easy in hilly regions, not suitable to buy for small rural families, and powered by electricity). Also, the briquettes produced by other researchers used only one material as a binding agent). In the present research, the intention was to design and develop a manually operated BM that can be easily transported anywhere, is easy to assemble and disassemble, is less weight, efficient, and affordable to buy by anyone to set up a small business for additional income. Also, the briquettes were made by utilizing abundantly available pine needles and a mixture of sawdust and paper pulp as the binding material.

2. Literature Survey

On average, forest fires release about one trillion kgs of carbon into the atmosphere yearly. These emissions influence the weather and air quality [8] and cause changes in the hydrological cycle [9]. Fire outflows are a significant supporter of worldwide mortality. The average mortality to scene fire smoke was 3,39,000 passings yearly, and the locale most influenced was Sub-Saharan Africa and Southeast Asia [10]. The threat to biodiversity and an increase in greenhouse gases have been increased due to forest fires around the globe [11]. These forest fires have emerged as one of the severe threats to humanity, wildlife, and natural regeneration in the Himalayan ecosystem. The Subtropical Chir Pine forests are found in the outer ranges and foothills of Himalayan ranges extending from Pakistan to Arunachal Pradesh in India [12]. These Pine trees pose a significant threat to forest fires yearly in the Himalayan range because their dry leaves can catch fire easily and spread it faster [13]. This forest bio residue can potentially address the issues of global energy crises, employment, and climate change.

In the Himalayan region of Uttarakhand (Nainital), a project was started between the government and private entrepreneurs on how to manufacture pine briquettes—the project aimed to solve the economic problems of the locals and protect the forest from fire. However, the project could not be sustained for long and was terminated in 2012-13. No significant local communities accept the challenge except for a few showcase examples on paper or a prototype model developed by a few departments & non-governmental organizations [6]. This leaves the scope for fabricating the briquettes using a manually operated machine with forest waste as the material source.

The world is intensely subjected to petroleum products, with over 81% of the world's essential vitality provided by non-renewable sources [14]. Too much dependency on fossil fuels is causing its depletion at a faster rate and is also causing climatic changes. Fossil fuels pollute the air and water by releasing toxic particles into the atmosphere. These compounds lead to serious side effects like acid rain and human respiratory damage [15]. Therefore, there is a need for transition in our society. Biomass can play an active role in this transition. Biomass is a renewable energy source obtained from agriculture, forest, and domestic organic waste, which can be converted into proper energy forms like biogas, briquettes, and biofuels through the waste-to-energy technique [16]. In India, many cities' municipal corporations and central governments have allowed subsidiaries to install biogas plants on society's premises. Due to this, organic waste is generated at home, and people dump it in biogas plants. This serves two purposes: waste management at the source itself and energy sustainability (cooking fuel, heating). India has vast resources of forest bio residue as it covers 7,67,419 km^2, 21.67% of the country's total geographical area [17]. In Haryana, Rajasthan, Maharashtra, Karnataka, Gujarat, and Andhra Pradesh, bio briquette plants are operative but mainly use agro residues like rice husk, bagasse, and sawdust. The percentage of briquettes manufactured using forest bio-residue as input material is shallow, though we have 21.67% of the geographical area covered by forest.

2.1. Purpose of Briquette Machine

The current work aims to build a compact and lightweight machine that could be utilized at Arya Vihar Ashram, Uttarkashi, Uttarakhand, a spiritual community where Sadhak's pursue their spiritual life. The ashram was established in 1994 by Sri Arya Trust, a non-profit charitable organization. The ashram has been very conscious about adapting practices regarding the construction of the place and other activities to ensure that the activities are ecologically friendly and truly sustainable in this fragile and environmentally sensitive region. They apply strict environmental conservation measures in their day-to-day activities, and practices like composting, organic farming, waste segregation, etc., are all carried out diligently. Even the construction at the ashram is eco-friendly, using organic materials like wood, lime, brick, and mud. Following this tradition, the intention was to build a manually operated briquette machine that could substitute the wood burning in the hills.

Additionally, the villagers, especially women, have to walk a long distance daily to collect firewood. This is not only heavy and taxing labor but also depletes the forest of its wood. Moreover, briquettes are considered even more eco-friendly than wood due to reduced smoke emissions. Further, in times of disaster, when electricity and cooking are often unavailable for months, such alternatives could be the lifeline for thousands. Since the source of electricity in village areas is inconsistent, the aim was to make a strictly manually operated machine. Adding pine needles will also help reduce the negative impact of the same in forest areas concerning forest fires. Pine needles cover the topsoil and prevent the native varieties of the plantation from growing. Additionally, the spread of pine needles all over makes the ground slippery and dangerous for the residents to climb the hills.

Briquetting machines benefit the local ecology in various ways:

- Forest fire mitigation: The BM uses biomass or agricultural waste instead of forest timber. This preserves forests and decreases the risk of forest fires caused by unsustainable harvesting or fuel collecting.
- Reduction of carbon emissions: These machines make briquettes with a reduced carbon impact compared to coal or wood. Briquets minimize greenhouse gas emissions and local air pollution when used to replace these fuels.
- Waste utilization: Briquetting devices can turn agricultural wastes, sawdust, and paper waste into fuel. This promotes recycling and reusing waste that would otherwise go to landfills or incinerators, minimizing pollution.
- Energy efficiency: Briquetting process combustion is often more efficient than raw biomass. This greater efficiency reduces energy consumption and environmental implications by using less fuel to generate the same quantity of electricity.
- Promoting sustainable practices: Briquetting devices promote sustainable energy and reduce fossil fuel use using renewable and local biomass resources. This conserves resources and boosts local economies.

Overall, the adoption of BM can boost local environmental conservation and sustainability.

2.2. Opportunities

- People in villages mainly depend on forest wood as a primary source of cooking fuel and often risk their lives by climbing trees. Moreover, cutting wood creates a loss of biodiversity.
- These pine needles can be easily converted into a much higher calorific value fuel by a simple physical process.
- Fuel made from pine needles will provide them with better-quality fuel and generate a livelihood opportunity.

Thus, the design and development of the manually operated BM will help to fabricate the briquettes using forest bio-residues, which can be used as an alternative to wood.

3. Design, Development, and Analysis of Different Models of Briquetting Machine

3.1. Material Selection and Fabrication Method

Hot-rolled mild steel (MS) plates were chosen to fabricate the machine's moving parts. The frame was fabricated using a standard 4-inch C channel (MS). All the raw materials were procured locally from M/s Gulati Traders, Roorkee. An 8-tonne capacity double-acting high-flow hydraulic jack was procured from M/s. Oriental Pumps and Fastener Solutions Pvt. Ltd, Yamuna Nagar, Haryana. Pine needles were procured from the foothills of the Himalayan range and were sundried for use. Fabrication of this machine (all different models) involved various operations such as lathe turning, lathe boring (of seamed pipes), vertical milling, grinder machine, drilling, and boring operations apart from metal inert gas (MIG) and arc welding techniques.

3.2. Design of BM 1.0

The design of the BM 1.0 (Fig. 1) was made with harsh working conditions in mind. The machine's first model was fabricated based on the theoretical knowledge available on the BM.

When using a hydraulic jack for fabricating briquettes, the following safety measures were considered:

- The operation and safety guidelines provided by the manufacturer in the manual were carefully read.
- Safety measures such as goggles, gloves, and sturdy footwear were worn.
- Before the operation, the hydraulic jack and associated equipment were inspected for any signs of oil leakage.
- The maximum load capacity specified for the hydraulic jack was never crossed.
- The materials were securely positioned within the BM cylinder each time before pressure was applied to the hydraulic jack.
- Hand and body parts were kept clear of moving parts to prevent crushing or pinch injuries while operating the jack.

By adhering to these safety measures, the risk of accidents was minimized, and the safe operation of the hydraulic jack was ensured in all the developed designs of BM.

3.2.1 Design Parameters and Calculations

- No. of briquettes formed in one cycle = 8
- The shape of the briquettes = Rectangular
- The dimensions of the cylinder mold:
  - Height of cylinder mould = 210 mm
  - The wall thickness of the mold = 3 mm
  - The diameter of holes on the periphery = 3 mm
- The dimensions of briquettes:
  - External diameter = 100 mm
  - Height = 100 mm
- Applied central load = 2T
- The operating height of the machine = 1000 mm
- The final weight of the machine = 200 kg

Fig. 1. Fabricated briquetting machine (BM 1.0)

3.2.2 User's Feedback on the First Model of the Machine

- During the compression, water discharge through the holes in the rectangular mold was not good enough, leaving the briquette wet.
- The alignment of the ram and the cylinders was not perfect

- The lower plate was difficult to remove after the compression.
- Briquettes made from BM 1.0 did not burn completely.
- The stability of the machine was not optimal.
- The top part of the machine, consisting of a plate of 5 mm thickness, did not manage to take the load often, and it bent upwards in a bow.
- Cleaning the machine post-briquette production was also tricky.
- Lowering the plate efficiently and raising it again once the briquettes were ejected was difficult.
- Rectangular briquettes were not preferred for handling, storage, and utility.

3.2.3 Proposed Solutions on the First Model of the Machine

- Separate the mold so the water will be discharged from all sides and convert them into cylinders for round briquettes. However, the mold's current dimension and volume are ideal (when filled to the brim) for producing the required briquette of 8 cm height.
- The machine should be perfectly aligned with the ramp, entering straight into molds.
- For better combustion, the briquette should have a central hole. So, the ram could have round pins attached to the lower plate.
- The lower plate should be able to go up and down with the help of a pulley manipulated with a handle. The lower plate should be able to sustain the load during compression and should be able to move up and down quickly.
- To ensure water discharge from the mold, the hole size should be more than 5 mm with a short distance between them.

3.3. Design of BM 2.0

The design of the BM 2.0 (Fig. 2) was made with improvements in the design of the first model (BM 1.0) based on the experience shared by the people who worked on the machine. A few problems in the first model were resolved in the second model of the BM 2.0.

3.3.1 Design Parameters and Calculations

- No. of briquettes formed in one cycle = 8
- The shape of briquettes = Cylindrical with a hole
- The dimensions of the cylinder mold:
    - Height of cylinder mould = 210 mm
    - The wall thickness of the mold = 4 mm
    - The diameter of holes on the periphery = 5 mm
    - No. of holes on periphery = 11*27 on each mould
- The dimensions of briquettes:
    - External diameter = 100 mm
    - Height = 100 mm
    - The diameter of the central hole = 10 mm
    - Depth of central hole = 100 mm
- Applied central load = 5T
- The operating height of the machine = 1200 mm
- The final weight of the machine = 175 kg.

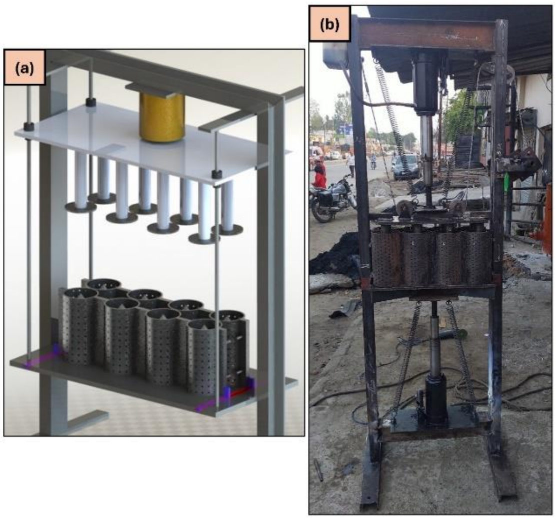


Fig. 2. (a) CAD model and (b) Fabricated briquetting machine (BM 2.0)

3.4. Design of BM 3.0

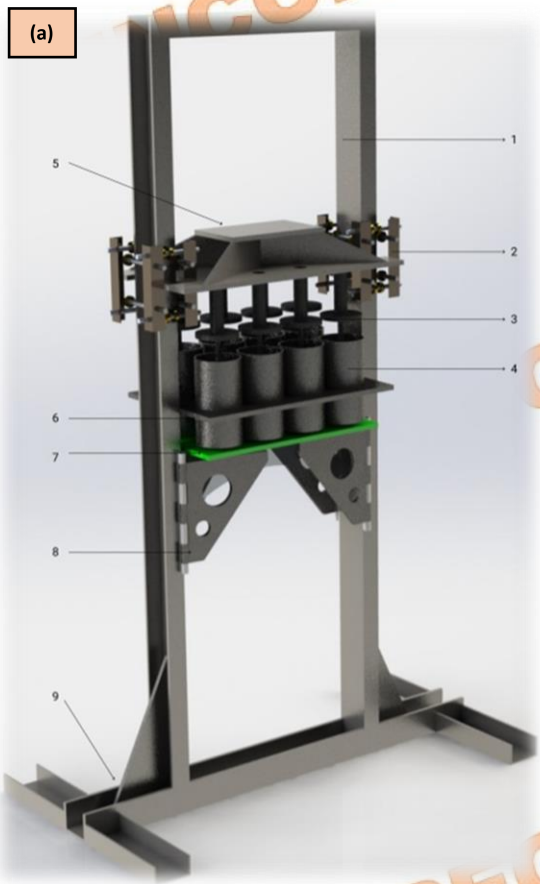
The design of the BM 3.0 (Fig. 3) was made considering harsh working conditions and improvements concerning the previous two models. Table 1 represents the function of each component of the machine. Provisions were made so that the apparatus works satisfactorily even after slight wear and percussive shocks during operation and shipping. BM 3.0 was designed with improved stability and efficiency compared to previous models.

3.4.1 Design Parameters and Calculations

- No. of briquettes formed in one cycle = 8
- The shape of briquettes = Cylindrical with a central hole
- The dimensions of the cylinder mold:
    - Height of cylinder mould = 210 mm
    - The wall thickness of the mold = 4 mm

- The diameter of holes on the periphery = 5 mm
- No. of holes on periphery = 11*27 on each mould

- The dimensions of briquettes:
  - External diameter = 106 mm
  - Height = 100 mm
  - The diameter of the central hole = 12 mm
  - Depth of central hole = 80 mm
- Bearing size for carriage sliders = 6001
- Compressive stress on briquette (at complete compression) = 1.12 MPa
- Applied central load = 5T
- The operating height of the machine = 1200 mm
- The final weight of the machine = 210 kg.



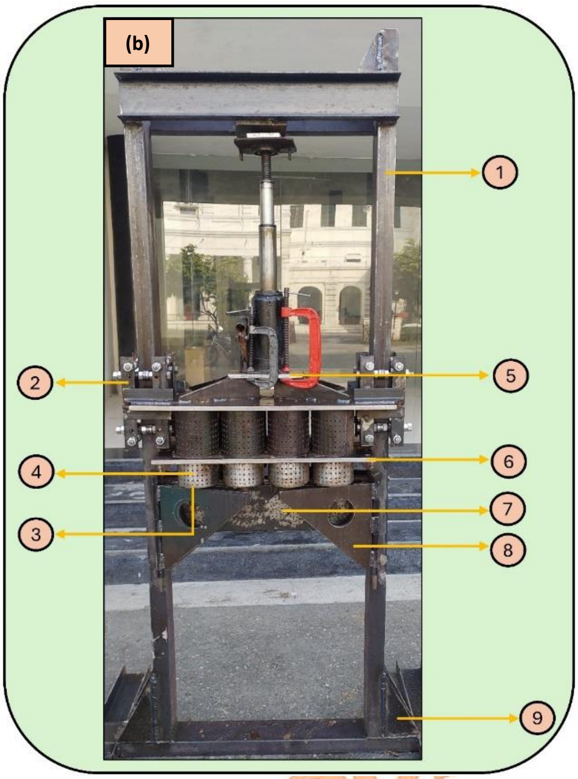


Fig. 3. (a) CAD model of BM 3.0, (b) Fabricated briquetting machine (BM 3.0) where 1: Upper frame body, 2: Carriage sliders, 3: Plunger head, 4: Cylinder mold, 5: Load equalizer, 6: Mould stencil, 7: Reaction plate, 8: Hinged supports, 9: Lower frame body

Table 1. The function of each component of the machine

Bubble No.	Name	Function

1	Upper frame body	To accommodate jack
2	Carriage sliders	To maintain precise motion of load equalizer
3	Plunger head	To compress organic matter inside the briquette molds. A +/- 0.5 mm tolerance was provided.
4	Cylinder mold	• Provides structural integrity to organic matter • Holes along the periphery allow excess fluids to drain out.
5	Load equalizer	Equally distributes the load on each briquette
6	Mould stencil	• Prevents misalignment of briquette mold • Prevents radial strain of mold under the application of excessive load from the jack.
7	Reaction plate	Acts as a lid for the mold
8	Hinged supports	• It allows the rapid and secure closing of the mold. • To transfer the load to the frame.
9	Lower frame body	• It prevents the machine from toppling. • It provides structural integrity to the machine. • It provides an ergonomic operating height.

3.4.2 FEM Analysis of Critical Components of BM 3.0

Finite element analysis was used to finalize the dimensions and tolerances of various machine parts. The static structural and topology enhancement module of ANSYS 18.1 was used for the above-said study.

3.4.2.1 Reaction Plate

The total deformation was 0.13 mm; thus, a safety factor = 3.8845 was achieved (Fig. 4). A high safety factor was considered as this particular part can be subjected to various dynamic forces while opening the mold.

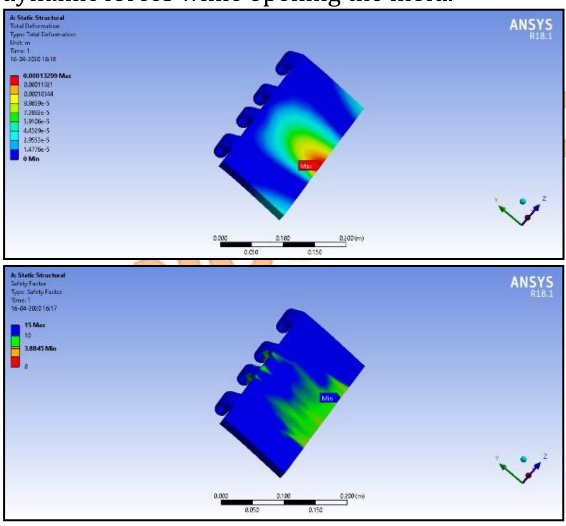


Fig. 4. FEM analysis of reaction plate

3.4.2.2 Hinged Supports

After assuming a uniform load distribution on the support's surface and each support, the maximum total deformation was found to be 5.3171e-5 m, and the factor of safety = 1.9607 (Fig. 5).

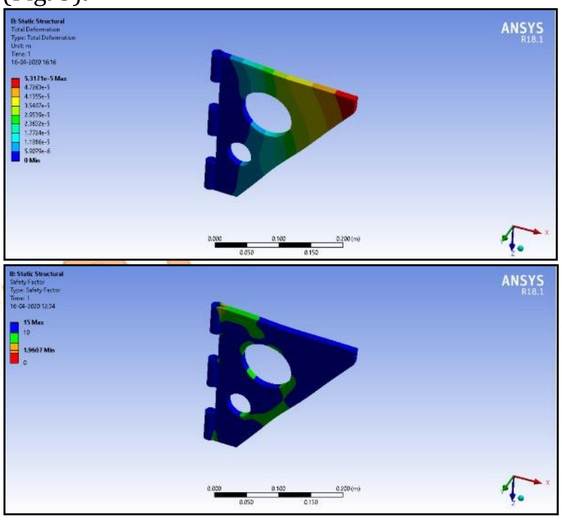


Fig. 5. FEM analysis of hinged supports

3.4.2.3 Load Equalizer

On assuming a uniform distribution of load from the jack onto the topmost surface of the pressure equalizer and taking the plunger head as fixed support, conditions similar to the complete stroke of the plunger were simulated (Fig. 6). These conditions also represent the state of maximum compression of organic matter inside the briquette mold. The maximum total deformation was found to be 0.1586 mm, and the factor of safety = 1.8974.

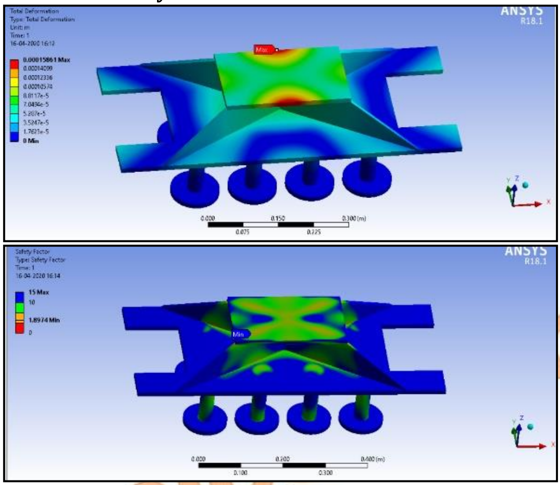


Fig. 6. FEM analysis of load equalizer

4. Methodology Followed for Fabricating Pine Needle Briquettes

Fabrication of briquettes starts with collecting raw materials like cardboard, pine needles, and sawdust. Cardboard paper was torn into significant bits and soaked in water for 2-3 days. This coarse material needs to be smashed into a pulpier state. This was usually done using an electric mixer. This efficiently mashes this soft, wet material into a sludge (pulp). Dry pine needles, straws, leaves, and twigs must be chopped down to size (tiny pieces not more than 20 mm long) to be incorporated successfully into a briquette. A traditional wheel used by farmers to cut rice straw was used to cut pine needles. It saves a lot of time and labor in the preparation of materials. Crushed pine needles were mixed with sawdust, paper pulp, and water in a ratio of 6:1:1:2 by volume. Once the mixture was ready, it was poured inside the cylinders of the BM, and a load of 5T was applied using a hydraulic jack to produce round briquettes.

The steps to be followed during fabrication of the briquettes are as follows and shown in Fig. 7:

1. Pine needles were crushed to achieve an average size of 20 mm.
2. Crushed pine needles were mixed with sawdust, paper pulp, and water in a ratio of 6:1:1:2 by volume.
3. The mixture thus obtained was mixed at 600 rpm for 5 min.
4. The reaction plate of the machine was lifted and locked using hinged supports. The hinge should lie at an inclination of 45 degrees from the axis of the reaction plates.
5. Each mold was filled with 1.85 L slurry.
6. The pressure equalizer was lowered using a double-acting jack.
7. The hydraulic jack was allowed to remain at the lowered position for 2 min.
8. Repeat steps 6 and 7 twice.
9. The pressure equalizer was then moved upward.
10. Hinged supports were moved back, and the reaction plate was lowered down.
11. Briquettes were finally taken out of the mold.

*Curing time was found to be three days at average temperature = 30°C and relative humidity = 70%.

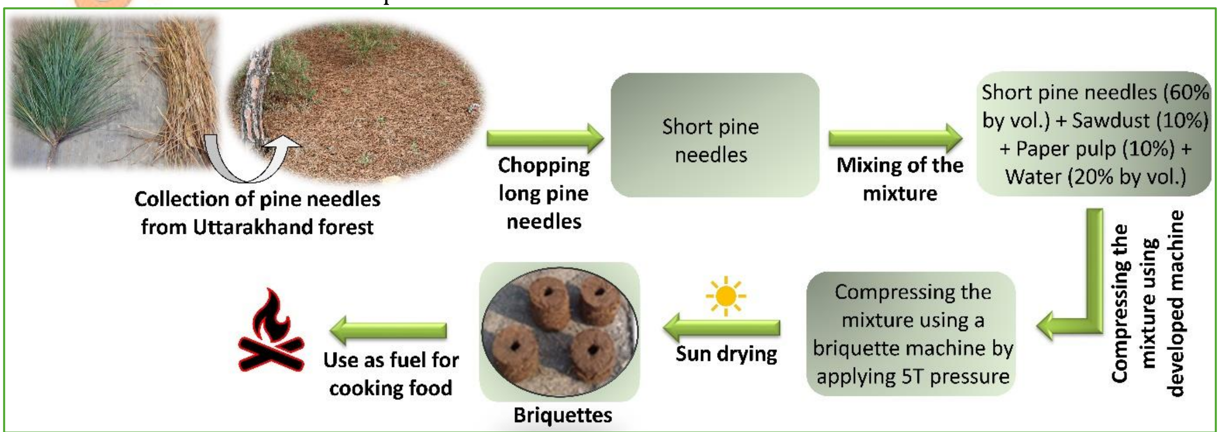


Fig. 7. Step-by-step process in fabricating briquettes

4.1. Output Calculation

Table 2 shows the average time required to complete each step in briquette fabrication. Output calculation is as follows, provided that;

- We have paper pulp, sawdust, and pine needles crushed to size ready at our disposal.
- One person operates the machine solitarily.
- Total number of briquettes produced in 1 cycle = 8

Table 2. Time required for the completion of each step-in briquette fabrication

Sr. No	Steps	Description	Time required (per cycle)
1.	Mixing of slurry	• Crushed pine needles were mixed with sawdust, paper pulp, and water in a ratio of 6:1:1:2 by volume.	3.5 min
2.	Clamping reaction plate using hinged supports	• Simultaneously check for any left-out slurry in briquette molds.	0.5 min
3.	Pouring slurry into briquette molds.	• Using a commonly available graduated mug	4 min
4.	Lowering of load equalizer using jack	• This process was repeated three times. Assuming it takes 30 s for a hydraulic jack to traverse the required length under no-load conditions.	6 min
5.	Unclamping reaction plate	• The briquettes slide down the mold due to self-weight	0.5 min

- Total time required for one cycle of briquetting = 14.5 min
- No. of cycles in 1 hour of complete operation = 60/14.5 = 4.13 cycles
- Total number of briquettes in 1 hour = 4.13*8= 33.1= 33 (approximately)

Thus, the production of 33 briquettes in 1 hour is estimated.

Let's suppose that the person works for 8 hr/day (including a 3-hour break), which means a person is working for a total of 5hr in a day. So, in one day, a person can fabricate = 33*5= 165 briquettes (as per calculations).

5. Conclusions and Future Scope

The rural people of the Uttarakhand region are unaware of the potential use of pine needles as a fuel source. They are more concerned about the immediate need to cut down trees for the wood. They are doing so for fuel, which is the daily need of every person to carry out their daily activities. Also, forest fires occur every summer, causing substantial environmental pollution and loss of natural habitat. To address the issues of climatic change, biowaste management, and local employment, need-based and straightforward inventions were required for the communities. With the help of local communities, the government is also trying to conserve the Himalayan ecosystem through various schemes. The present briquetting machine design, fabricated for Arya Vihar Ashram (Sri Arya Trust), Uttarkashi, Uttarakhand, is one solution that can solve the purpose of climate change mitigation, energy, and rural employment. The machine BM 3.0 is entirely manual-operated, durable, affordable, reliable, replicable, and portable, and it is currently being installed at the ashram. Field studies (i.e., data collection) on the latest version of the machine (BM 3.0) are being carried out to determine the machine's efficiency and briquettes' efficiency. As per the data collected from the Arya Vihar Ashram, around 30 briquettes/hr are produced from the BM 3.0 and 150 briquettes/day with a single operator operating the machine. The ashram people use fabricated pine needle briquettes as fuel for cooking food. Additionally, these briquettes can be widely used for any type of thermal application, such as steam generation in boilers, heating purposes, drying processes, and gasification plants, to replace conventional solid fuels like coal and wood.

This machine was strictly fabricated in consultation with experts, technical people, villagers, and Arya Vihar Ashram, and there is ample scope for further research to increase the efficiency and productivity of the machine, such as;

1. The calorific value of produced briquettes can be measured using a bomb calorimeter and compared to typical solid fuels like coal and wood.
2. Various fuel properties such as burning rate, specific fuel consumption, level of smoke evolution, and efficiency of the briquettes produced from BM 3.0 can be determined further for clear scientific understanding.

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3. Proximate analysis such as moisture content, ash, volatile matter, and fixed carbon of the pine needles can be determined.
4. Other raw materials such as bagasse, rice, and wheat husk can be explored with this machine to produce briquettes.
5. The pine needle briquettes can be bonded with different binding agents like starch, nutshell, coconut husk, cow dung, cassava starch, and clay, and their efficiency can be compared.
6. Biomass gasification technology can be used to generate producer gas, electricity, and byproducts, i.e., pine needle char, which can be explored in this machine to produce briquettes.
7. Various optimization techniques can be explored to optimize the BM input parameters.
8. The present machine, BM 3.0, can be upgraded to run on renewable solar energy.
9. The fabricated briquettes can be used to partially replace conventional fuel sources in industrial boilers and centralized hot water supply systems.
10. Training sessions and workshops can be organized for rural people on efficiently working with machines.
11. Various government agencies/ departments can be approached for funding.

Nomenclature

BM	Briquetting machine
T	Ton
hr	Hour
s	Second
kg	Kilogram
°C	Degree Celsius
mm	Millimeter
%	Percentage
L	Liter
min	Minutes
IHR	Indian Himalayan Region
SDGs	Sustainable development goals
AQI	Air quality index
rpm	Revolution per minute

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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