

**DESIGN AND DEVELOPMENT OF SHREDDER CUM
BRIQUETTING MACHINE**

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2017

DESIGN AND DEVELOPMENT OF SHREDDER CUM BRIQUETTING MACHINE

A thesis submitted to the

Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani

In partial fulfillment of the requirements for the

Degree of

MASTER OF TECHNOLOGY

(AGRICULTURAL ENGINEERING)

in

FARM MACHINERY AND POWER ENGINEERING

By

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JUNE 2017

CANDIDATE'S DECLARATION

I, hereby declare that, the entire work embodied
in this dissertation or part thereof,
has not been previously submitted
by me for a degree of
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Institution.

Place : Parbhani
Date : / /2017

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ACKNOWLEDGEMENT

With ever regardful memories

The successful completion of any task would be incomplete without expression of appreciation to the people who made it possible. Though words are inadequate to express the sense of gratitude towards everyone who helped me directly or indirectly. This is a humble attempt to do so.

*First of all I would like to thank my chairman **Prof. R.T. Rameteke**, Head, Department of Electrical and Other Energy Sources, College of Agricultural Engineering & Technology, C.A.E.T., V.N.M.K.V., Parbhani, for his constant encouragement throughout my research work and I really feel lucky to be guided by him. He generously spared time throughout the research work during which most of the ideas of this research project were conceptualized.*

*My special thanks to the Members of my advisory committee are **Prof. Solanki S.N.** Dept. Head, Dept. of Farm Machinery and Power Engineering, C.A.E.T., V.N.M.K.V., Parbhani, **Prof. Munde P.A.** Assistant Professor, Dept. of Farm Machinery and Power Engineering, C.A.E.T., V.N.M.K.V., Parbhani and **Dr. G.U. Shinde**, Assistant Professor, Dept. of Farm Machinery and Power Engineering, C.A.E.T., V.N.M.K.V., Parbhani.*

*My sincere gratitude to **Dr. Khadale**, Associate Dean and Principal, Dept. Head, Dept. of Irrigation and Drainage Engineering, C.A.E.T., V.N.M.K.V., Parbhani, who had contributed a great deal through unstinted co—operation and timely help in many ways in the successful completion of the research work.*

*I also express my deep sense of gratitude to **Prof. D. D. Tekale**, Assistant Professor, Dept. of Farm Machinery and power Engineering, C.A.E.T., V.N.M.K.V., And **A. A. Waghmare**, Senior Technical Assistant, UAE, AICRP, C.A.E.T., V.N.M.K.V., Parbhani, and, Dept of Farm Machinery and*

power Engineering, C.A.E.T., V.N.M.K.V., Parbhani for providing help and guidance as and when required for the completion of project work.

I also thank to **Prof. D. V. Patil**, Dept of Farm Machinery and Power Engineering, CAET, V.N.M.K.V. Parbhani and **Pawar R. B.**, for their kind support and care bestowed on me all through the course of my study and their keen meticulous editing of this thesis and **Saddawarte, Yende, Wadmare**, whose rewarding guidance and kind help in providing necessary facilities in time made the research study an achievement.

My vocabulary utterly fails in expressing my accolade to my revered parents **Shivappa B. and Kusuma** who brought me to this stage. I realize that it is of immense significance too. I have been highly fortunate and lucky to express my heartfelt respect to my brother, sister and my family rocks **Sampath Kumar, Asha(Hema), Shanmuka, Unnati, Nuthan**.

Selfless love is the dearest commodity on this planet and only a few in this world are kind enough to extend their helping hands, just for love and affection shown to me by my blossom friends, Chandan(Shanda), Sanjay, Basava, Gajendra, Raghunath Jagtap, Lokesh, Chandan, Saranya, Hareesh, Chittappa, Wasiya Farzana and my batchmates Nimbalkar and all B.Tech. (Ag.Engg.) juniors for their everlasting source of inspiration, love and my senior friends, Shashikumar, Avinash Kakade, Muralimohan, and Special thanks to Avad mahadev, Bahrat cutting, Roopesh kakade who helped me a lot during my research work.

Finally, I thank God for bestowing me with divine spirit, essential strength and necessary support to find my way towards a glorious career amidst several hurdles and struggle.

Parbhani.

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CERTIFICATE - I

This is to certify that the thesis entitled "**DESIGN AND DEVELOPMENT OF SHREDDER CUM BRIQUETTING MACHINE**" submitted to Marathwada Agricultural University, Parbhani in partial fulfillment of the requirement for the award of the degree of **Master of Technology (Agril. Engineering) in Farm Machinery and Power Engineering** embodied the results of the bonafied study carried by **Mr. MANJUNATHA B. S.** under my guidance and supervision. I also certify that the thesis has not been previously formed the basis for the award of any degree, diploma, associate ship, fellowship or other similar titles.

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LIST OF ABBREVIATIONS AND SYMBOLS USED

Anon	:	Anonymous
&	:	and
cc	:	cubic centi meter
cm	:	centimeter
Ca	:	Calcium
Cu	:	Copper
d.b	:	dry basis
°C	:	Degree celsius
Deptt	:	Department
<i>et al</i>	:	others
Engg	:	Engineering
Fig.	:	Figure
>	:	greater than
g cc ⁻¹	:	gram per cubic centimeter
h	:	hour
hp	:	horse power
kg	:	kilo gram
kg h ⁻¹	:	kilo gram per hour
kW	:	kilo Watt
kg kW-h ⁻¹	:	kilo gram per kilo Watt hour
km h ⁻¹	:	kilo meter per hour
kN	:	kilo Newton
kg-m	:	kilo gram-meter
kW-h t ⁻¹	:	kilo Watt hour per ton
kg day ⁻¹	:	kilo gram per day
kg m ⁻³	:	kilogram per meter cube

kW-hMg^{-1}	:	kilo Watt hour per milli gram
<	:	less than
mm	:	milli meter
m	:	meter
M ha	:	Million hectares
ms^{-1}	:	Meter per second
MJkg^{-1}	:	Milli Joules per kilogram
MS	:	Mild steel
ml	:	milli liter
Mg	:	Mega gram
min	:	minute
urn	:	Micron meter
<i>viz</i>	:	Namely
N-m	:	Newton meter
N	:	Newton
N-mm	:	Newton-millimeter
Rs h^{-1}	:	Rupees per hour
Rs kg^{-1}	:	Rupees per kilogram
rpm	:	revolutions per minute
t h^{-1}	:	ton per hour
W	:	Watt

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Introduction



CHAPTER- I

INTRODUCTION

Globally, 140 billion metric tons of biomass is generated every year from agriculture. This volume of biomass can be converted to an enormous amount of energy and raw materials, equivalent to approximately 50 billion tons of oil. Agricultural biomass waste converted to energy can substantially displace fossil fuel, reduce emissions of greenhouse gases and provide renewable energy to 1.6 billion people in developing countries which still lack access to electricity. As raw materials, biomass wastes have attractive potentials for large-scale industries and community-level enterprises.

Biomass takes the form of residual stalks, straw, leaves, roots, husk, nut or seed shells, waste wood and animal husbandry waste. Widely available, renewable and virtually free, waste biomass is an important resource.

In India about 46% of total energy consumption is estimated to be met from various biomass resources, i.e. agricultural residues, animal dung, forest waste, redwood, etc. India produces a huge quantity of agricultural residues and a major part of it is consumed in traditional uses (such as fodder for cattle, domestic fuel for cooking, construction material for rural housing, industrial fuel for boilers, etc). The direct burning of agricultural residues in domestic as well as industrial applications is very inefficient. Moreover, transportation, storage and handling problems are also associated with its use. One of the approach that is being actively pursued worldwide towards improved and efficient utilization of agricultural and other biomass residues is their densification so as to produce pellets or briquettes. The process of compaction of residues into a product of higher density than the original raw material is known as densification or briquetting. The briquetting of biomass improves its handling characteristics, increases the volumetric calorific value, reduces transportation costs and makes it available for a variety of applications.

The practice of briquetting of sawdust and other agricultural residues has been adopted for over five decades in many countries. The basic concept of briquetting is not new in India, as the preparation of cow-dung cakes and balls of coal dust have been in use for many decades. Mechanized briquetting technology was introduced in India in early 1980s. At present, there are about seven commercial manufacturers of briquetting machines in India based on piston-press technology. One of them, M/s Solar Science Consultancy Pvt. Ltd., New Delhi, has installed about 150 briquetting machines all over the country in the last few years.

Biomass resource potential

The current availability of biomass in Maharashtra is estimated at about 32029.3 kHa area covering agricultural and forest residues corresponding to potential of 3725.3MW. In Marathwada region the total biomass generation is 13126.3 kT/Yr and surplus amount of biomass is 5100.6 kT/Yr (MNES report). So this surplus amount of biomass can be converted into briquettes for fuel purpose. Hence, keeping the above factors in view, an attempt has been made to develop briquetting machine which has following scopes and advantages.

Scope of Bio Briquetting technology in India

From the energy scenario and fuel use pattern of the country, assessment of Bio briquetting technologies and technological capability, waste biomass resource base and past experience on briquetting, there is ample scope for biomass briquetting because the organic matter will be shredded in small pieces to enable the farmer to make use of the same for manufacturing direct manure/ organic manure and vermi compost.

Development of hydropower is very expensive and takes considerable amount of time to develop it before the country can totally rely on it. Till then biomass briquetting could serve as an alternative source of energy for domestic and industrial use and there is a good resource base - agricultural biomass residues, forest waste and other resources which can be used as raw materials

for producing different briquette fuels. This will not only rationally use the waste biomass (waste to energy) but also generate employment opportunities.

Advantages of using briquettes compared to other solid fuels

Biomass briquettes are cheaper with higher practical thermal value, lower ash content, uniform combustion. Briquettes give much higher boiler efficiency because of low moisture and higher density and can replace the following conventional fuels such as diesel, kerosene, furnace oil, lignite, coal, firewood.

The briquetting biomass is very efficient for storage of biomass that requires less space and also reduces the transportation cost. In rural areas the biomass in the loose form is available in abundance which could either be burnt inefficiently for generation of heat or it may be used as fodder for animals. Also, there is a problem of storage of biomass which results in uneconomic use and in environmental pollution, hence if such biomass is processed to prepare briquettes, it could be used economically for generation of heat, power etc.

In view of the above facts, the project entitled "Design and Development of shredder cum briquetting machine" was undertaken at Department of Farm Machinery and Power, College of Agricultural Engineering & Technology, V.N.M.K.V., Parbhani. (M.S.) with the following objectives.

1. To study the physical properties of biomass.
2. To develop shredder cum briquetting machine.
3. To evaluate the performance of shredder cum briquetting machine.
4. To study the economics of shredder cum briquetting machine.



*Review of
Literature*



CHAPTER-II

REVIEW OF LITERATURE

In this chapter, the comprehensive research work done by various research workers relevant to present study is presented and summarized under sub headings.

1. Physical properties of biomass.
2. Development and fabrication of briquetting machine.
3. Performance evaluation of briquetting machine.
4. Economics of briquetting machine.

2.1 Physical properties of biomass

Rajvanshi and Joshi (1989) reported that leucaenaleucocephala was a leguminous fast growing tree species which was being popularized in India for energy plantation. Calorific value of wood was 17.6-18.4 MJ kg⁻¹, true density was 700-720 kgm⁻³. Bulk density was 200-220 kg/m and ash content was 1 - 2%.

Talib *et al.* (1989) reported that the proximate analysis and heating value of the eucalyptus as follows; volatile matter: 73.8%, ash content: 5.54%, fixed carbon: 16.1% and calorific value: 22.0 MJ/kg.

Gangde *et al.* (1998) determined the physical properties; proximate analysis and heating values of babool (*acacia nilotica*) wood without bark, subabool (*leucaenaleucocephala*) roundwood with bark, safflower (*carthamustinctorius*) residue briquette and tur (*cajanuscajan*) stalks were studied. Moisture content was below 10 per cent in all four fuels. Babool wood had the highest bulk density and volatile matter as 0.73 t m⁻³ and 83.63 per cent, respectively. Subabool had the greatest heating value 18.68 MJkg⁻¹ LHV and least ash content 1.6 per cent than rest of the fuels. Safflower residue briquette had the highest ash content 14.82 per cent and lowest value of fixed carbon 9.1 per cent.

Xianyang *et al.* (2007) found that China has one of the most abundant straw resources in the world, producing more than 620 million tons of straw in 2002, and representing about 33 to 45% of energy consumption for livelihood

in rural areas. Utilization of straw as energy with high efficiency and rationality not only meets the demands for energy as the economy grows, but also provide a basis for environmental protection and sustainable development of society in China. This paper reviewed the present utilized technologies of straw in biomass energy, including improved stove, biogas, straw gasification and straw briquette, which are already commercialized and popularized in China. Other technologies, such as liquefaction, straw carbonization and bio-coal, are also presented. Based on the technology status and potential, the future research and development of straw in the biomass energy portfolio in China were proposed.

Zhang *et al.* (2012) studied physical properties of major agricultural crop residues. The moisture content determined were 7.79, 6.58, 6.40, 7.30, 8.15, 7.86 and 7.45 per cent for wheat straw, rice straw, corn stalk, soybean, sugarcane stalk, coffee husk and cotton stalk respectively. The average particle sizes for the wheat straw, rice straw, corn stalk, soybean stalk, sugarcane stalk, coffee husk and cotton stalk were 0.42, 0.40, 0.49, 0.43, 0.55, 0.67 and 0.38 mm respectively. The average bulk density was 160.75, 166.29, 127.32, 242.34, 110.86, 349.06 and 230.55 kg *m*³ for the wheat straw, rice straw, corn stalk, soybean stalk, sugarcane stalk, coffee husk and cotton stalk, respectively. The average porosity was 51.25, 83.20, 58.51, 68.03, 77.58, 64.85 and 74.55 per cent for the wheat straw, rice straw, corn stalk, soybean stalk, sugarcane stalk, coffee husk and cotton stalk, respectively. Cotton grown in the United States today is mechanically harvested. After the cotton is harvested, the stalks are cut or shredded. Before invention, attempts were made to combine the harvesting element and the stalk shredder. The harvesting element was carried by a vehicle having front and rear wheels. The harvesting element often was located between the front and rear wheels and the stalk shredder was mounted behind the rear wheels in these previous inventions. The device for elevating the harvested cotton to an overhead basket was usually mounted behind the rear wheels as well. The excessive weight behind the rear wheels tended to unbalance the vehicle.

Zhang *et al.* (2012) studied the physical properties of corn residues. They found that the moisture content of maize stalk was 6.4 per cent (w.b.) after shredding operation. The average bulk density of corn residue was 81.61 kg m⁻³ and the average macro porosity was found that 58.51 per cent.

Khardiwar (2013) conducted a study on physical properties of crop residues briquettes used for gasification. They found that bulk densities of soybean briquette, pigeon pea briquette and mix briquette were in the range of 598 to 675 kg m⁻³. The bulk density was found more with pigeon pea briquette.

Demirbas (2004) concluded that that waste paper may be used as a partial binder material alone or in briquetting of wheat straw. Briquetting of wheat straw is very difficult at ambient temperature. For briquette quality control, the physical parameters such as density, moisture content and compressive strength were found to be the best indicator of additive quality. Tests have shown that combustible bio wastes can be compressed and stabilized to densities of the order of 7±10 times that of normal bales by the application of pressures of between 470±780 MPa. Only the wheat straw was heated to a temperature of between 345 and 435 °K before compression. The briquette obtained from wheat straw was resistant to attrition, but may be reconstituted to its original form by soaking in water. Physical parameters such as density, moisture content and strength were found to be the best indicators for briquette quality. Briquetting of wheat straw samples without binder material gave products low water resistance.

Pongsak Jittabuta (2015) studied the physical and thermal properties of the briquette by varying rice straw and sugarcane leaves ratios of 100:0, 80:20, 50:50, 20:80 and 0:100 using molasses as the binding agent. The briquette-molasses to binder ratio of 100:50 was used. Ultimate and proximate analyses were carried out to determine the average composition of their constituents. The physical properties studied included species density, compressive strength and moisture content. Fuel properties were determined using standard laboratory methods. The results indicated that the density, high heating value, and compressive strength were also tested. Results showed that fixed carbon

was 9.0613.63%, volatile matter was 68.14-74.67%, ash content was 7.84-12.85%, and moisture content was 4.2-6.2%. Results from ultimate analysis showed that the content of C H O N S was follows; 38.6-43.2%, 5.4-6.2%, 34.536.4%, 0.27-0.44% and 0.02-0.04%. The high heating value was in the range of 16.3-17.83 MJ/kg. The density was in the range of 0.53-0.58 kg m⁻³ .

Qiang Hu *et al.* (2016) investigated the densifications of bio-chars pyrolyzed at different temperatures to elucidate the effect of temperature on the properties of bio-char pellets and determination the bonding mechanism of pellets. Optimized process conditions were obtained with 128 MPa compressive pressure and 35% water addition content. Results showed that both the volume density and compressive strength of bio-char pellets initially decreased and subsequently increased, while the energy consumption increased first and then decreased, with the increase of pyrolysis temperature. The moisture adsorption of bio-char pellets was noticeably lower than raw woody shavings but had elevated than the corresponding char particles. Hydrophilic functional groups, particle size and binder were the main factors that contributed to the cementation of bio-char particles at different temperatures. The result indicated that pyrolysis of woody shavings at 550-650 °C a shredded followed by densification was suitable to form bio-char pellets for application as renewable biofuels.

2. Development and fabrication of briquetting machine

Whipple (1954) states the objective of this invention was to provide means for mounting a plurality of chopping blades whereby the blades, when drawn over a cotton field after the cotton bolls are removed, cut the stalks just above the ground and chop the stalks into comparatively fine particles. Another object of the invention was to provide a cotton stalk shredding machine which cut stalks positioned vertically, laterally, and at substantially any angle between a vertical and a horizontal position. A further object of the invention was to provide' a cotton stalk shredding machine which was of a simple and economical construction.

Gunter and Nache (1984) reported that only suitable method of compacting biomass was the extrusion agglomeration process which could be applied in different ways, depending upon the characteristics of the raw material for making pellets from coarse materials with low bulk density and bad flow characteristics, the extrusion press with flat dies had been proved to be universally applicable. In Japan, briquetting seemed to have been common until recently with widespread use of Oxalate fuel briquettes made of saw dust. The Japanese technology has spread to Taiwan and from there to other countries and Thailand. This technology was based on screw press principle.

Papneja (1986) felt need of development of appropriate briquetting machine and a model was developed at Prototype Development and Training Centre, Okhla, which used binder less technology working at a pressure of 1400 kg/cm². It used 22 kW power. The equipment could handle biomass which was dried, shredded and sieved to a particular size. Limited trials were conducted which showed that production dropped from 350 kg h⁻¹ to 290 kg h⁻¹ in 42 hours and quality of briquettes was also poor. The die, ring and punch, etc. was worn out within a short period. However, with use of high speed steel, wear rate was reduced by 50 per cent.

Rama Rao and Kodra (1986) reported about installation of a plant manufactured by M/s. Farm Implement Madras based on "PARU" technology of ITF Delhi. The output of pyroliser was only 50 per cent of rated output which was 4 tones out of 6 tons raw material. The machine designed for agricultural wastes, such as rice-husk, straw, groundnut shell, etc. was useful and all these materials found more profitable uses. However, there were frequent breakdowns of the unit.

Srivastava *et al.* (1986) developed two prototypes of machines working on 2.2 kW and 3.70 kW power electrical motors keeping in view the requirement of a small scale briquetting unit for utilization in a village eco-system, where biomass of agricultural origin were available in scattered manner with small to large farmers and agro-based industries,. The small machine was used for agro- wastes with binding material such as clay etc. had

a capacity of 50 to 60 kg h⁻¹. The other was charcoal briquetting machine of capacity 60 to 70 kg h⁻¹ using charcoal and dung slurry. Though both machines were reported to be viable for cottage industries but it involved many manual operations and a vast variation in output. The sustained supply of wastes was not considered with machine.

Choudhary (1986) reported that there were about 15-20 manufacturers of briquetting equipment, both for organic biomass and pyrolysed char. During past few years many machines were sold / installed but most of them failed to attain desired goal for many reasons.

Gusain (1986) at Development Alternatives developed a hand operated ram type brick and briquette making press of capacity 500 to 800 kg briquette per day on 8 hour shift. The machine was a low cost model, priced at Rs. 10,000/- and handled both raw and pyrolysed biomass.

Car *et al.* (1984) reported that straw was successfully compressed to form briquette or pellets in USA to be used as fodder, additives and fuel, using screw or piston press. In palletization, ring or flat die presses were used. The material was extruded through a perforated breaker plate and the products were small cylinders 6 to 22 mm in diameter. The palletization had advantages of higher output between 4 to 6 tones h⁻¹. Wide range of moisture content could be accepted (up to 20 per cent wb) with a more convenient operation. However, the mean straw length ought to be less than 25 mm.

Srivastava *et al.* (1986) studied that in the screw presses, material fed continuously into a screw which forced it into a cylindrical die. The die was often heated to raise the temperature to the point where lignin flow occurred. The pressure built up smoothly along the screw rather than discontinuously under the impact of piston. Screw presses could be of the capacity 75 to 250 kg h⁻¹ though larger machines were available.

Srivastava *et al.* (1986) reported that the carbonized material could be briquetted in a screw press and in this, as lignin had been destroyed; a binder had to be employed. The capital cost of screw machines may be a little less

than piston units; however, because of variation in capacities it was difficult to compare them directly.

Srivastava *et al.* (1986) quoted that probably first briquetting machine was fabricated in 1920. It was a special press which produced cylindrical briquettes of 76 mm diameter and 254 mm height. They reported that in 1940, during early world war, almost every household in Switzerland owned a small briquetting press for pressing water soaked news prints.

Eriksson and Prior (1990) found that the maintenance cost of screw presses was high due to higher wear of screw, which needed frequent rebuilt. If the heating of die was to be avoided, the binding by lignin flow will not take place and a separate binder would be needed. The earliest development work on screw presses was carried out in USA in the 1930's resulting in the widespread use of the PRES-TO-LOG model which was based on the conical type of screw extruder. The Belgian Biomat design also used conical extruder. A Japanese design developed in World War II used heated die and a prolonged tapered central shaft of the screw resulting in a hollow briquette. It was very successful and a manufacturer claimed to have sold 600 such units.

Bhattacharya *et al.* (1990) found that the ICS programs in most developing countries of the World led to dissemination of improved cooking stoves (ICS) so as to relieve pressure on biomass resources. Most of the ICS programs were directed towards development of improved household cooking stoves, while relatively less work had been done on development of bigger stoves that could be used in institutional kitchens or certain traditional rural cottage industries. Three different designs of such stoves, using biomass briquettes as fuel, had been studied.

Grover (1990) reported that out of 70 plants sold by two countries, except 6-7, most of these plants became non-functional. It was also reported that not only briquetting plants stopped working but it resulted in discontinuation of manufacturing operations of these machines by 2-3 companies.

Hasan (2003) designed and developed two hay chopping machines i.e. chopper with helical Knives (CHK) and suction type hay chopper with rotary blades (SCRB) machine to improve feed intake and digestibility of hay by ruminants. The SCRB machine consists of radial blower and rotary disk with changeable 2 to 4 blades these two mounted together on a vertical shaft. The diameter of rotary disk was 300 mm to ensure enough air suction and peripheral speed. The CHK machine consisted of a feeding unit and chopping unit. The feeding unit consisted of a pair of counter rotating roller that has 37 mm clearance between them to pull by pressing hay. Rollers have 55 mm length, 144 mm diameter and special teeth to capture pressed material. The feeding unit was to feed the material to chopping unit. Six helical knives are fixed to the rotor shaft which is adjustable gap with counter shear.

Shailendra *et al.* (2004) developed a water hyacinth chopper with crusher to reduce volume and weight of freshly harvested water hyacinth in order to overcome the problem of high cost of transportation of freshly harvested water hyacinth from water bodies to the factories. They studied the feed rate and knife speed to determine relationships between changes in specific volume, knife speed; percent weight loss and feed rates. Weight reduction studies showed that increasing feed rate and knife speed resulted in a decrease in weight loss. Maximum weight loss of 34 per cent was achieved with the minimum feed rate of 1 t h⁻¹ and a knife speed of 3.1 m s⁻¹. The machine reduced the specific volume and weight of fresh water hyacinth up to 64 per cent and 32 per cent respectively at a feed rate of 1 t h⁻¹ and knife speed of 4.7 m s⁻¹. The average power and specific energy required to run the machine was 0.10 kW and 14 kW-h t⁻¹ dry matters, respectively. The output capacity of the chopper with crusher was found to be 14 t h⁻¹.

Dexter *et al.* (2005) developed Sugarcane Charcoal Extruder which compressed carbonized sugarcane into environment friendly charcoal briquettes and comparable to wood charcoal in burn performance, cost and durability. An improved design that was more portable, more robust, and less expensive to build than the original versions. The new design loads the bagasse

and binder directly into the feed screw and compresses the mixture using threads of decreasing pitch.

Sathitruangsak *et al.* (2006) carried out study with an objective to design an extrusion screw to produce biomass solid fuel in a cold extrusion process and investigated the effects of molasses used as a selected adhesive on the physical properties of extruded products. The material consisted of crushed coconut shell char and coconut fibre char mixed in a ratio of 40:60. The ratios of molasses in the mixture were 10:100, 15:100 and 20:100 (by weight) and the extrusion die angles were 1.0, 1.1, 1.2, and 1.3 degrees gradation per experiment. The experimental results showed that the newly designed screw could function properly in the output range of 0.75-0.90 kg min⁻¹, which was close to the design value. Regarding the molasses's effect on solid fuel properties, increasing the share of molasses was positive for both output and strength of the resulting briquettes, whereas the results of increasing die angle showed decrease in both output and strength. The compressive strength varied between 2.49 to 2.87 MPa in all circumstances, which was considerably higher than acceptable industrial level. Furthermore, the extruded solid fuel showed excellent resistance to impact force. Regarding energy consumption, the amount of electrical energy used in the extrusion process was insignificant, ranging between 0.040 to 0.079 kWh kg⁻¹.

Andrzej and Waldemar (2006) analyzed the quality of briquettes produced by a mixture of wood particles, sawdust and dust using perpetual screw briquette machines with a heated mould matrix and the stability of the production process was further monitored. The moisture content and fractional composition of the waste products used for briquettes production along with the density and degree of pressing of briquettes was determined. The quality of briquettes assessed on the basis of the macroscopic structure and physical parameters was very good. The density was close to 1200 kg m⁻³, the moisture content of about 3%, with smooth external surface and homogeneous cross-section structure. The good quality briquettes were characterized by proportional contribution of particular fractions of the lignocelluloses blend.

The most important reason for the instability of briquette production process was found to be inhomogeneous distribution of wood dust and not its fractional size in the bulk of the lignocellulosic mass introduced into the briquetting machine.

Adgidzi (2007) developed a forage chopper for chopping crop residues like maize stovers, millet stovers, sorghum stovers, rice straws, gamba grass and elephant grass in wet and dry conditions. The cutting blade parameters of the machine were knife edge thickness; knife thickness and sharpening angle (level angle) 80µm 4mm, 25degree respectively. The average chopping efficiencies for the wet and dry materials were 86 and 92per cent respectively. The average chopping rate for the dry materials was 24 kg h⁻¹ and the average chopping rate for the wet materials was 15.6 kg h⁻¹ respectively. These values indicated that the machine performed better with dry materials than the wet materials. The average length of cut of materials was 25 mm, this length makes it suitable for the preparation of dry season animal feeds with the chopped crop residues as major component and minerals, proteins and vitamins as a constituents. It requires only one person to operate and used either in rural or urban areas, using either a diesel or petrol engine of 8.5kW and above.

Thakur and Garg (2007) developed paddy stubble harvester cum chopper for chopping left out paddy straw in the combine harvester field for sowing wheat. The chopper was evaluated in the paddy field at different moisture content of stubbles (3 levels), forward speed of the machine (3 levels) and chopper speed (3 levels). Three seeding machinery i.e. traditional seed drill after incorporation with two disking and two planking, no-till drill and strip-till drill without incorporation were used for sowing of wheat. Fuel consumption and size of cut of paddy residue were taken as performance parameters. Per cent size of cut (less than 10 cm length) of paddy residue increased with increase in the chopper speed and moisture content but decreased with increase in the forward speed. Fuel consumption and size of cut of paddy residue were taken as performance parameters. For better performance, the stubble harvester-cum-chopper was operated at 70 per cent (w.b) moisture content of

the stubbles, with a forward speed of 2 km h⁻¹ and at a chopper speed of 1500 rpm. There was no significant difference in the yield of wheat crop in the three seeding systems. Chopping of paddy stubble was recommended immediately after combine harvesting because at higher moisture content chopping performance was found better.

Pathak *et al.* (2008) developed and evaluated tractor operated shredder used for shredding horticultural pruned waste *viz.*, mango, sapota, cashew, nutmeg branches and harvested grasses in order to utilize them as organic matter as well as industrial applications. 35 hp, 540 ± 10 PTO rpm tractor operated shredder was used with a capacity of 300 kg h⁻¹ and reported that, at optimum speed of the cutter speed i.e 450 rpm, more than 80 per cent cut pieces were observed in the length group of 20 to 24 mm and 40 to 60 mm with a capacity for all five crop waste. The required operation period for 100 kg pruned branches of mango, sapota, cashew, nutmeg and grasses was 0.36, 0.40, 0.46, 0.51 and 0.32 h.

Isaac and Bolufawi (2009) stated that for the densification of guinea corn residue, a source of biomass material is necessary for the purpose of handling and space requirements. The plant part of the guinea corn residue was collected from the field at a moisture content of 9.08% dry basis (db), reduced and sieved into three particle sizes d₁, d₂ and d₃. Starch mutillage of 40, 45, 50 and 55% by weight of the residue was added as binder. The bulk density of the unprocessed and processed guinea corn residue was determined using ASAE standards. Briquettes were produced using hydraulic press and a cylindrical die (56 mm) at pressures of 7.5, 8.5, 9.5 and 10.5 MPa. The particle sizes were separated into three distinct size ranges of 4.7 mm (d₁), 1.7 mm (d₂) and 0.6 mm (d₃). The mean moisture content of the relaxed briquettes was 7.15% (db). The bulk density of the unprocessed material was 46.03 kg m⁻³, and the mean relaxed briquettes bulk density was 208.15 kg m⁻³ with a volume reduction of about 450%. The maximum density of the briquettes ranged from 789 to 1372 kg m⁻³. The maximum and minimum axial relaxation occurred in the first 30 minutes of the extrusion with values 138.64 and 28% respectively in the

longitudinal axis, the maximum and minimum radial relaxation were 11.5 and 1.4% respectively. The briquettes were kept safely for a period of six months without deterioration.

Jibrin *et al.* (2013) designed and developed crop residue crushing machine. They reported that crop residues majorly used for livestock feed during dry season and fifty eight per cent of farm residue used for livestock feed during rainy season. In the peak of the dry season, stubble pasture supplies more than ninety per cent of livestock feed. The supply of residues such as corn, millet, wheat, and other cereal stovers as a livestock feed crop residue crushing machine was developed. This residue crusher admitted residue, chopped it and then crushed to desired grain size. Designed crusher was run by 10kW diesel engines.

Nithyananth *et al.* (2014) designed a waste shredder machine to reduce the agro waste so as to convert it into useful nourishing fertilizer and it reduced the heap amount of pollution. It decreases the man work thus making the farm neat and clean. In this shredder input power and rigid support was provided by a KAMCO Tera-trac 4 W tractor by means of PTO (Power Take Off) shaft and three point linkage. PTO shaft of the tractor acted as a basic power input and the three point linkage provided a rigid support to the machine. Various kinds of blades were used for chipping and powdering operations like sawing blades, rotary blades, and triangular shape blades. These types of blades were used to attain maximum fineness of agro-waste.

Mridaney *et al.* (2014) described rice husk briquetting industries which could be run profitably in Nepal, if simple extruder machines are used instead of making huge investment on the import of complicated technology from abroad. Rice husk the basic raw material for briquetting, is very abrasive in nature with over 19 % ash which causes the wearing of the screw. The project has undertaken research to address the technical problem of wearing of the screw by the introduction of new type of spray welding techniques to enhance the life of screw.

Ali Nurrakhmad Siregar *et al.* (2014) designed a single screw extruder and analyzed using Finite Element Method (FEM) and Computational Fluid Dynamics (CFD). Three different geometrical dimensions of screw extruder were designed and analyzed using FEM and CFD with software ANSYS POLYFLOW to study simulation of the flow and the behavior of Jatropha dough through a single screw extruder. In a preliminary study, this study focused to simulate the velocity profile and local shear rate indie section with a power law model. The result obtained revealed that three important Parameters as in designing a single screw extruder were gap area (clearance) in the range of 0.5 to 1.0 mm, chamber area (normal pitch) in the range 17 to 22 mm and root area.

Anak Agung Putu Susastriawan *et al.* (2014) designed small scale screw extrusion machine is designed and tested it for making compact sawdust briquettes in rural area in Indonesia. The extrusion machine was powered by 5,5 HP gasoline internal combustion engine. In this work, briquetting machine was used to produce sawdust briquettes which two different ratios of starch-sawdust. The ratios of starch to sawdust were 1:4 and 2:4. Sawdust briquettes have a length of 3 cm and 4 cm for both composition ratios. The performance of the machine was investigated in term of density changes of briquettes after three days. The density of sawdust briquettes just after extrusion process was compared with the density of sawdust briquettes after 3 days sunlight drying. The result shows that the extrusion machine is able to produce compact sawdust briquettes with different ratios of starch to sawdust. The result also indicated that 3 cm long sawdust briquettes which starch to sawdust ratio 2 : 4 has the lowest density changes and has the highest compressive strength.

3. Performance evaluation of briquetting machine

Mohan (1986) and TIDE (1992) quoted that marketing of briquettes of a large scale commercial unit (more than one tone) had several problems such as regular availability of raw material, storage space, packing, marketing of product and levy of taxes by some of the governments, competitive price of firewood and high price of raw material.

Bhattacharya *et al.* (2002) conducted experiments on a heated-die screw-press briquetting machine. Average savings in the electrical energy consumption due to preheating were 23.5 % at heater and 10.8 % at motor respectively. The average total energy saving was about 10.2 %. The lowest electrical energy consumption for rice-husk was 0.172 and 0.150 kWh/kg of briquettes produced, without and with pre-heating respectively. The biomass stove developed for die-heating was found to perform satisfactorily, and requires periodical fuel loading and ash-scraping. The stove could heat the die to the required temperature range of 300-320°C for briquetting during continuous operation. Average electrical energy saving due to replacement of electrical heaters with the biomass stove for die-heating was estimated to be about 35 % of total electrical energy consumption.

Renewable Energy Technologies in Asia (2003) evaluated the effect of raw material type on the performance of the integrated biomass briquetting system, consisting of the biomass pre-heater, die-heating stove and smoke removal system. Results indicated considerably less energy consumption when mixed raw materials (rice husk and sawdust, at 1:1 ratio by volume) were used in comparison with pure rice husk as raw material. Significant reductions in electrical energy consumption have been realized with the introduction of the die-heating stove to replace the electrical coil heaters. The smoke recycling system has also improved the working environment at the briquetting plant, by significantly reducing smoke in the vicinity.

Fabienne *et al.* (2006) tested and evaluated several methods and procedures for the determination of particle density of pellets and briquettes. Round robin trials were organized involving five European laboratories, which measured the particle densities of 15 pellet and five briquette types. The test included stereo metric methods, methods based on liquid displacement (hydrostatic and buoyancy) applying different procedures and one method based on solid displacement. From the results for both pellets and briquettes, it became clear that the application of a method based on either liquid or solid displacement (only tested on pellet samples) led to an improved reproducibility

compared to a stereo metric method. For both, pellets and briquettes, the variability of measurements strongly depended on the fuel type itself. For briquettes, the three methods tested based on liquid displacement lead to similar results. A coating of the samples with paraffin did not improve the repeatability and the reproducibility. Determinations with pellets proved to be most reliable when the Buoyancy method was applied using a wetting agent to reduce surface tensions without sample coating. This method gave the best values for repeatability and reproducibility, thus less replications were required to reach a given accuracy level. For wood pellets, the method based on solid displacement gave better values of repeatability; however, this instrument was tested at only one laboratory.

Yousif *et al.* (2006) reported that briquetting of the carbonized agricultural residues represents one of the possible solutions to the local energy shortages in many developing countries. It constitutes a positive solution to the problem of increasing rates of desertification in many areas worldwide. Agricultural residues are not attractive as a household fuel source for urban areas because they are very bulky and have low energy intensity. Also, to eliminate the smoke generation when burning agricultural residues requires processing it by carbonization before being used as a house-hold indoor fuel. Previously investigated, briquetting machines lacked high productivity and were of complicated designs. The present study put forward a machine of simple design which could be manufactured locally in Sudan and of much higher productivity. The local Sudanese briquetting experience was overviewed, studying all the alternative available options and the market potential. The study presented a detailed design study of the new briquetting machine. The prototype was made and tested in the field at *al-gazeera* area in Sudan. The investigation results indicated that the new machine has a production rate better than all the previous alternatives. This low pressure screw briquetting machine was found to have a production rate equivalent to about eight times better than the production rate of the best local competitor. The production cost was found to be lower due to the lower binder requirement

for the new machine, which is lower by about 65%. The initial moisture content of the feed stock required for this machine is lower by about 30 % compared to the best alternative, which results in shorter drying time for the fuel briquettes produced. The quality of the produced briquettes was found to be better and of lower smoke generation when burned due to the lower binder content.

Mohamed (2008) evaluate the performance of shredder for shredding crop residues such as rice straw, cotton stalks and maize stalk in Egypt. They used three shredder machines (Kader, Mabrouk and Vermeer) which were operated by 60 hp, Massey Ferguson tractor under cutting rotor speeds ranging from 1000 to 2000 rpm. Comparison of machines was made based on productivity, consumed energy, cutting length and total costs. Mabrouk has the highest productivity for three crop residues at 1800 rpm (0.98, 1.02 and 0.91t h⁻¹) for rice straw, cotton stalk and maize stalks respectively. Vermeer shredder had the lowest consumed energy for cotton and maize stalks at 1800 rpm 26.60, 26.72 kW-h t⁻¹ respectively. However the Mabrouk shredder had the lowest operation cost and had the highest cutting length percentage than kader and vermeer shredder.

Gonulol *et al.* (2009) evaluated three different stalk chopper machines by using of alternative stalk chopping methods in sunflower farm. The different stalk chopper machines were two different rotary type machines (RT₁ and RT₂) and heavy duty disc harrow (CON). They determined particle size distribution after chopping, management parameters of the machine and energy requirement in the sunflower farm. The smaller particle size was achieved by using rotary type machines. The chopping which was done by machines with rotary type was recommended in sunflower farm, because they were more economical and gave desired stalk particle size than heavy duty disc harrow.

Juri Olt and Mihkel Laur (2009) analyzed the features of producing briquette from different herbaceous biomaterial and cardboard waste and described the problems that can arise in the pressing operation. The screw press was used. The proper briquette was formed from wheat straw, rye straw and

cardboard and the satisfactory one from rye straw together with meadow hay. While the rye straw briquette exhibited the highest calorific value and the lowest ash content, the leafbriquette had the highest ash content and the lowest calorific value.

Basher *et al.* (2010) designed, developed and evaluated a stalk chopper. Stalk chopper was constructed by using locally available materials and the chopper was developed for supply of fodder for animal husbandry business. It has a material capacity of 45.69 kg h⁻¹ and cutting efficiency of 91 per cent.

Adarsh *et al.* (2010) studied on ergonomic assessment of manual fodder cutter. They determined the human energy expenditure in operating a manual chaff cutter for that, they selected three operators of different age groups and selected different types of fodder crops *viz.*, maize, pearl, millet and sorghum. Increase in energy expenditure with increase in feeding rate was reported. The specific energy of fodder cutter increased with increase in diameter stalk and also specific energy varied with material, and was lower in case of dried material of similar diameter

Arshdeep *et al.* (2011) evaluated a tractor mounted straw chopper cum spreader to overcome the problem of left out straw after combine harvesting in the paddy field for paddy wheat rotation. They first chopped the paddy straw by using this machine and then incorporated in soil with minimum tillage efforts. They selected two levels of moisture content of paddy straw *viz.*, 30 & 40 per cent (w.b), three levels of chopping speed *viz.*, 1300, 1450 & 1600 rpm and three levels of forward speed *viz.*, 2.0, 2.5 & 3.0 km h⁻¹ respectively. Effect of moisture content on size of chopping was found to be non-significant. Per cent size of cut (up to 4 cm) of paddy straw increased with increase in chopper speed and decreased with increase in forward speed. Fuel consumption at lower moisture content was low. Fuel consumption (l h⁻¹) increased with increase in chopping speed as well as with increase in forward speed. Finally optimized the combination of chopping speed and a forward speed were 1450 rpm and 2.0 km h⁻¹ respectively.

Gaikwad and Bhargav (2012) studied on size reduction machine for arecanut sheath for animal fodder. They reported that the machine can chop about 92 kg h⁻¹ of the arecanut sheath having moisture content in the range of 10 - 15 per cent db at rotational speed of 700 rpm. The dry fodder produced by the machine can be fed to all kinds of farm animals including buffaloes, cows, oxen's, sheep and goat.

Gaikwad and Bhargav (2012a) studied the cutting characteristics of arecanut sheath for use as animal fodder. A factorial experiment was therefore conducted using texture analyzer to study the cutting characteristics of the arecanut sheath for proper size reduction. Three different cutting configurations were evaluated for cutting energy requirements, peak cutting forces required and the quality of cut obtained. A two dimensional shearing configuration was found to be suitable for size reduction of arecanut sheath with peak cutting force of 350 N. The inclination angle of cutter knife and speed of cut were not found to be significantly affecting the phenomenon of cutting.

Ramesh M. Singh (2013) revealed the reviews on briquetting scope and potential in Nepal, which still relies heavily on traditional sources of energy for cooking, heating and livestock feeding. In search for alternatives to fuel wood and utilization of waste biomass, briquetting was introduced in 1982 by the private sector to produce charred rice briquettes and rice husk briquette in 1987. A close analysis of the situation during the 1980s revealed that the entire briquetting efforts came from the private sector, without any government support in terms of policies, incentives and motivation. Also there was no technical backstopping and very little R&D to support briquetting. So because of various techno-economical problems, most of the briquetting industries closed down.

Gunasekaran *et al.* (2014) studied on selectivity and palatability of tree fodders in sheep and goat fed by cafeteria method. They were selected four Madras red breed of sheep and four kanni breed of goats fed with four locally available tree species viz., albizialebbek, gliricidiasepium, leucaenaleucocephala and ingadulce was studied through intake studies by

cafeteria method for a period of 35 days. The nutrient composition of the tree leaves was analyzed. *Leucaenaleucocephala* was mostly preferred by sheep and goats and the consumption of tree leaves was 24.41 ± 0.67 and 33.90 ± 3.27 g-DM kg^{-1} metabolic body weight per day respectively. In both sheep and goat, palatability of *leuceanaleucocephala* and *ingadulce* were ranked first and second respectively. *Gliricidiasepium* was ranked third in goats followed by *albizzialebbeck* in whereas *albizzialebbeck* was ranked third in sheep followed by *gliricidiasepium*. The study concluded that leaves of *leuceanaleucocephala* could serve as a better tree fodder for small ruminants.

Malakhova (2015) proposed a method of compacting of Seversk CHPP (Russia) ash by vibration briquetting using a number of binders (polyvinyl alcohol, glyoxal, liquid sodium glass). The main characteristics of Seversk CHPP ash such as chemical composition, particle size distribution, bulk density, content of unburnt carbon and radioactivity have been determined. Investigation of the effect of binder concentration on the static strength of granules revealed that the increase of binder concentration resulted in the growth of static strength of the dried granules that reached a maximum at the concentration of 10 wt %: 0.28 MPa for polyvinyl alcohol, 0.63 MPa for glyoxal and 0.40 MPa for liquid sodium glass.

Husain *et al.* (2015) concluded that an attempt has been made to convert these residues into solid fuel. The palm shell and fibre is densified into briquettes of diameter 40, 50 and 60 mm under moderate pressure of 5 to 13:5 MPa in a hydraulic press. Experiments were carried out to determine density, durability, impact and compressive strength of the briquettes. The heating value, burning characteristics, ash and moisture content were other objects of the study. A relationship between press pressure and the briquette density has been established. The produced briquettes have densities between 1100 and 1200 kg m^{-3} . The briquettes properties are quite good with good resistance to mechanical disintegration, and will withstand wetting. The gross calorific value is about 16:4 MJ kg^{-1} (maf), and the ash content was about 6% and the equilibrium moisture content was about 12%. Further work is required to

acquire complete understanding of the densification process before good quality and durable briquettes could be made free from cracks.

4. Economics of briquetting machine

Jorapur and Rajvanshi (1997) evaluated the economics of a throat less down draft gasifier of rated capacity 1080 MJ h⁻¹ and the output of 675 MJ h⁻¹. The economics was more attractive for the gasification system.

Anon (1999) reported that intense flame emitted from gasifier burner replaces conventional diesel fired burners in industries. The payback period for 50000 kcal h⁻¹, Thermal gasifier was 18 months and for 250000 kcal h⁻¹, it was 12 months.

Tripathi *et al.* (1999) evaluated the unit cost of thermal energy for biomass gasifier-based institutional cooking systems and compared with that for LPG and coal-based institutional cooking options. It works out to Rs 0.37MJ⁻¹ for a 29 kW_a, (25 000 kcal h⁻¹) biomass gasifier system while for a 291 kW_a, (250 000 kcal h⁻¹) system it is Rs 0.23MJ⁻¹. Biomass gasifier-based institutional cooking systems were always financially more attractive than corresponding coal-based systems and were even better than LPG based systems.

Savani *et al.* (2004) reported on the economics for agricultural waste shredder. They revealed that the cost required for shredding of one ton of castor stalk, cotton stalk and pigeon pea stalk was Rs. 272, 282 and 246 respectively and benefit-cost ratio was 2.44.

Pathak *et al.* (2008) developed a tractor operated stationery shredder and they studied the cost economics for shredder and concluded that the total cost of tractor operated shredder was Rs. 33,800 excluding tractor cost.

Elfatih *et al.* (2010) evaluated the modified chopper for cutting rice straw for composting and they studied the cost economics for modified chopper and they concluded that the highest cost of operation was 240.7 LE t⁻¹, Meanwhile the lowest cost was 129.2LE t⁻¹.

Mohamed and Ghanem (2010) were studied the performance of modified thresher. They reported that lowest cost for producing of one Mg

from shredded green rice straw was of 14.05LE and the consumed energy for the unit was of 5.632 kW-h Mg⁻¹ at feed rate of 300 kg h⁻¹, shredding cylinder speed of 18.4 m s⁻¹ and concave clearance ratio of 1.0.

Teerapot Wessapan (2010) designed a compact screw-press briquetting machine which combined three functions including crushing, mixing and briquetting in a single unit. By eliminating individual machines, the significantly higher savings in space, material handling and worker, and the improved efficiency can be realized. This technology also helps to reduce cost and production time, and improve productivity, and eventually led to be able to survive in competitive environments. This paper also presented characterizing property of the briquettes produced by the developed machine. Finally, a cost analysis for the compact briquetting machine is presented.

Manoj Kumar Sharma (2015) concluded extrusion production technology of briquettes is the process of extrusion screw wastes (straw, sunflower husks, buckwheat, etc.) or finely shredded wood waste (sawdust) under high pressure. There is a tremendous scope to bring down the waste of convention energy sources to a considerable level through the development, propagation of non-convention briquettes technology i.e. briquettes machine , briquettes plant, biomass briquettes plant for production of agro residue briquettes to meet thermal energy requirement. Therefore, this substitute energy medium is given national priority as appears to be the only permanent solution into restriction of the national laws and avoid pollutions.



*Material and
Methods*



CHAPTER-III

MATERIALS AND METHODS

This chapter deals with the methods adopted in development of the shredder cum briquetting machine and the experimental methodology used to evaluate the machine as influenced by the biomass, machine and operational parameters are described. The development work and laboratory trials have been conducted at Deptt. of Farm Machinery and Power Engineering, College of Agricultural Engineering & Technology, VNMKV, Parbhani. For conducting the study, efforts are made to design and development of shredder cum briquetting machine in order finalizes their dimensions for the capacity of 120 kg h⁻¹ output ofbriquettes. Also the physical parameters of raw material in terms of bulk density, sphericity, arithmetic mean diameter and geometric mean diameter, moisture content and calorific value was studied. The procedure adopted for evaluating its performance and machine economics are also discussed. The residues were procured from Vasant Rao Naik Marathwada Krishi Vidyapeeth fields. The study was conducted in the following sequence.

1. Physical properties of biomass.
2. Development and fabrication of shredder cum briquetting machine.
3. Performance evaluation of shredder cum briquetting machine.
4. Economics of shredder cum briquetting machine.

3.1 Study of selected physical properties of Physical characteristics of biomass:

1. Bulk density
2. Sphericity
3. Arithmetic and Geometric mean diameter
4. Moisture content
5. Calorific value

3.1.1 Bulk density

Bulk density of biomass was determined by using water displacement method. This method was used to measure the volume of individual biomass. (Kharidwar *et al.*, 2013).

$$\hat{\text{Bulk density, kg m}^{-3}} = \frac{\text{Weight of biomass, kg}}{\text{Volume of biomass, m}^{-3}} \quad \dots (3.1)$$

3.1.2 Sphericity

Sphericity of biomass was determined by using following equations (Mohsenin, 1970).

$$\hat{f} = \frac{(L \times W \times T)^{1/3}}{D} \quad \dots (3.2)$$

Where,

$\langle f \rangle$ = Sphericity

L = Length of residue, mm

W = Width of residue, mm

T = Thickness of residue, mm

3.1.3 Arithmetic and geometric mean diameter

For each biomass, the length, width and thickness of biomass were measured on randomly selected biomass. The length, width and thickness of samples were measured using a metal tape and digital calliper with an accuracy of 0.01 mm. The arithmetic mean diameter (Da) and geometric mean diameter (Dg) of the samples were calculated by using the following equations (Mohsenin, 1970).

$$D_a = \frac{L + W + T}{3} \quad \dots (3.3)$$

$$D_g = (L \times W \times T)^{1/3}, \text{ mm} \quad \dots (3.4)$$

3.1.4 Moisture content

The moisture content of biomass is defined as the quantity of water per unit mass of the wet sheath. Moisture content of biomass at the time of freshly fallen varies drastically (Biddappa, 1960). The moisture content of biomass was measured by oven dry method. Initially the sample with the known weight (25 g) was kept in oven at 105 °C for 24 hours. The oven dry sample is then weighed. The moisture content of sample was calculated by the following formula (Khardiwar *et al.*, 2013).

$$M.C = \frac{W_1 - W_2}{W_1} \times 100 \quad (3.5)$$

Where,

M.C = Moisture content of biomass, per cent

W₁ = weight of sample before drying, g

W₂ = weight of sample after drying, g

3.2 Design and development of shredder cum briquetting machine

3.2.1 Design of biomass shredder

The biomass shredder has been designed for chopping of biomass into small pieces suitable for briquettes. The biomass shredder consists of cylindrical cutter head with blades which compress and advance the biomass into the cutterhead. The shredder is operated by an electric motor and power is transmitted to the cylindrical cutterhead through the shaft *via* the pulley's v-belt. It is manually fed with continuous process through the feeding chute. The whole biomass passes horizontally and vertically against the rotating blades and meet the knives which is mounted inside the cutter head frame, while rotating cutter blades biomass rubs and crushes and it is chopped into small pieces like powder (3 to 6 mm) and it comes down through meshes which is placed at the bottom. The overall size of biomass shredder was 765 mm in

length, 610 mm in width and 1065 mm in height. The biomass shredder unit gets power for motion from electric motor mounted on bottom of the main frame.

3.2.2 Selection of prime mover:

The selection of suitable power source is very important while developing any type of agricultural machine. So, the electric motor or diesel engine is to be selected as a power source which drives the chopping cutterhead unit carrying the knives in the shredder. A pulley of 150 mm diameter was provided on electric motor which acts as prime mover.

For getting high speed, motor was connected large pulley and cylindrical cutterhead shaft connected to small pulley.

The electric motor was mounted on the main frame by using two pairs of MS angles and provision was made to slide the motor to get desired tension on the belt. In between motor and MS angle frame, a wooden plank of 20 mm thick and 460 mm length was placed in order to absorb the vibration offered by the motor during the operation. The isometric view and front view of biomass shredder cum briquetting machine was shown in Fig. 3.1 and 3.2. The isometric view and front view of biomass shredder cum briquetting machine designed in solid works was shown in Fig. 3.3 and 3.4.

3.2.3 Design consideration:

3.2.3.1 Design of shafts:

a. Design of cylindrical cutterhead shafts

The torque transmitted by the shaft was calculated by using formula suggested by Khurmi and Gupta (2006).

$$2 \times 7ix N \dots (37)$$

Where,

T = torque transmitted by the shaft, N-mm

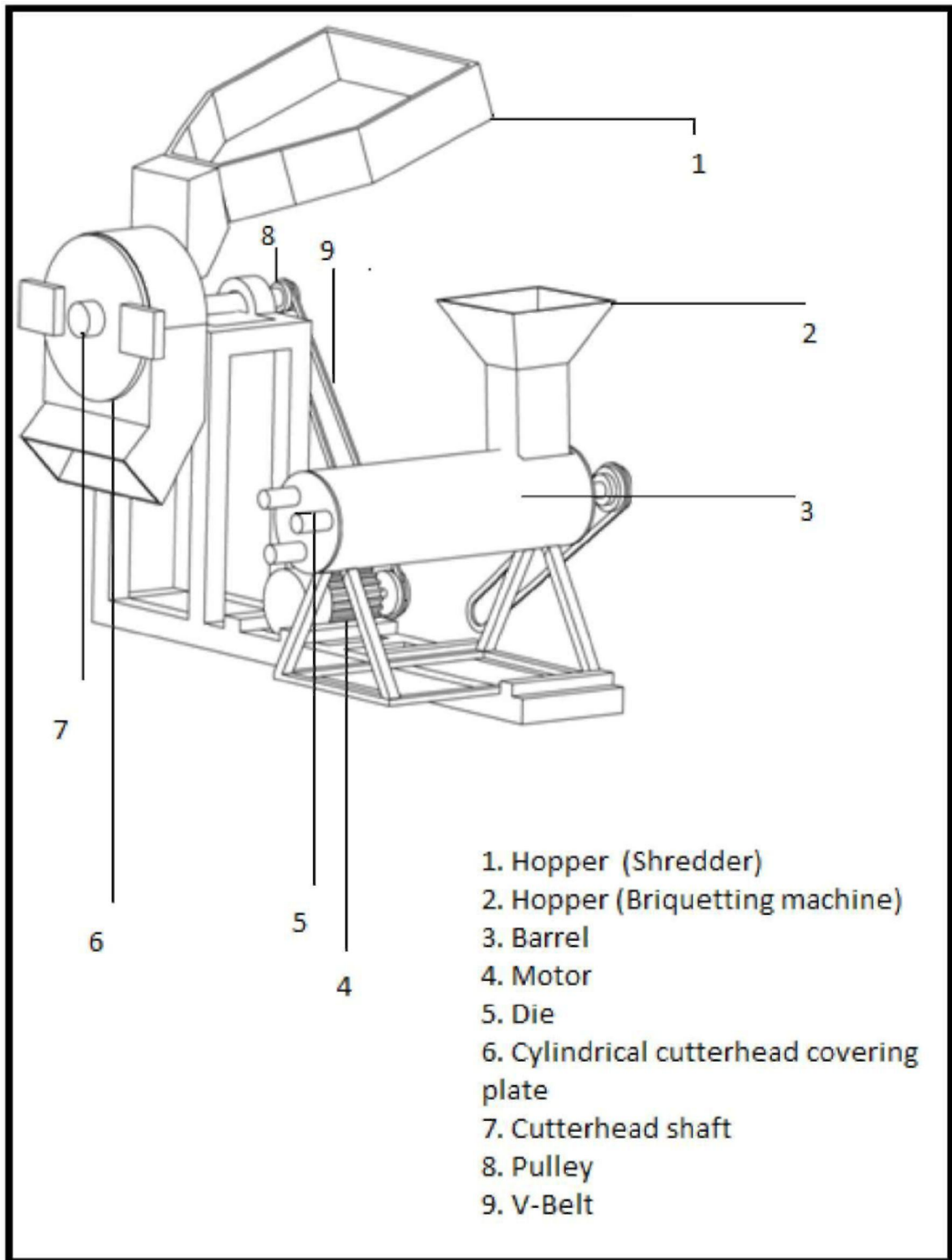


Fig. 3.1 Front view of shredder cum Briquetting Machine

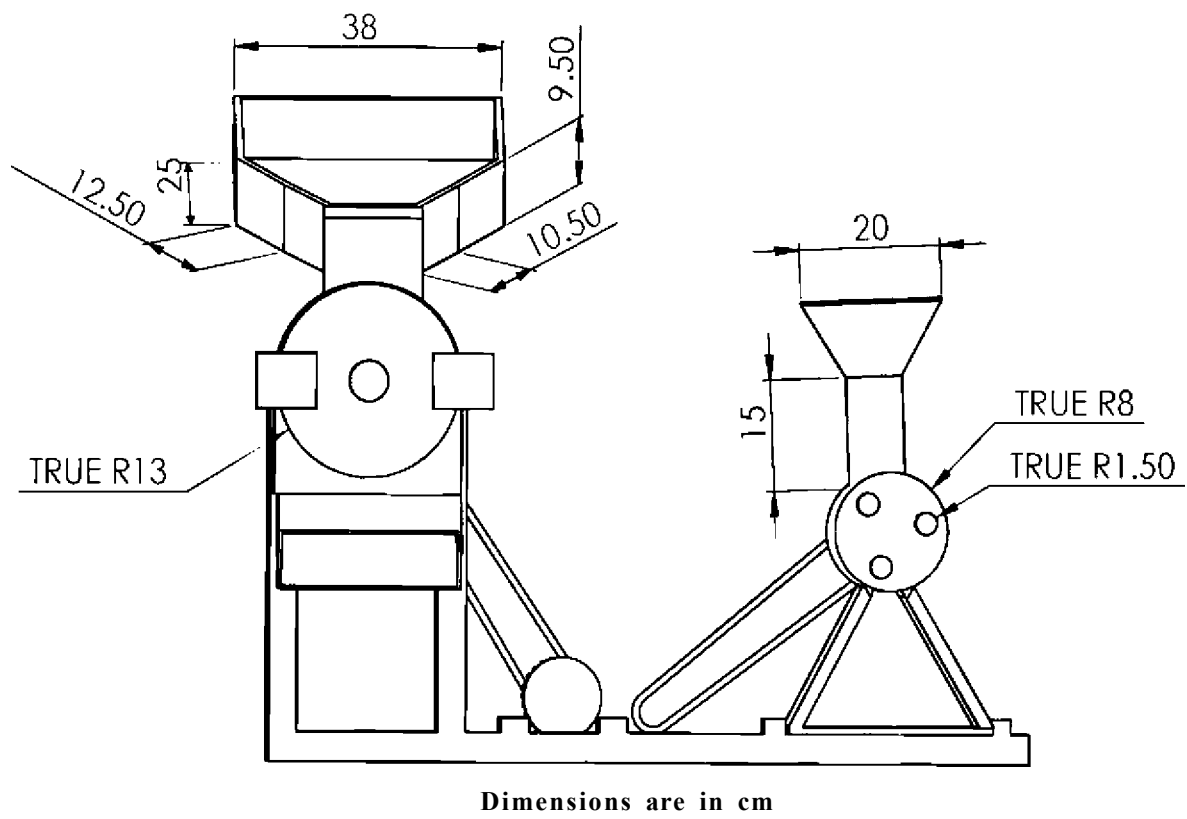


Fig. 3.2. Isometric view of shredder cum Briquetting Machine

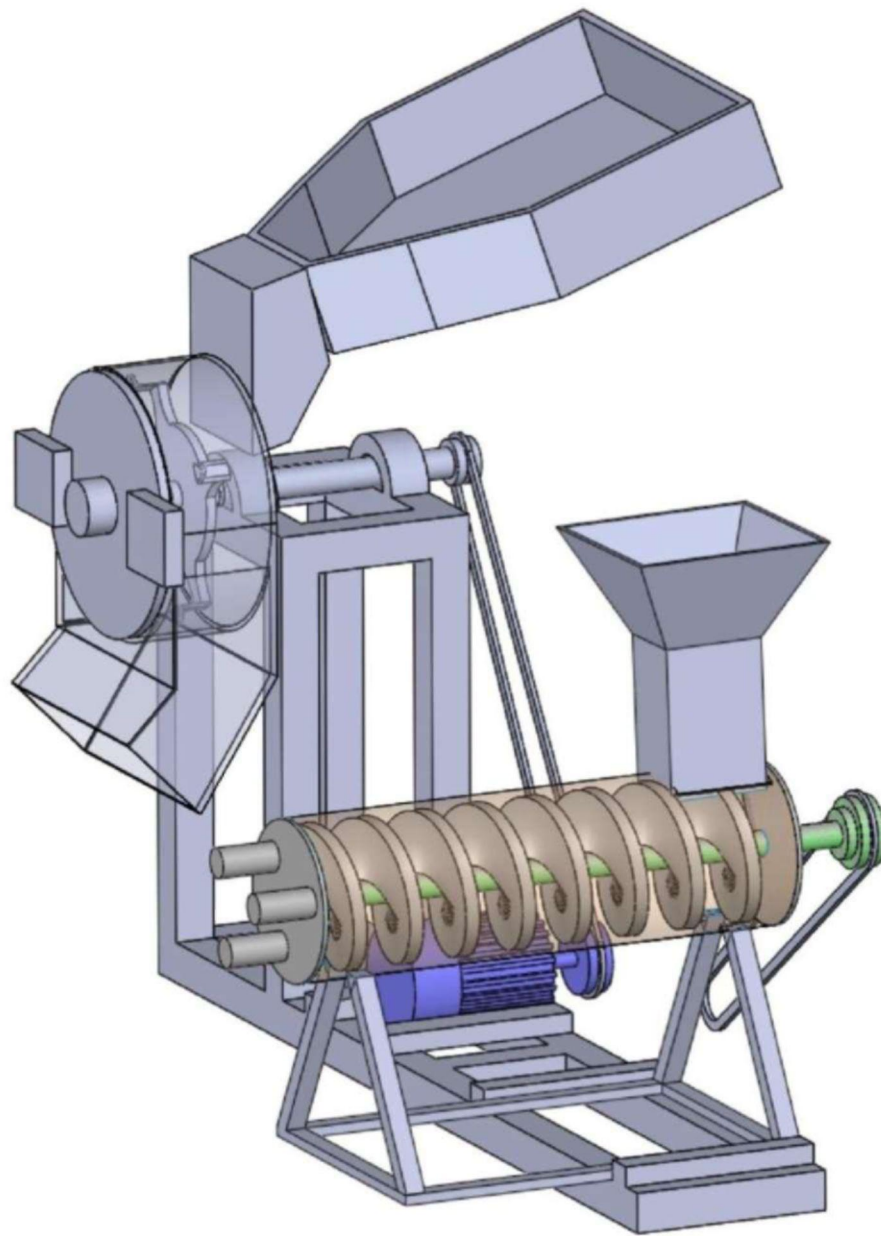


Fig. 3.3. Isometric view of shredder cum Briquetting Machine in Solid Works

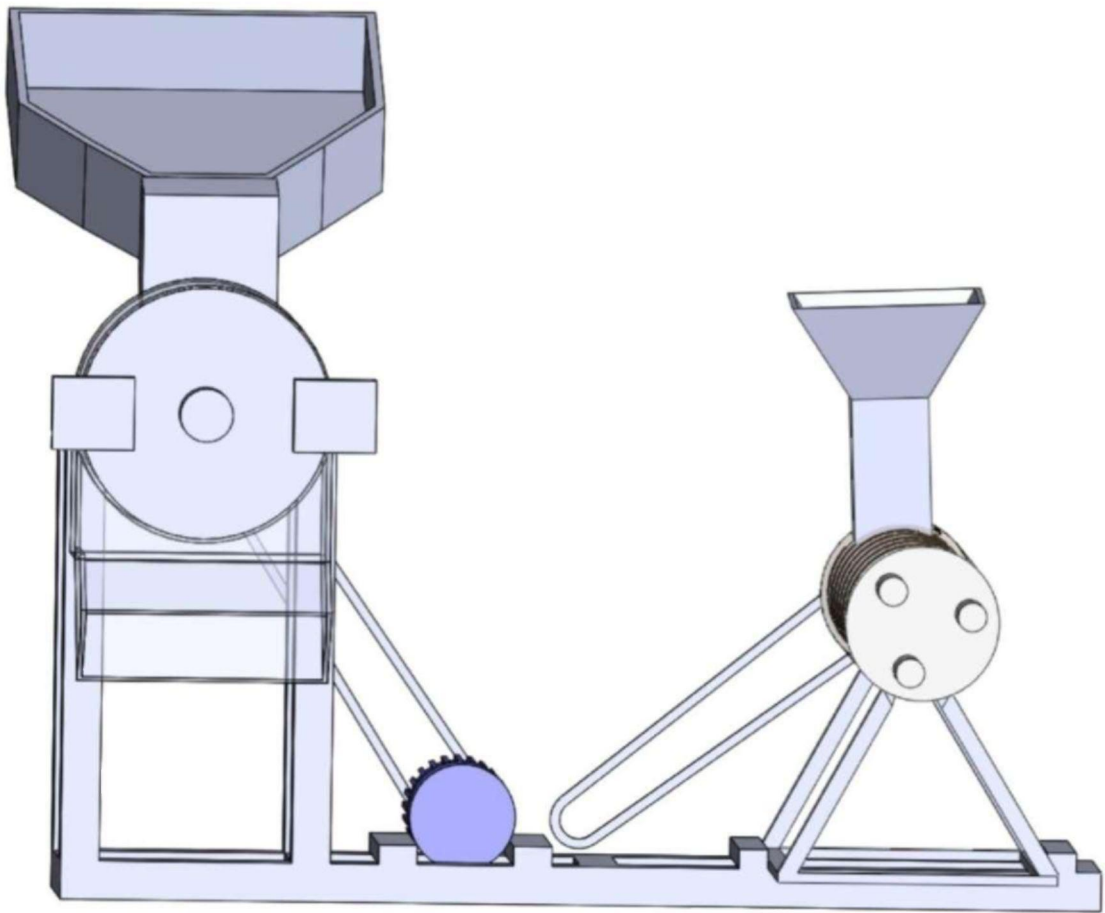


Fig. 3.4. Front view of shredder cum Briquetting Machine in Solid Works

P power, W

N rpm of shaft

$$T = \frac{1490 \times 60}{2 \times 3.142 \times 900}$$

T 15.81 N-m

T 15.81 x 10³ N-mm

The torque transmitted by the shaft (T)

$$T = \tau r x d^3 \tag{3.8}$$

Where,

T = Torsional shear stress, MPa (for Mild Steel T = 42 MPa Khurmi and Gupta, 2006)

d = diameter of the shaft, mm

$$15.81 \times 10^3 = \tau \times 42 \times \frac{d^3}{16}$$
$$15.81 \times 10^3 \times 16 = 3.142 \times 42 \times d^3$$

$$d = 12.42 \times 2 \text{ mm}$$

$$d = 24.84 \text{ mm}$$

The shaft diameter was selected as 25 mm.

3.2.3.2 Design of power transmission system

V-belt drive system of was selected for power transmission as this system works satisfactorily at linear speed from less than 0.5 m s⁻¹ up to 20 m s⁻¹. The selection of the pulley and belts for cylindrical cutterhead shaft were made based on following criteria.

> Rated power developed by electric motor, kW = 1.49

> Rated speed of motor drives pulley, rpm = 1440

> Cylindrical cutterhead diameter, mm = 260

> Assume of cylindrical cutterhead speed, rpm = 900

3.2.3.3 Design of belt and pulley

a. Design of pulley

The pulley was used to transmit power from electric motor shaft to cylindrical cutterhead shaft. Before design of pulley assume cylindrical cutterhead shaft speed as 900 rpm. (Shashi, 2015)

$$\text{Cylinder peripheral speed (m s}^{-1}\text{)} = \frac{\pi D N}{60} \quad (3.9)$$

Where,

D = Cutterhead diameter, m

N = Cylindrical cutterhead speed, rpm

So,

$$\text{Cylinder peripheral speed (m s}^{-1}\text{)} = \frac{\pi \times 0.26 \times 900}{60}$$

$$\text{Cylinder peripheral speed (m s}^{-1}\text{)} = 12.246$$

$$\text{Velocity ratio} = \frac{\text{Motor shaft speed, rpm}}{\text{Cylinder shaft speed, rpm}} \quad (3.10)$$

$$\text{Velocity ratio} = \frac{1440}{900} = 1.6$$

The diameter of the pulley (d1) on motor shaft was determined as following,

$$d2 = \text{Velocity ratio} \times d1 \quad \dots (3.11)$$

Where,

d2 = Diameter of drive pulley, mm

d1 = Diameter of driven pulley, mm

$$150 = 0.9 \times d1 = 93.75 \text{ mm}$$

Hence a pulley of standard 75 mm size was selected and provided on the

cutterhead shaft.

b. Design of V-Belt

A belt provides a convenient means of transferring power from one shaft to another. Belts are frequently necessary to reduce the higher rotational speeds of electric motors to lower values required by mechanical equipment. The belt driver relies on frictional effects for its efficient operation. When the belt connecting two pulleys is stationary, the tensions in the two portions of the belt are equal but when torque is applied to the driving pulley, one portion of the belt is stretched and the other portion becomes slack.

The properties of a V-belt viz., density, cross sectional area and allowable tensile stress (σ) were taken as 1000 kg m^{-3} , 150 mm^2 and 2.5 MPa . A groove angle (θ) of 35° , pulley of 0.25 m was considered as co-efficient of friction (μ) between pulley and belt (Khurmi and Gupta, 2006).

The mass of the belt per unit length,

$$m = \text{Cross section area, } m^2 \times \text{Length, } m \times \text{Density, } \text{kg m}^{-3} \quad \dots (3.12)$$

$$m = 150 \times 10^{-6} \times 1.6 \times 1000 = 0.24 \text{ kg per meter length of belt}$$

The centrifugal tension of the belt (T_c) given by;

$$T_c = m \times v^2, N \quad (3.13)$$

Where,

m mass of the belt per meter length

v Velocity of the belt, m s^{-1}

$$v = (\pi \times D \times N)/60 \quad (3.14)$$

$$v = 3.142 \times 75 \times 900/60 = 3.53 \text{ m s}^{-1}$$

$$\text{So, } T_c = 0.24 \times 9.81 \times 3.53^2, N$$

$$T_c = 29.33 N$$

Maximum tension in the belt,

$$T = \sigma \times \text{Section area of belt, mm}^2 \quad (3.15)$$

Where,

σ = Allowable tensile stress = 2.5 MPa

$$T = 2.5 \times 10^6 \times 150 \times 10^{-6}$$

$$T = 375 \text{ N}$$

Therefore,

Tension in tight side of the belt,

$$T_1 = T - T_c \quad (3.16)$$

$$T_1 = 375 - 29.33 = 345.67 \text{ N}$$

The tension in the slack side of the belt (T_2) calculated as follows

For open belt drive

$$\sin a = \frac{O_2 - O_1}{2x} = \frac{660 - 660}{2 \times 660} = 0.056 \quad (3.17)$$

$$a = 3.21^\circ$$

Angle of lap on smaller pulley (*i.e.* pulley on motor shaft),

$$\theta = 180 - (2 \times 3.21) \quad (3.18)$$

$$\theta = 173.58^\circ$$

$$\theta = 173.58 \times \pi / 180 = 3.02 \text{ rad.}$$

To find tension at slack side, following formula were used;

$$2.303 \log \frac{T_1}{T_2} = p \times \theta \times \operatorname{cosec} (\theta/2) \quad (3.19)$$

$$2.303 \log \frac{T_1}{T_2} = 0.25 \times 3.02 \times \operatorname{cosec} (35/2) = 2.50$$

$$\log \frac{T_1}{T_2} = 2.51/2.303 = 1.085$$

T_2 ;

$$T_2 = \frac{345.67}{12.02} = 28.75 \text{ N}$$

$$T_2 = 345.67/12.02 = 28.75 \text{ N}$$

The power transmitted per belt;

$$P = (T_1 - T_2) v = (693.99 - 60.45) 2.35 \dots (3.20)$$

$$P = 1118.72 \text{ W} = 1.119 \text{ kW}$$

Therefore,

Number of V-belts required to transfer power to cylinder pulley from motor pulley was calculated by following this formula;

$$\text{Number of V belts required} = \frac{\text{Total power transmitted}}{\text{Power transmitted per belt}} \dots (3.21)$$

$$\text{Number of V - belt required} = \frac{1.49}{1.11} = 1.34 = \text{Say } 1$$

So, one V-belt was selected for power transmission.

The length of the belt was calculated based on the diameters of the driver and driven pulleys and centre to centre distance between the pulleys. The formula used for calculating the length of the belt is,

$$L = n(r_2 - r_1) + 2x + \dots (3.22)$$

$$L = n(75 - 37.5) + 2(660) + \dots$$

$$L = 1359.63 \text{ mm}$$

3.2.4 Fabrication of electric motor operated biomass shredder

3.2.4.1 Feeding chute

The feeding chute was the component of biomass shredder, which receives the biomass and fed it to the cutter head. It was kept in trapezoidal shape. The biomass was manually fed with continuous process. The feeding

chute was made from mild steel sheet (Ojha and Michael, 2003). The overall dimensions of the feeding chute were 480 mm x 380-130 mm x 95 mm length, top and bottom width and height of feeding chute, respectively.

3.2.4.2 Cylindrical cutterhead

a. Shape

In this study biomass shredder consist of a cylindrical cutterhead was used for shredding biomass. It was a cylindrical shape cutterhead with blades on a revolving cylinder for chopping materials into required size. It was mounted on the shaft. A cylindrical type cutterhead was developed and evaluated for chopping of biomass. The overall dimensions of cutterhead were 260 mm diameter and 110 mm length.

b. Blades

The blade is an important component in the cylindrical cutterhead of biomass shredder. In this study, straight hammer blades are used for chopping of biomass. The blades are mounted parallel to the cylinder axis to get better performance. The length of the hammer blades is kept equal to the length of the cylinder. To obtain a clean cut, blades operate close to the shear plate without striking (Ojha and Michael, 2003). It is made from high carbon steel (Gagadishwar, 2010) and a view of Fabrication work of shredder has been shown in plate 3.1 and cutterhead unit was shown in plate 3.2.

- No. of blades vary on cylindrical cutterhead = 4
- Angle between four number of blades = 90°
- Material of cutting blades = High carbon steel
- Length of cutting blades, mm = 120
- Width of cutting blades, mm = 80
- Thickness of cutting blades, mm = 15



Plate 3.1. A view of fabrication work of shredder

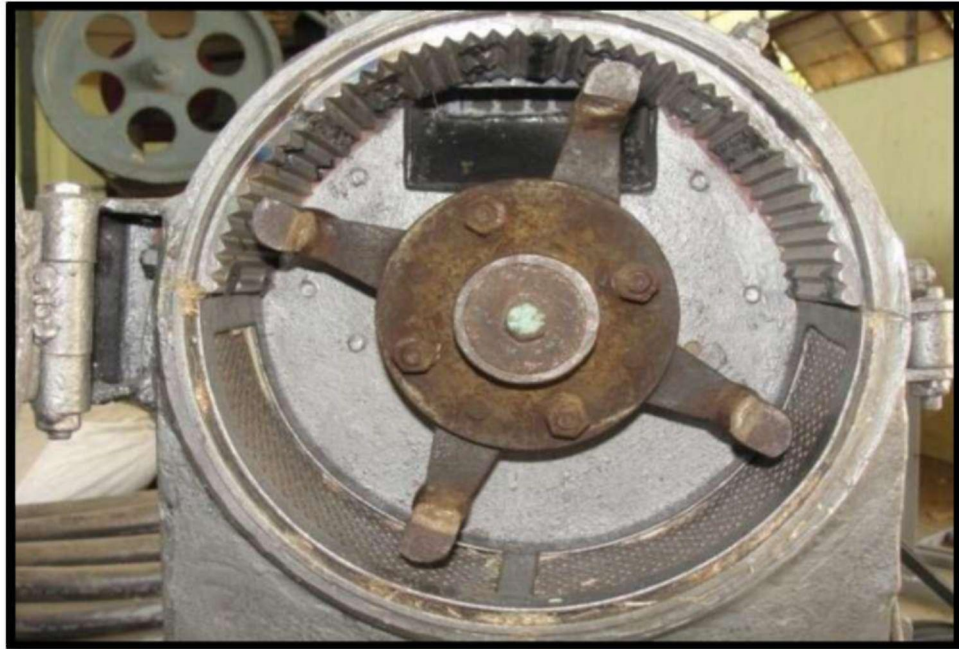
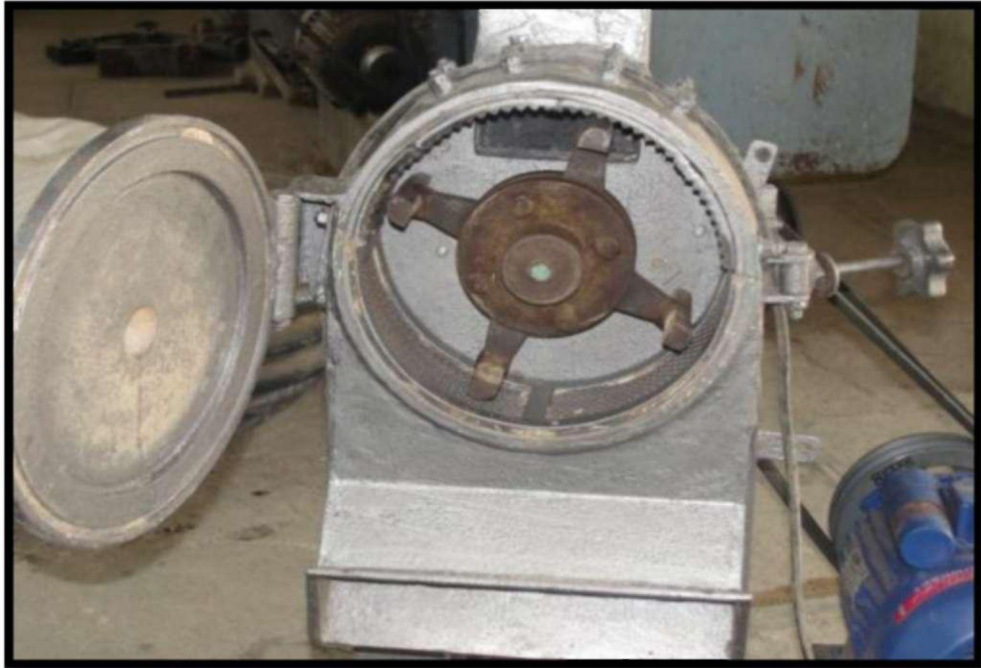


Plate 3.2 Cutterhead unit of shredder

Table 3.L Specification of biomass shredder

Sr. No	Components/parts	Shape/dimensions
1	Main frame	
	Shape of the frame	Rectangular
	Length x width x height, mm	765x610x1065
2	Chopping unit	
	Cylindrical cutterhead (length x diameter), mm	310x 260
	Shape	Cylindrical
	Type of blades	Straight
	Number of blades varying on cylinder periphery	4
	Size of the knives (width x height x thickness), mm	80x120x15
	Cylinder shaft (length x diameter), mm	450x30
	Shape	Cylindrical
3	Feeding unit	
	Feeding chute length, mm x top and bottom width, mm x height, mm	480 x 380-130 x 95
	Shape	Trapezium
4	Power transmission system	
	Size of the motor drive pulley (groove x diameter), mm	1 x 150
	Size of shaft (diameter), mm	25
	Size of the driven pulley on cylinder shaft (groove x diameter), mm	1 x 75
5	Prime mover	
	Type	Single phase Induction motor
	Frame of the electric motor (length x width, mm)	500x300
	Electric motor capacity, kW	1.49
	Rated speed, rpm	1440

3.2.5 Design and development of briquetting machine

3.2.5.1 Screw press briquetting machine

The developed briquetting machine was a single extrusion die screw press. It consists mainly of driving motor, screw, die, belts and the housing with a hopper. The belt transmits power from the motor to the screw through the pulley. When the motor is started, raw material is fed into the machine through the hopper; the raw materials are compressed in the barrel, and extruded through the die. The machine has a production capacity of about 120 kg h⁻¹ and it is driven by a 1.49 kW, 1440 rpm electric motor driving the screw shaft at 300 revolutions per minute (rpm). During operation, the rotating screw takes the material from the hopper through the barrel and compresses it against the die which forms a build up of pressure gradient along the screw. The screw continuously forces the materials into the die and A view of fabrication of briquetting machine plate 3.3 and Screw extruder has shown in the plate 3.4.

3.2.5.2 Components of briquetting machine

Briquetting machine has following components

- a) Briquetting stand:** A base which supports the briquetting barrel & screw assembly.
- b) Drive mechanism:** The briquetting machine is driven with electrical motor with the help of pulley drive. The groove pulley is mounted on motor as well as on the shaft of connecting rod for power transmission to obtain desire speed.
- c) Thrust bearings:** The briquetting screw is normally supported with a bearing at the driven end. A significant rearward thrust is absorbed by the bearing to compensate for the force imparted to the briquetted material as it is being moved forward along the length of the screw.
- d) Feed hopper:** The feed hopper provided the opening through which feed materials enter the screw.



Plate 3.3. A view of fabrication work of briquetting machine



Plate 3.4. A View of Screw Extruder

- e) **Barrel:** The barrel of the extruder is often manufactured in sections which are bolted together as barrel sections are heavy, such construction aids disassembly and allows for replacement of sections without replacing entire barrel.
- f) **Die:** The extruder is equipped with a series of cylindrical shaped holes where briquetting material emerges from the machine in the form of briquettes. The die hole take number of shapes to form the briquettes into rods, spheres, denotes, tubes, strips etc.

3.2.5.3 Theoretical considerations

The design of briquetting machine involved the relationship between screw and barrel geometry and feed material properties with flow rate, pressure drop and power consumption. To solve the basic flow equations, the following assumptions were made:

- i. Flow should be laminar.
- ii. Flow should be steady.
- iii. Flow should be fully developed.
- iv. Barrel should be stationary and the screw is rotating.
- v. Slip should not occur at the walls.

3.2.5.4 Design consideration

Basic design parameters considered were as follows:

- a. Machine Capacity (Q) = 120 Kg h⁻¹
- b. Die diameter (D_d) = 30 mm
- c. Bulk Density (p) in Kg m⁻³

Similarly, the assumed Parameters were

- d. Diameter of Screw in mm
- e. Pitch of the screw press in mm
- f. Shaft Diameter in mm

3.2.5.4.1 Calculation of helix angle

The briquetting machine consisted of extruder screw rotating in a barrel, fitted tightly with connecting rod. The briquetting screw consisted of a central shaft upon which a helical flight was wrapped. The open area bounded by the flights on the sides was lead. The helix angle is calculated by formula given by (Deepali 2010)

$$\theta = \tan^{-1} \frac{S}{D} \quad \dots (3.23)$$

where,

θ = Helix angle, degree

S = Pitch of the screw, m

D = Inside diameter of the barrel, m

3.2.5.4.2 Determination of theoretical screw volume per pitch

The basic design consideration for the screw design is the capacity of the waste process and the average bulk density of the raw waste after size reduction. The theoretical screw volume has been calculated by the formula (Deepali, 2010)

$$V_s = \text{Area} \times \text{Pitch}$$

$$V_s = \frac{\pi}{4}(D^2 - d^2) \times S \quad \dots (3.24)$$

Where

V_s = Theoretical volume of screw per pitch, m

D = Screw diameter, m

d = Shaft diameter, m

S = Pitch of the Screw, m

3.2.5.4.3 Determination of screw revolution

Speed of screw is calculated by considering mass flow rate, product density, theoretical screw volume per pitch (V_s) and filling. (Deepali, 2010)

$$m = \frac{\kappa}{60} \dots (3.25)$$

$$\frac{m}{V_{sp}(j)} \quad (3.26)$$

Where,

Q = Capacity of briquetting machine, kg h⁻¹

N = Screw revolution, rpm

m = Mass flow rate, kg min⁻¹ capacity of briquetting machine, kg h⁻¹

f = Filling efficiency, %

p = Bulk density of biomass, kg m⁻³

3.2.5.4.4 Determination of drive power

Drive power was dependent on flow rate, gravity, displacement length, resistance and calculated by formula as follows (Deepali, 2010)

$$P (m, V_s, L, p, f, r_d)$$

(3.27)

Neglecting gravitational effects (g = 1)

Drive power (Pd),

$$m \times L \times \frac{m}{30000} \times g \quad (3.28)$$

30000

Torque on the screw, $T = \dots$ (3.30)

Where,

L = Length of the screw press, m

n d = Efficiency of drive, %

f_i = Material factor

3.2.5.4.5 Pulley shaft power

Shaft Power (P_s) required for briquetting machine after considering the pulley efficiency was (Deepali, 2010)

$$P_s = \frac{P_m}{\eta} \quad \dots (3.31)$$

Where, η = Efficiency of pulley, %

3.2.5.4.6 Motor power

Motor power P_m was estimated from the given equation. (Deepali, 2010)

$$P_m = P_s (1 + S) \quad \dots (3.32)$$

The factor S is the allowances made for motor efficiency taken from Appendix I.

3.2.5.4.7 Actual motor speed

The actual motor speed (n) was given by selected slip factor "s" as follows (Deepali, 2010)

$$n = N (1 - S) \quad \dots (3.33)$$

Slip factor was selected on the basis of calculated capacity of electrical motor from Appendix II.

3.2.5.4.8 Design of pulley

The diameter of smaller pulley was determined by applying Savarin's empirical formula. Pulley design was mainly dependent on the power to be transmitted and required revolution of the machine. The simple drive mechanism was selected for the design. Small pulley diameter was

Where,

P_m = Power, to be transmitted, kW

V_{max} Maximum speed of shaft, rpm

Now the big pulley diameter is calculated by following formula

$$N_1 d_2 = N_2 d_1$$

Where,

N_1 = Revolution of machine shaft, rpm

N_2 = Revolution of motor shaft, rpm

d_2 = Diameter of pulley on motor shaft, mm

d_1 = Diameter of pulley on machine shaft, mm

Table 3.2 Specification of the briquetting machine

No. of screws	1
Diameter of shaft, mm	25
No. of exit tubes	3
Diameter of exit tube, mm	30
Overall length of machine, mm	630
Overall width of machine, mm	380
Overall height of machine, mm	660
Rotations of screw, rpm	300
Power required, kw	1.49
Capacity of machine, (kg h ⁻¹)	120

3.3 Performance and evaluation of shredder cum briquetting machine.

The performance of shredder cum briquetting machine was evaluated under lab conditions. The parameters such as chopping length, machine output capacity, power consumption, percentage loss and moisture content, capacity of briquetting machine, and briquetting efficiency were recorded during the lab tests. As there was no specific test code available for testing of shredder cum briquetting machine, the pertinent parameters relevant to machine performance determination are measured. The laboratory trials were carried out at College of Agricultural Engineering & Technology, Parbhani during 2016-17.

3.3.1 Performance of biomass shredder:

The performance of biomass shredder was evaluated under lab conditions. The parameters such as chopping length, machine output capacity, power consumption, percentage loss were recorded during the lab tests. As there was no specific test code available for testing of biomass shredder, the pertinent parameters relevant to machine performance determination were measured. The laboratory trials were carried out at College of Agricultural Engineering and Technology, Parbhani during 2016-17. The samples of Biomass were brought from the Marathwada Agricultural University fields such as soybean husk, wheat straw, cotton stalk, forestry waste shown in the plate 3.5.

The various performance evaluation parameters were calculated by observations made on each treatment. The dependent parameters on each treatment combinations were shown below.

1. Chopping length, mm
2. Output capacity, kg h^{-1}
3. Percentage loss, per cent
4. Power consumption, kWh

3.3.1.1 Chopping Length

The chopping length of biomass mainly depends on the number of blades used and cylindrical cutterhead speed. The chopping length of biomass after shredding operation was measured in mm by using digital vernier calipers. The chopping length of biomass was recorded randomly in the lab by laying 1m size frame. It was expressed by using the formula (Ojha and Michael, 2003).

NK

... (3.37)



Soybean Husk



Wheat Husk



Cotton Stalk



Forestry Waste

Plate 3.5. Biomass Samples Taken For Operation

Where:-

L = Chopping length, mm

D = Diameter of feed cutter, mm

N = Cylindrical cutter head speed, rpm

K = Numbers of blades on the cutter head

3.3.1.2 Output capacity

Output capacity of biomass shredder was measured by weighing the amount of biomass shredded in unit time. It was calculated in metric units by duffee's formula (Ojha and Michael, 2003).

$$C = W \times H \times L \times N \times R \times K \dots (3.38)$$

Where:-

C = Output capacity of biomass shredder, kg h⁻¹

W = Width of throat, mm

H = Height of throat, mm

L = Chopping length, mm

N = Number of knives on the cutterhead

R = Cutterhead speed, rpm

K = Constant equal to 2 x 10⁶

3.3.1.3 Percentage loss

The percent loss of biomass was obtained in the powder form after chopping of biomass by shredder was considered as a percentage of loss of biomass. Percentage loss of biomass incurred during chopping of biomass was expressed by using formula (Fayose, 2007)

... (3.39)

$$\text{Percentage loss, \%} = \frac{\text{Total mass of sample (kg)} - \text{Mass after cutting (kg)}}{\text{Total mass of sample (kg)}} \times 100$$

3.3.1.4 Power consumption (C_p)

The power consumption of biomass shredder was calculated by using formula (Shashi, 2015)

$$C_p = \frac{\text{Amount of material fed, kg}}{\text{Time taken for feeding, h} \times \text{Average wattmeter reading, kW}} \quad (3.40)$$

3.3.2 Performance of briquetting machine

Mixture of biomass and binder with appropriate moisture content around 40% in predetermined proportion was prepared with thorough uniform mixing. Mixture for briquette production was prepared 2 hours before the actual working.

Well prepared biomass mixture is fed in the barrel through hopper. Extrusion screw driven by single phase, 2hp electric motor conveys the material to the die of cylinder. At last stage, screw compresses the feed material with die and briquettes come out from narrow opening of die. These briquettes were collected in trays so that moistened briquettes should not fall down and get damaged. Briquettes were carried to sun drying so as to get dried briquettes of premium quality.

Table 3.3 Proportion for production of briquettes from various biomass.

Sr No.	Materials	Proportions
1	Soybean Husk + Water + Dung + Ash	65 : 25 : 10 : 5
2	Wheat Straw + Water + Dung + Ash	65 : 25 : 10 : 5
3	Cotton stalk + Water + Dung + Ash	65 : 25 : 10 : 5
4	Forest waste + Water + Dung + Ash	65 : 25 : 10 : 5

3.3.2.1 Properties of biomass

Assessment of the physio-chemical properties of biomass for briquetting purpose was planned to evaluate its suitability. The TGA analysis of this biomass would be useful for its anticipated wider applications. Development of

un-carbonized biomass briquetting for domestic uses using cheap biomass such as soybean husk, wheat straw, cotton stalk, forestry waste may be justified when appropriate devices for the production of the briquetted biomass were developed or made available in the country and the price of the product is competitive with conventional fuel. Thus it was needed to utilize the biomass waste in a suitable form which was easy to carry and store. There is a need to promote a technology to convert this loose biomass waste in the form of solid fuel through the route of densification.

Properties of biomass like moisture content, bulk density, calorific value, volatile matter, ash content were studied. These properties are more useful for designing of briquetting machine. The details procedure to find out the characteristics of raw biomass is followed by the guidelines given in text book of Biomass production and utilization technology (Rathore et al. 2007)

3.3.2.2 Properties of Briquettes

The properties of briquettes including moisture content, density, calorific value, volatile matter, carbon content and ash content was calculated by standard formulas are following

3.3.2.2.1 Determination of moisture content

The moisture content of raw biomass was determined by calculating the loss in weight of material using hot air oven drying method at 105 °C to 110°C for one hour and up to constant weight loss. (Dara, 1999)

$$\text{Moisture content (\% wb)} = \frac{W_2 - W_1}{W_3} \times 100 \quad \dots (3.41)$$

Where,

w_1 = weight of crucible, g

w_2 = weight of crucible + sample, g

w_3 = weight of crucible + sample, after heating, g

3.3.2.2.2 Determination of volatile matter

The dried sample left in the crucible was covered with a lid and placed in an electric furnace (muffle furnace), maintained at $925 \pm 20^\circ\text{C}$ for 7 minutes. The crucible was cooled first in air, then inside a desiccator and weighed again. Loss in weight was reported as volatile matter on percentage basis. (Dara, 1999)

$$\text{Volatile matter (\%)} = \frac{W5 - W6}{W5 - W4} \times 100 \quad \dots (3.41)$$

Where,

w4 = weight of the empty crucible, g

w5 = weight of empty crucible + sample, g

w₆ = weight of the crucible + sample after heating, g

3.3.2.2.3 Determination of ash content

The residual sample in the crucible was heated without lid in a muffle furnace at $700 \pm 50^\circ$ for one half hour. The crucible was then taken out, cooled first in air, then in desiccators and weighed. Heating, cooling and weighing was repeated, till a constant weight obtained. The residue was reported as ash on percentage basis (Dara, 1999).

$$\text{Ash content (\%)} = \frac{W9 - W7}{Wg - W7} \times 100 \quad \dots (3.42)$$

Where,

w7 = weight of the empty crucible, g

w8 = weight of empty crucible + sample, g

w9 = weight of the crucible + ash, g

3.3.2.2.4 Fixed carbon determination

The fixed carbon percentage was calculated by using following relationship. Percentage of fixed carbon = $100 - \% \text{ of (moisture content +$

volatile matter + ash)

3.3.2.2.5 Calorific value

The calorific value of briquetted fuel was determined by using bomb calorimeter. The calorific value of briquetted fuel was determined by using following formula (Dara, 1999).

$$\text{Calorific value (Kcal/kg)} = \frac{(W+w)(T_2 - T_1) \times 8.3}{X} \dots (3.43)$$

Where,

W = weight of water in calorimeter, kg

w = water equivalent of apparatus

T₁ = initial temperature of water, °C

T₂ = final temperature of water, °

X = weight of fuel sample taken, kg

3.3.2.3 Briquette density

For briquette density measurement, the briquette length and diameter were measured and thus the volume was calculated. The briquettes were weighed using a digital balance. The briquette density was calculated by dividing the average mass of the briquette over its volume.

3.3.2.4 Capacity of briquetting machine

The capacity of the machine is the total mass taken from the outlet and determined by using weighing balance to the total time taken. It was calculated by given formula

$$\text{Capacity } Q, \text{ g}^{\text{h}} = \frac{M}{T} \dots (3.44)$$

3.3.2.5 Efficiency of briquetting machine

Efficiency is a measure of how much work or energy conserved in a process. The efficiency is the machine output, divided by the machine input,

and expressed as a percentage.

$$\text{Efficiency, } n = \frac{\text{Machine Output (kg)}}{\text{Machine Input (kg)}} \times 100\%$$

3.3.2.6 Parameter tested for Briquetting machine

1. Effect of screw speed:

Two different size of driving pulleys were used to determine the effect of screw speed on production rate, energy consumption and density of various biomass materials.

3.3.2.7 Sun drying of briquettes

Sun drying is being considered as a possible alternative for drying the biomass briquettes. The energy is freely available which makes it an attractive energy source. Briquettes were carried to sun heating so as to get dried briquettes of premium quality.

3.4 Economics of shredder cum briquetting machine.

Cost of operation was calculated by considering fixed and variable costs. Fixed costs were calculated by considering parameters were depreciation, interest, shelter and insurance. Variable costs also called as operational costs. It includes repair and maintenance, power consumption, oil or lubrication and labour costs. The total fabrication cost of the shredder cum briquetting machine was calculated taking into consideration the materials used and labor charges. Knowing the output capacity of the unit, the cost of operation of machine was calculated.

3.4.1 Cost of machine

The total production cost of biomass shredder cum briquetting machine is the total cost of materials used for various components of machine and total cost of labor used for fabrication works.

3.4.2 Cost of Operation

The cost of operation of biomass shredder cum briquetting machine includes the fixed cost and variable cost. The fixed cost generally includes

depreciation, interest on investment, insurance, taxes and housing. Operating cost includes the cost of repairs and maintenance, electricity charge and labour charges.

3.4.3 Breakeven point

The breakeven point of machine is an indication that the machine should work at least for that estimated time in hours of operation per year. The breakeven point of shredder cum briquetting machine was expressed by considering the relations between annual fixed costs, custom charges per hour and total operating cost which is given below: (Shashi, 2015)

$$\hat{BEP} = \frac{\text{Annual fixed cost, (Rs h}^{-1}\text{)}}{\text{Income (Rs h}^{-1}\text{) - Total operating cost (Rs h}^{-1}\text{)}} \quad \dots (3.39)$$

3.4.4 Payback period

The payback period for the developed biomass shredder cum briquetting machine was calculated to know the time required to get back the investment. The payback period was estimated by using the following formula. (Shashi, 2015)

$$\hat{\text{Payback period}} = \frac{\text{Initial cost of machine}}{\text{Average net annual benefit}} \quad \dots (3.40)$$

3.4.5 Benefit-cost ratio

Benefit-cost ratio is the comparison of present worth of cost with present worth of benefits. The benefit cost ratio was calculated by using the following formula. (Shashi, 2015)

$$\text{Benefit - cost ratio} = \frac{\text{Total benefit}}{\text{Total cost of investment}} \quad (341)$$

$$\text{Total benefit} = \text{Average annual net profit (Rs)} \times \text{Life of machine in years}$$



*Results &
Discussion*



CHAPTER-IV

RESULTS AND DISCUSSION

In this chapter, the results pertaining to physical properties of biomass, design and development of different components of shredder cum briquetting machine, performance evaluation of shredder cum briquetting machine for shredder at different cylindrical cutterhead speeds, and with numbers of blades and for briquetting machine the factors that mainly influence the selection of raw materials are moisture content, ash content, flow characteristics and particle size are used, presented and analyzed. The economics of shredder cum briquetting machine is also presented in this chapter. The results are presented under the following headings.

4.1 Physical characteristics of biomass:

The different physical characteristics of selected biomass was determined and represented in Table 4.1 and it was shown in the Fig. 4.1.

Table 4.1 Physical characteristics of biomass

Sr. No.	Samples	Bulk density, kg/cm ³	Sphericity, mm	Arithmetic mean diameter, mm	Geometric mean diameter, mm	Moisture content, %
1	Soybean husk	290.99	0.230	8.91	3.65	9.6
2	Wheat straw	128.97	0.039	173.47	8.005	9.5
3	Cotton stalk	209.33	0.033	481.41	13.89	9.2
4	Forest waste	275.40	0.248	33.36	4.45	12

4.1.1 Bulk density

The procedure followed to measure the bulk density of biomass was explained under 3.1.1 Section. The maximum bulk density was found to be 290.99 kg *m* for soybean husk and the minimum bulk density was recorded to be 128.97 kg *m* for wheat straw at 9 to 12 per cent of moisture content (w.b).

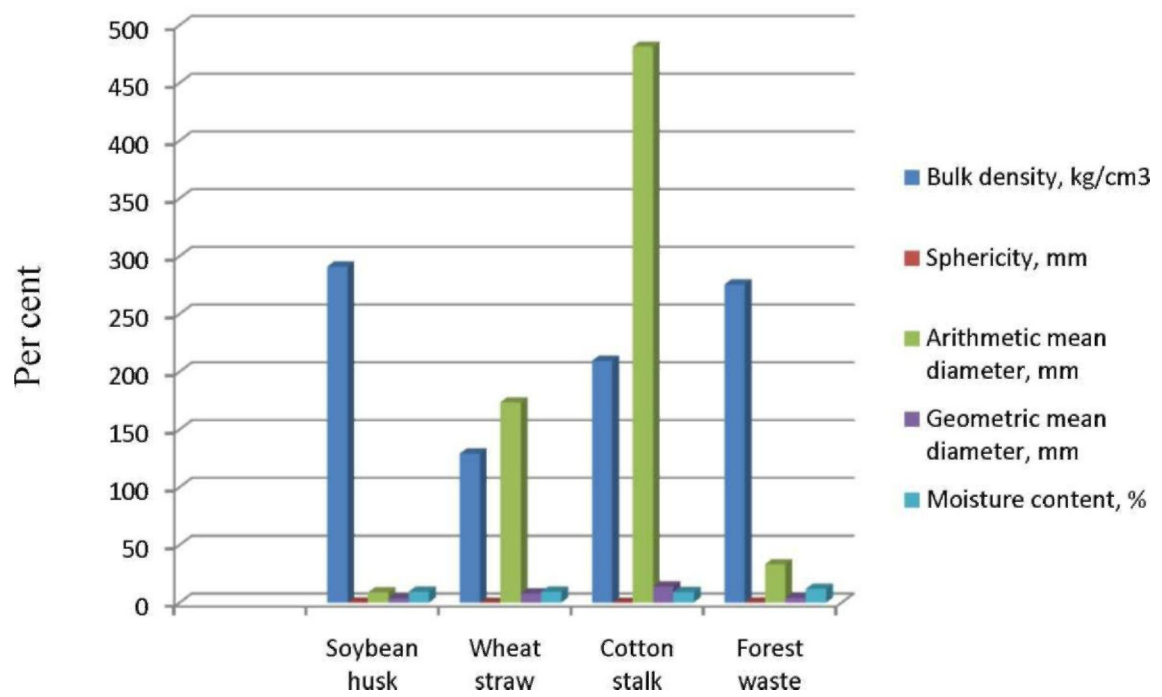


Fig. 4.1 Physical characteristics of selected biomass

4.1.2 Sphericity

The procedure followed to measure the sphericity of biomass was explained under 3.1.2 Section. The maximum sphericity of biomass was 0.248 mm for forestry waste, while it was minimum of 0.033 mm for cotton waste at 9 to 12 per cent of moisture content (w.b).

4.1.3 Arithmetic and geometric mean diameter

The procedure followed to measure the arithmetic mean diameter of biomass was explained under 3.1.3 Section.

The arithmetic mean diameter of the biomass was found to be maximum of 484.41 mm for cotton stalk, while minimum for 8.91 mm for soybean husk at 9 to 12 per cent of moisture content (w.b).

The geometric mean diameter of biomass was maximum of 13.89 mm for cotton stalk, while minimum for 3.65 mm for soybean husk at 9 to 12 per cent of moisture content (w.b).

4.1.4 Moisture content

The procedure followed to measure the moisture content of biomass was explained under 3.1.4 Section. The maximum moisture content of dry biomass was found to be 12 per cent while it was a minimum of 9 per cent respectively. From the results it was found that the proper/ efficient shredding was occurred in the range of 9 to 12 percent moisture content for different biomass.

4.2 Design and development of different components of shredder cum briquetting machine

The different components of shredder cum briquetting machine were designed and developed as explained in the Section 3.2. The results pertaining to the design and development of shredder cum briquetting machine are presented below and a view of electric motor operated shredder cum briquetting machine was shown in the plate 4.1.



Plate 4.1. A View of electric motor operated Shredder cum Briquetting Machine

4.2.1 Design of shredder

The details pertaining to selection of shredder was explained in Section 3.2.1.

The electric motor operated biomass shredder designed and fabricated for chopping of biomass residues used for a briquettes as a solid fuels. It consist of a main frame, shear plate, feeding chute, cylindrical cutterhead unit and power transmission system. The overall dimensions of prototype of biomass shredder were 765 mm in length, 610 mm in width and 1065 mm in height.

4.2.1.1 Selection of prime mover

The details pertaining to selection of prime mover was explained in Section 3.2.2. A single phase electric motor of 1.49 kW power rated and speed of 1440 rpm was selected as prime mover for biomass shredder.

4.2.1.2 Design of shafts

The details pertaining to selection of design of shafts was explained in Section 3.2.3.1. The design was based on torsion strength considered by calculating the drive torque of rotating shaft which was subjected to twisting moment only.

a. Design of cylindrical cutterhead shaft

The details pertaining to design of cylindrical cutterhead shaft was explained in Section 3.2.3.1. (a) The diameter of shaft was calculated by using formula 3.7 and 3.8. Hence, the diameter of cylindrical cutterhead shaft was selected as 30 mm.

4.2.1.3 Design of power transmission system

The details pertaining to design of power transmission system was explained in Section 3.2.3.2. The power transmission system of the power operated biomass shredder was designed by considering an electric motor as

prime mover having 1.49 kW power and rated speed of 1440 rpm. The power from the electric motor is transmitted to cylindrical cutterhead shaft by using the V - belt. The suitable diameter of pulley were selected and mounted on cylindrical cutterhead shaft that can be explained in Section. 3.2.3.3.(a) and 3.2.3.1. A single grooved pulley of 150 mm diameter was provided on electric motor to transmit the power.

4.2.2 Fabrication of biomass shredder

Shredder machine was fabrication as per the design procedure. The specifications were presented in the table 3.1.

4.2.3 Design and development of briquetting machine

Briquetting machine was designed and fabricated as per design procedure. The calculations were presented in Appendix 1.

4.3 Performance and Evaluation of Shredder cum Briquetting machine

4.3.1 Performance and Evaluation of Shredder:

The various performance evaluation parameters were calculated by observations made on each treatment. The dependent parameters on each treatment combinations were shown below. The performance of shredder machine was shown in the plate 4.2 and a view of Shredded raw materials has shown in plate 4.3.

1. Chopping length, mm
2. Output capacity, kg h^{-1}
3. Percentage loss, per cent
4. Power consumption, kWh



Plate 4.2. Performance of Shredder



Soybean Husk



Wheat Straw



Cotton Stalk



Forestry Waste

Plate 4.3. A view of shredded raw materials

4.3.1.1 Chopping Length

Table 4.2 Effects on chopping length of biomass shredder

Sr. No.	Samples	Chopping length, mm		
		1	2	3
1	Soybean husk	3.5	3.2	3.6
2	Wheat straw	4.5	5	4.9
3	Cotton stalk	5	5.2	5.5
4	Forest waste	3.5	4.5	4.6

The procedure adapted to find out the chopping length of biomass shredder was explained under 3.3.1.1 Section. Effects on chopping length of biomass shredder were presented in Table 4.2. It was observed that, the chopping length for 4 numbers of blades varied in the range of 3.2 to 5.5 mm with cylindrical cutterhead speed of 900. The minimum chopping length 3.2 mm was recorded while maximum length was 5.5 mm.

4.3.1.2 Output capacity

Table 4.3 Effects on output capacity of biomass shredder

Sr. No.	Samples	Output Capacity kg h ⁻¹
1	Soybean husk	40
2	Wheat straw	36
3	Cotton stalk	20
4	Forest waste	48

The procedure adapted to find out the output capacity of biomass shredder was explained under 3.3.1.2 Section. The effect of output capacity of biomass shredder was presented in Table 4.3.

For 4 numbers of blades, output capacity varied in the range of 20-48 kg h⁻¹. The minimum capacity obtained for cotton stalk is 20 kg h⁻¹, while maximum capacity 48 kg h⁻¹ for forest wastes. Because the cotton stalk

material was rigid and hard so it has taken more time to shred the material than others.

4.3.1.3 Percentage loss

Table 4.4 Effects on Percentage loss of biomass shredder

Sr. No.	Samples	Total mass of Samples, kg	Mass after cutting, kg	Percentage loss, Percent
1	Soybean husk	10.2	10.1	0.98
2	Wheat straw	6.5	6.48	0.30
3	Cotton stalk	5.5	5.48	0.36
4	Forest waste	13	12.8	1.5

The procedure adopted to measure the Percentage loss of biomass shredder was explained under 3.3.1.3. Effects of percentage of loss of biomass shredder were presented in Table 4.4.

For 4 numbers of blades, the percentage of loss varied in the range of 0.30 to 0.98 per cent with cylindrical cutterhead speed of 12.246 m s^{-1} . The minimum percentage of loss 0.30 per cent was recorded for wheat straw, while maximum percentage of loss 1.5 per cent for forest wastes.

4.3.1.4 Power consumption (Cp)

Table 4.5 Effects on power consumption of biomass shredder

Sr. No.	Samples	Power consumption, kWh kg ⁻¹
1	Soybean husk	0.0125
2	Wheat straw	0.0132
3	Cotton stalk	0.0400
4	Forest waste	0.0102

The procedure adopted to measure the power consumption of biomass shredder was explained under 3.3.1.4. The effects of power consumption of biomass shredder are presented in Table 4.5.

For 4 numbers of blades, power consumption varied in the range of 0.0102 to 0.0400 kWh kg⁻¹. The maximum power consumption was 0.0400 kWh kg⁻¹ for cotton and minimum 0.0102 kWh kg⁻¹ for forest waste.

4.3.2 Performance and Evaluation of Briquetting machine

The experimental results of performance of briquetting machine were reported in the following tables given below. It was observed that production capacity of the design machine was in the range of 115 to 125 kg per hour and good quality briquettes could be produced and the required shredded raw materials and binders were shown in the plate 4.4 and preparation of raw materials shown in plate 4.5 and the performance of briquetting machine was shown in the plate 4.6

4.3.2.1 Properties of biomass

The properties of biomass like calorific value, moisture content, ash content, volatile matter, density were studied as per the standard method as explained in section 3.3.2.1

4.3.2.2 Properties of Briquettes

The properties of briquettes like calorific value, moisture content, ash content, volatile matter, density were evaluated as per the standard method as explained in section 3.3.2.2 and the experimental findings are given in the Table 4.6 and proximate analysis of briquettes were shown in fig. 4.2.

Table 4.6 Different treatments for productions of briquettes with properties

Sr. No.	Materials	Weight (kg)	Density (kg cm ⁻³)	Moisture content (%)	Volatile matter (%)	Ash content (%)	Fixed Carbon (%)	Calorific Value (kcal kg ⁻¹)
1	Soybean Husk + Dung + Water + Ash	0.045	1141.09	6.8	22.62	6.8	13.54	4520
2	Wheat Straw + Dung + Water + Ash	0.044	1148.94	10.20	68.80	7.9	18.2	4285
3	Cotton stalk + Dung + Water + Ash	0.045	1269.03	7.89	58.30	3.5	21.98	4860
4	Forest waste + Dung + Water + Ash	0.046	1188.59	8.62	60.72	9.6	16.50	3596



Plate 4.4. Shredded Raw Material and Binders



Plate 4.5. Preparation of Raw Materials



Plate 4.6. Performance of Briquetting Machine

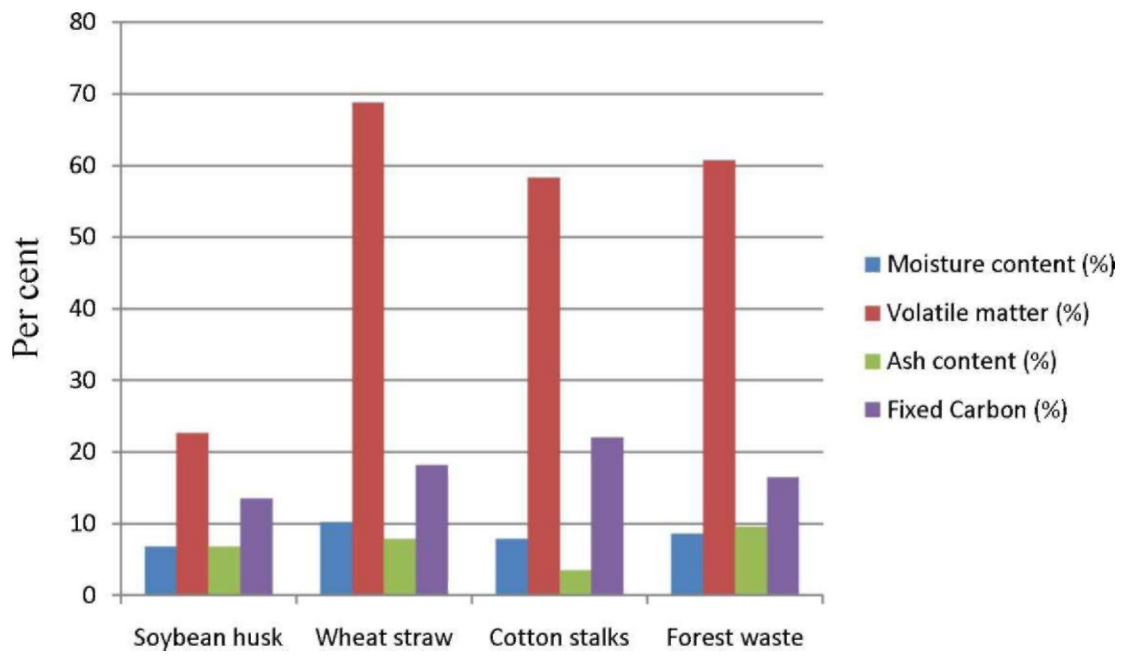


Fig. 4.2 Proximate analysis of briquettes

Table 4.7 Comparison of calorific value of raw materials and their briquettes

Sr. No.	Raw materials	Calorific value of raw materials (kcal kg ⁻¹)	Calorific value of briquettes (kcal kg ⁻¹)
1	Soybean Husk	4170	4520
2	Wheat straw	3800	4285
3	Cotton stalk	4252	4860
4	Forestry waste	3000	3596

From above table 4.7 it was found that calorific value of briquettes was found in the range of 3596 to 4860 kcal kg⁻¹ and it was observed that amongst all the treatment, calorific value of briquettes was more than the calorific value of raw material because briquettes has more density and compaction than loose materials.

4.3.2.3 Density of Briquettes:

The densities of briquettes were calculated by using method was explained under section 3.3.2.3 and various samples of experimental findings are given in table 4.8, 4.9, 4.10, 4.11 and the measurements of physical properties to determine the bulk density were shown in plate 4.7.

Table 4.8 Density of Soybean Husk + Dung + Water + Ash

Sample	Weight(kg)	Diameter(m)	Length(m)	Volume(m ³)	Density(kg m ⁻³)
1	0.048	0.030	0.056	3.95x10 ⁻⁵	1215.18
2	0.045	0.030	0.060	4.23x10 ⁻⁵	1063.82
3	0.046	0.030	0.057	4.027x10 ⁻⁵	1142.28

It was estimated from above table that average density of Briquettes obtained was **1141.09 (kg/m³)**



Plate 4.7. Measurement Of Physical Properties To Determine The Density Of Briquettes

Table 4.9 Density of Wheat Straw + Dung + Water + Ash

Sample	Weight(kg)	Diameter(m)	Length(m)	Volume(m ³)	Density (kg m ⁻³)
1	0.045	0.030	0.060	4.23x10 ⁻⁵	1063.82
2	0.047	0.030	0.055	3.88x10 ⁻⁵	1211.34
3	0.043	0.030	0.052	3.67x10 ⁻⁵	1171.66

It was estimated from above table that average density of Briquettes obtained was **1148.94 (kg/m³)**

Table 4.10 Density of Cotton stalk + Dung + Water + Ash

Sample	Weight(kg)	Diameter(m)	Length(m)	Volume(m ³)	Density (kg m ⁻³)
1	0.048	0.030	0.059	4.16x10 ⁻⁵	1153.84
2	0.049	0.030	0.055	3.88x10 ⁻⁵	1262.88
3	0.052	0.030	0.053	3.74x10 ⁻⁵	1390.37

It was estimated from above table that average density of Briquettes obtained was **1269.03 (kg/m³)**

Table 4.11 Density of Forest waste + Dung + Water + Ash

Sample	Weight(kg)	Diameter(m)	Length(m)	Volume(m ³)	Density (kg m ⁻³)
1	0.046	0.030	0.056	3.95x10 ⁻⁵	1164.55
2	0.049	0.030	0.058	4.09x10 ⁻⁵	1198.04
3	0.045	0.030	0.053	3.74x10 ⁻⁵	1203.20

It was estimated from above table that average density of Briquettes obtained was **1188.59 (kg/m³)**

An overall result shows that "Cotton stalk + Water + Dung + Ash" mixture has highest density among all mixtures tested.

4.3.2.4 Capacity of briquetting machine:

The capacity of the briquetting machine was calculated by using formula as explained under 3.3.2.4 and shown in table 4.12.

Table 4.12 Capacity of briquetting machine

Observations	Weight(kg)	Time required(min)	Capacity(kg h ⁻¹)
Soybean Husk + Water + Dung + Ash			
1	6.00	2.85	124.56
2	6.50	2.75	126.21
Wheat Straw + Water + Dung + Ash			
1	5.00	2.75	109.09
2	6.00	3.05	118.03
Cotton stalk + Water + Dung + Ash			
1	6.50	3.80	102.63
2	6.00	3.06	114.28
Forest waste + Water + Dung + Ash			
1	8.00	3.80	126.31
2	8.50	3.90	130.76

It was observed that, capacity of briquetting machine for " Forest waste + Water + Dung + Ash" mixture was more than capacity of other mixtures as it has high resistance for compaction.

4.3.2.5 Briquetting efficiency

The briquetting efficiency of machine was calculated by using formula as explained under 3.3.2.5 and shown in table 4.13.

Table 4.13 Efficiency of briquetting machine

Observations	Input(kg)	Output(kg)	Briquetting Efficiency (%)
Soybean Husk + Water + Dung + Ash			
1	6.00	5.80	96.66
2	6.50	6.35	97.69
Wheat Straw + Water + Dung + Ash			
1	5.00	4.60	92.00
2	6.00	5.65	94.16
Cotton stalk + Water + Dung + Ash			
1	6.50	6.15	94.61
2	6.00	5.70	95.00
Forest waste + Water + Dung + Ash			
1	8.00	7.95	99.37
2	8.50	8.35	98.23

It was observed that, efficiency of briquetting machine for "Forest waste + Water + Dung + Ash" mixture was more than others as it has high resistance for compaction.

4.3.2.6 Effect of Screw speed:

The effect of screw speed on production rate, energy consumption and density was explained under section 3.3.2.6 and obtained findings of those parameters are given in the table 4.14

Table 4.14 Effect of screw speed with different parameters

Sl no.	Samples	Speeds	
		Screw speed (300 rpm)	Screw speed(350 rpm)
1	Production rate (kg/hr)	120	135
2	Total energy consumption (kWh)	1.7	15
4	Density (kg m ⁻³)	1262	956

3

It was observed that the density was very poor 956 kg m⁻³ at screw speed of 350rpm while, density was good 1262 kg m⁻³ at screw speed of 300 rpm. So slow speed rpm was suitable to attain good quality of briquettes.

4.3.2.7 Sun drying of briquettes:

Sun drying of briquettes was explained under section 3.3.2.7 and obtained results are shown in the given table and after drying the pictorial view of various briquettes has shown in the plate 4.8. and shown in table 4.15.

Table 4.15 Sun drying of briquettes:

Sr. No.	Samples	Time, hr	Initial weight, kg	Final weight, kg
1	Soybean husk	3.59	0.0460	0.0255
2	Wheat straw	4.45	0.0455	0.0238
3	Cotton stalks	5.38	0.0465	0.0265
4	Forest waste	4.23	0.0460	0.0232



Soybean husk



Wheat Straw



Cotton Stalk



Forestry waste

Plate 4.8. A pictorial view of various briquettes

It was observed that briquettes have lost their weight more than 4 0% in sun drying. The time required for drying cotton stalk briquette was maximum to bring its weight from 0.0465 kg to 0.0265 kg, least time was required for soybean husk. This may be due to highest bulk density of cotton stalk briquettes amongst all.

4.4 Economics of Shredder cum Briquetting machine.

The cost of operation of Shredder cum Briquetting machine was determined as per the procedure enumerated by RNAM (1983) and formulae's are explained under section 3.4. The economics of Shredder cum Briquetting machine were calculated and was presented in Table 4.16. It was observed that, the cost of operation of shredder cum briquetting machine was 97.53 Rs h⁻¹ and 4 Rs kg⁻¹ for market price of briquettes and income from briquettes 180 Rs h⁻¹. Breakeven point, payback period and benefit cost ratio were 109.27 h annum⁻¹, 1.72 year and 4.6 respectively. The cost estimation of Shredder cum Briquetting machine was presented in Appendix - IV.

Table 4.16 Economics of Shredder cum Briquetting machine

Items	Rs.	Remarks
Cost of Shredder	30000	Complete Fabrication cost
Cost of Briquetting machine	27000	Complete Fabrication cost
Market price of briquettes, Rs kg ⁻¹	4	Harvesting/ transportation
Operating cost shredder + Briquetting machine (fixed cost + operation cost)	97.53	Rs per hour
Machine Capacity	120	Kg h ⁻¹
Total production	180	Rs per hour
Net profit	32988	Rs per year
Payback period	1.72	years
B-C ratio	4.6	years



*Summary and
Conclusions*



CHAPTER-V

SUMMARY AND CONCLUSION

Adequate supply of energy at a reasonable cost is a key factor in the economic development of country. Biomass is the third largest primary energy resource in the world, after coal and oil. In all its forms, biomass currently provides about 1250 million tones oil equivalent (MTOE) of primary energy. The renewable source of energy based on biomass was utilized to fulfill world's 14 per cent of energy supply (Hall et al. 1991). For developing and Agriculture based countries, the utilization of the residues from agricultural sector as primary or secondary source of energy is considerably attractive. With regards to energy shortage and environmental issues, it is widely accepted that renewable energy seems to be one of the promising energy resource and shall play a major role in the foreseeing years. Direct combustion of biomass may generate smoke and is not efficient. Briquetting of biomass provides cleaner fuel for power generation and thermal application directly or after charring (pyrolysis).

Present investigation was undertaken at College of Agricultural Engineering & Technology, VNMKV, Parbhani on important issues of biomass shredder cum briquetting machine with objectives viz., Study of physical properties of biomass, Design development shredder cum briquetting machine and performance evaluation of shredder cum briquetting machine and economics of developed shredder cum briquetting machine. The results are summarized and the conclusions were drawn and presented under here.

The selected physical properties of biomass in terms of (bulk density, sphericity, arithmetic and geometric mean diameter and moisture content) were determined by using standard procedures. Various components of the prototype shredder cum briquetting machine were designed and developed and the machine components were fabricated. The developed shredder cum briquetting machine was operated by 2 hp electric motor.

For optimizing the operational parameters of prototype shredder cum briquetting machine, the performance evaluation of shredder cum briquetting machine was carried out with major influencing factors *viz.*, for shredder - cylindrical cutterhead speed (12.246 m s^{-1}), numbers of blades (4) and screw speed (300 rpm) . The performance evaluation of shredder cum briquetting machine was conducted at Dept. of Farm Machinery and Power, CAET, VNMKV, Parbhani and the residues were procured from Vasantrya Naik Marathwada Krishi Vidyapeeth fields. The various parameters are *viz.*, for shredder - chopping length, output capacity, percentage of loss and power consumption and for briquetting machine - density, moisture content, calorific value and proximate analysis (volatile matter, fixed carbon and ash content) were determined and analyzed. The conclusions were drawn from the findings of the experiment conducted in the present investigation were summarized under the following headings.

- > The bulk density of residues like soybean husk, wheat straw, cotton stalk and forestry waste was 290.99, 128.97, 209.33 and 275.40 kg m^{-3} respectively and sphericity was 0.230, 0.039, 0.033 and 0.248 respectively and arithmetic mean diameter was 8.91, 173.47, 481.41 and 33.36 mm respectively and geometric mean diameter was 3.65, 8.005, 13.89 and 4.45 mm respectively., at 9 to 12 per cent moisture content (w.b).
- > The chopping length of biomass shredder increased as the cylindrical cutterhead speed decreased.
- > The chopping length was found in the range of 3.2 to 5.5 mm for 12.246 m s^{-1} cylindrical cutterhead speed with 4 numbers of blades.
- > The output capacity of biomass shredder was found in the range of 20 to 48 kg h^{-1} for 12.246 m s^{-1} cylindrical cutterhead speed with 4 number of blades.

- > The percentage of loss was found in the range of 0.30 to 15 percent for cylindrical cutterhead speed of 12.246 m s⁻¹ with 4 numbers of blades.
- > It was observed that the power consumption were recorded in the range of 0.0102 to 0.0400 kWh kg⁻¹ for 12.246 m s⁻¹ cylindrical cutterhead speed with 4 number of blades.
- > The screw press briquetting machine was designed as per standard procedure and fabricated satisfactory for the capacity of 120 kg h⁻¹. As per design and fabrication the machine found satisfactory for different agricultural and forest waste.
- > It was observed that the cost of operation of shredder cum briquetting machine was 97.53 Rs h⁻¹ and cost of briquettes was 4 Rs kg⁻¹.
- > Breakeven point and payback period were 109.27 h annum⁻¹ and 1.72 year, respectively.
- > Benefit-cost ratio was 4.6.

Considering from the above following results we concluded the briquetting machine:

- > For soybean husk the output capacity of machine was 125 kg h⁻¹ and with 97.17 % efficiency.
- > For wheat straw the output capacity of machine was 113 kg h⁻¹ and with 93.08 % efficiency.
- > For cotton stalk the output capacity of machine was 108 kg h⁻¹ and with 94.80 % efficiency.
- > For forestry waste the output capacity of machine was 128 kg h⁻¹ and with 98.80 % efficiency.

SUGGESTIONS FOR FUTURE WORK

The following suggestions were made for improvement of the present work and scope of related work.

- > Studies can be undertaken for shredding of biomass by modifying shredder for organic manure purpose and preparing compost.
- > The performance of the briquetting machine with variable speed drive mechanism has to be evaluated.
- > Long term test of machine has to be done.
- > Testing of various briquettes for its performance in down draft gasifier, improved cook stove and furnaces may be studied.
- > Automation system has to be done for whole system.(mixing, conveying, heating)



*Literature
Cited*



LITERATURE CITED

- Adarsh, K., Singh, J. K. and Charanjit, S., 2010, Ergonomic assessment of a manual fodder cutter. *J. Agric. Eng.*, 47 (4): 1-9.
- Adgidzi, D., 2007, Development and performance evaluation of a forage chopper. *J. Agric. Eng. Technol.*, 15: 12-24.
- Ali Nurrakhmad Siregar., Wan Mohd Faizal. Wan Mahmud., Jaharah A. Ghani., Che Hassan Che Haron. and Muhammad Rizal., 2014, Design and Analysis of Single Screw Extruder for Jatropha Seeds Using Finite Element Method, *Research Journal of Applied Sciences, Engineering and Technology* 7(10): 2098-2105
- Anak Agung Putu Susastriawan. and Bambang Wahyu Sidharta., 2014, Development of small scale screw extrusion machine for production of sawdust briquettes in rural area in Indonesia, *International Journal of Energy and Power Engineering* 2014; 3(5): 250-253
- Andrzej Krauss., Waldemar Szymanski., 2006, Briquetting of lignocellulose waste in perpetual screw briquetting machine. *Wood Technology.* 9(3) Article 13: 2224
- Anonymous., 1999, Biomass gasifier. Seminar on renewable energy 2000 held at Coimbatore, Tamilnadu, 157-64.
- Arshdeep, S., Dhaliwal, I. S. and Dixit, A., 2011, Performance evaluation of tractor mounted straw chopper cum spreader for paddy straw management. *Ind. J. Agric. Res.*, 45 (1): 21-29.
- Basher, I. M., Zubairu, M. and Garba, U. A., 2010, Design construction and evaluation of a stalk chopper. *J. Res. National Dev.*, 8 (2): 1-7.
- Bhattacharya, S. C., Leon, M. A. and Rahman, M. M., 2002, A study on improved biomass briquetting. *Energy for Sustainable Development.*

- Bhattacharya, S. C., Siddique, A. H., Md. M. R., Leon, M. A., Pham, H. L. and Mahandari, C. P., 1990, A study on improved institutional biomass stoves.
- Biddappa, K. G., 1960, Utilization of arecanut waste. *J. Arecanut.*, 11: 106-108.
- Car. and Hartog J., 1984, A new densification Process - Original Use of the final Product, Biomass Conversion, Elsevier Applied Science Publishers, London.
- Chaudhary S., 1986, Briquetting of Biomass. A techno-economic analysis. Proc. Of National workshop on briquetting of organic residue, National Productivity Council, New Delhi.
- Dara S. S., 1999. Text book of Engg. Chemistry, Published New Delhi, 7th Edition.
- Deepali Sahadeorao Mandwe., 2010, Design and Development of Briquetting Machine for Eco-Friendly Fuel, Unpublished thesis submitted to Maharana Pratap University of Agriculture and Technology, COET, Udaipur
- Demirbas, A. H., 2004, Briquetting properties of biomass waste materials. *Energy Sources* 26: 83 -91. Published by Taylor & Francis Group, [online @tandf.co.uk](http://online.tandf.co.uk)
- Dexter W. Ang., 2005, Designing the Sugar Cane Charcoal Extruder, *Massachusetts Institute Of Technology.*
- Elfatih, A., Arif, E. M. and Atef, A. E., 2010, evaluate the modified chopper for rice Straw composting. *J. AppliedSci. Res.*, 6 (8): 1125-1131.
- Eriksson, S. and Prior, M., 1990, the Briquetting of Agricultural Wastes for Fuel. FAO Environment and energy paper 11. FAO, via delle Terme di Caracalla, 00100 Rome, Italy.

- Fabienne R., Michae T., Thorsten B., Hans H., Peter D. J., Josef R., Juan C., Miguel F., (2006) Particle density determination of pellets and briquettes. *Biomass and Bioenergy*, 30: 954-963.
- Fayose, F. T., 2007, Development of a cutting machine for food materials. *J. Agric. Eng. Technol.*, 15: 58-65.
- Gagadishwar, S., 2010, Elements of agricultural engineering 4th Ed., Standard publishers distributors, Nai Sarak, New Delhi, pp. 374-375.
- Gaikwad, B. B. and Bhargav, V. K., 2012, Size reduction machine for arecanut sheath- enabling alternative animal fodder generation. *J. Agrotechnol.*, 1 (2): 64.
- Gaikwad, B. B. and Bhargav, V. K., 2012a, Cutting characteristics of arecanut sheath for use as animal fodder. *J. Agrotechnol.*, 1 (2): 66.
- Gangde, C. N., Patil N. E., Madansure, V. N. And Chaudhary, A. A., 1998, Characterization of biomass fuels for gasification. *PKV Research Journal*, 22(1):101-04
- Gonulol, E., Dalmis, I. S., Kayisoglu, B., Bayhman, Y. and Kocabiyik, H., 2009, Evaluation of alternative stalk chopping methods in sunflower farming. *Afr. J. Agric. Res.*, 4 (12): 1398-1403.
- Grover P. D., 1990, Country study on status of biomass densification in India, University of Twente, the Netherland.
- Gunasekaran, S., Viswanathan, K. and Bandeswaran, C., 2014, Selectivity and palatability of tree fodders in sheep and goat fed by cafeteria method. *Int. J. Sci. Env. Technol.*, 3 (5): 1767 - 1771.
- Gunter Frank and Nache A. K. (1984). Compaction of biomass by Extrusion Presses. Proc. Of BioEnergy 84 Vol. III Biomass Conversion, Elsevier Applied Science Publishers, London.

- Gusain P. S., 1986, Briquetting of Biomass On small Scale Technology and Economics, Proc. of national workshop on briquetting of organic residue, National Productivity Council, New Delhi.
- Hall D. O., Rosillo-Calle F. and Woods J., 1991, Biomass, its importance in balancing CO₂ budgets. In: Grassi G, Collina A, Zibetta H, editors. Biomass for energy, industry and environment, 6th E.C. Conference Elsevier Science, London: 89-96.
- Hasan, Y., 2003, Design construction and performance analysis of two hay chopping machines. *Agric. Mechanization. Asia. Afr. latin Am.*, 34 (4): 50-54.
- Husain, Z., Zainac, Z., Abdullah,Z., 2015, Briquetting of palm fibre and shell from the Processing of palm nuts to Palm Oil School of Mechanical Engineering, University Sains Malaysia, 14300 Nibong Tebal, Pulau Pinang, Malaysia
- IS: 7897-1975, Test code for chaff cutter, Indian standard institution, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi-110001, 1-26.
- Isaac Bamgboye. and S. J. Bolufawi., 2009, physical characteristics of briquettes from guinea corn (sorghum bi-color) residue agricultural engineering international, *The CIGR Ejournal. Manuscript 1364.*
- ISES 99 SolarWorld Congress, Israel, 4-9 July 1999.
- Jibrin, M. U., Amony, M. C., Akonyi, N. S. and Oyeleran, O. A., 2013, Design and development of a crop residue crushing machine. *Int. J. Eng. Invention.*, 2 (8): 28-34.
- Jorapur, R. and Rajvanshi, A. K., 1997, Sugarcane leaf-bagasse gasifiers for industrial Heating applications. *Biomass and bioenergy.* 13 (3) 141-46.
- Juri Olt and Mihkel Laur., 2009, Briquetting different kinds of herbaceous biomaterial Engineering for Rural Development: 225- 228.

- Kharidwar, M. S., Dubey, A. K., Mahalle, D. M. and Kumar, S., 2013, Study on physical and chemical properties of crop residues briquettes for gasification. *Int. J. Ren. Ener. Tech. Res.*, 2 (11): 237-248.
- Kurmi, R. and Gupta, J., 2006, a text book of machine design 8th Ed., Eurasia publishing house pvt ltd., Ramnagar, New Delhi. p. 511-512.
- Malakhova, A.A., Mosina, V.M., Gorlushko, D.A., Nalesnik, O.I., Usoltseva N.V., 2015, Vibration briquetting of ash of combined heat and power plant, *Published by Elsevier*.
- Manoj Kumar Sharma., Gohil Priyank., Nikita Sharma., 2015, Biomass Briquette Production: A Propagation of Non-Convention Technology and Future of Pollution Free Thermal Energy Sources, *American Journal of Engineering Research (AJER)* e-ISSN: 2320-0847 ISSN: 2320-0936.
- Mohamed, A. B. and Ghanem, G. H. A., 2010, Modifying a thresher for ensiling the green rice straw by shredding. *Misr J. Agric. Eng.*, 27 (2): 482 - 500.
- Mohamed, S. O., 2008, Study of the performance of the most widely used shredders for crops residues in egypt. *15th Annu. Conference. Misr. Soc. Agric. Eng.*, Egypt, 12-13 march., 339-357.
- Mohan, A., 1986, Marketing of Briquetted Fuel for Industrial Sector. Proc. Of national workshop in briquetting of organic Residue, National Productivity Council, NewDelhi.
- Mohsenin, N. N., 1970, Structure, physical characteristics and mechanical properties. Gordon and breach science publishers, inc., New York, pp. 65-67.
- Mridaney, S. Poudel., Krishna R.Sreshta. and Ramesh M. Singh., Screw extruder biomass briquetting, *Rentech Symposium Compendium, Volume I*.

- Muhammad S. N., Muhmmad A. A., Abdul N. and Anjum M., (2016) Design and Fabrication of Biomass Extruder of 50 mm Diameter Briquette Size. *Innov Ener Res* 5: 128.
- Nithyananth, S., Samuel, L., Mathew, N. and Suraj, S., 2014, Design of waste shredder machine. *Int. J. Eng. Res. Appl.*, 4 (3): 487-491.
- Ojha, T. P. and Michael, A. M., 2009, Principles of Agricultural Engineering Volume-I. Reliance industries pvt. ltd., New Delhi, 467-476.
- Papneja, A. S., 1986, Development of appropriate briquette making machine suitable to Indian conditions, Proc. Of National Workshop On Briquetting Of Organic Residue, National Productivity Council, New Delhi.
- Pathak, S. V., Powar, A. G. and Dhande, K. G., 2008, Development and performance evaluation of tractor operated shredder. *Int. J. Agric. Sci.*, 4 (1): 88-94.
- Pongsak Jittabuta., 2015, Physical and Thermal Properties of Briquette Fuels from Rice Straw and Sugarcane Leaves by Mixing Molasses, International Conference on Alternative Energy in Developing Countries and Emerging Economies, *Published by Elsevier Ltd.*
- Qiang Hu., Haiping Yang., Dingding Yao., Danchen Zhu., Xianhua Wang., Jingai Shao., Hanping Chen., 2016, the densification of bio-char: Effect of pyrolysis temperature on the qualities of pellets, *Bio resource Technology*, Elsevier Ltd
- RNAM., 1983, Test code and procedure for Farm Machinery. Technical series No. 12. United Nations Development Programme, Pasay City, Philippines, 415-1785.
- Rajvanshi, A. K. and M. S. Joshi., 1989, Development and operational experience with topless wood gasifier running a 3.75 kW diesel engine pump set. *Biomass*. 19: 47-56.

- Rama Rao. and Kodna P.M., 1986, Prospects, problems and prospective in marketing briquetted fuel, proc. Of national workshop on briquetting of organic residue, National productivity council, New Delhi.
- Ramesh, M. Singh., 2013, Bio briquetting In Nepal - Scope And Potentials: A Review. Center for Energy and Environment Nepal (CEEN)
- Rathore N. S; Panwar N. L. and Kothari S. (2007). Biomass production and utilisation technology: 56-58.
- Renewable Energy Technologies in Asia, 2003, Heated-die Screw-press Biomass Briquetting Machine: Design, Construction and Operation Manual. Regional Energy Resources Information Center (RERIC) Asian Institute of Technology, P.O. Box 4, Klong Luang Pathumthani, 12120, Thailand
- RNAM, 1983, Test code and procedure for Farm Machinery. Technical series No. 12. United Nations Development Programme, Pasay City, Phillipines, 415-1785.
- Sathitruangsak, P., Madhiyanon, T. and Soponronnarit, S., 2006, Design of an Extrusion screw and solid fuel produced from coconut shell.
- Savani, J. B., Vagadia, V. R. and Kathiria, R. K., 2004, Design and development of agricultural waste shredder. *J. Agric. Mechanization Asia. Afr. Latin Am.*, 35 (2): 41-46.
- Senthilkumar, T., Manian, R. and Kathirvel, K., 2010, Blade and operational parameters on shredding efficiency on cotton in experimental cotton stalk shredder. *J. Madras Agric.*, 97 (7-9): 304-307.
- Shailendra, M., Mathur. and Singh, P., 2004, A cylindrical chopper with crusher for water hyacinth volume and biomass reduction. *J. Aquat. Plant Manage.*42: 95-99.
- Shashikumar., 2015, Development And Performance Evaluation Of Arecanut Sheath Shredder, unpublished thesis submitted to UASR, CAET, Raichur.

- Srivastava P. K., Maheshwari, R. C. and Ojha T. P., 1986 a, Comparative Performance of small scale Briquetting Unit, Proceeding of National Workshop on Briquetting of Organic Residue, National Productivity Council, New Delhi.
- Srivastava P. K., Maheshwari, R. C. and Ojha T. P., 1986, Prospects and Technologies for Briquetting of Biomass, Proceeding of National Workshop on Briquetting of Organic Residue, National Productivity Council, New Delhi.
- Srivastava P. K., Maheshwari, R. C. and Ojha, T. P., 1990, Design, Development and Testing of Charcoal Briquetting Machine, Proceedings of XXVI Annual Convention of Indian Society for Agricultural Engineers.
- Talib, A., Goss, J. R., Flanigan, V. J., Grsover, P. D., Mathur, H. B. and Durgaprasad, M. B., 1989, Development and field testing of small biomass gasifier-engine systems in India: A Joint Project by an American and Indian Team. *Biomass*. 19: 99-122.
- Teerapot Wessapan., Nisakorn Somsuk. and Theerapong Borirak., 2010, Design and Development of a Compact Screw-Press Biomass Briquetting Machine for Productivity Improvement and Cost Reduction, *The First TSME International Conference on Mechanical Engineering, Ubon Ratchathani*.
- Thakur, S.S. and Garg, I.K., 2007, Paddy straw management by chopping for sowing wheat in combine harvested field. *J. Res. Punjab. Agric. Univ.*, 44 (3): 243-248.
- TIDE., 1992, Vol. 2 No. 4, Dec. 1992.
- Tripathi, A. K., Iyer, P. V. R. And Kandpal, T. C., 1999, Biomass gasifier based institutional cooking in India: A preliminary financial evaluation. *Biomass and bioenergy*. 17(2): 165-73.
- Whipple, H.W., 1954, horizontally revolving stalk shredder.

- Xianyang, Z., Yitai, M., Lirong, M., 2007, Utilization of straw in biomass energy in China. *Renewable and Sustainable Energy Reviews.* 11: 976-987
- Yousif, A., Abakr, Ahmed E., Abasaeed., 2006, Experimental evaluation of a conical- screw briquetting machine for the briquetting of carbonized cotton stalks in Sudan. *Journal of Engineering Science and Technology,* 1(2):212- 220
- Zhang, Y., Ghaly, A. E. and Bingxi, L., 2012, Availability and physical properties of residues from major agricultural crops for energy conversion through thermochemical processes. *Am. J. Biochem. Biotechnol.,* 7 (3): 312-321.
- Zhang, Y., Ghaly, A. E. and Bingxi, L., 2012, Physical properties of corn residues. *Am. J. Biochem. Biotechnol.,* 8 (2): 44-53.

*Thesis
Abstract*



for screw press briquetting machine. The drive power of 2 hp motor was used to get the denser briquette through this developed screw press.

The economic analysis of the briquetting process was evaluated for the net annual benefit , benefit to cost ratio and payback of the system and found to be Rs. 32988, 4.6 and 1.72 years respectively.



Appendix



APPENDIX-I

Design Development of Briquetting Machine:

Calculation of helix angle

The helix angle for the screw design mainly depends on the diameter of the screw and the pitch of screw press. It was calculated from the given formula below

$$\theta = \tan^{-1} \frac{\pi T}{D}$$

$$\theta = \tan^{-1} \frac{3.14 \times 0.16}{0.07}$$

$$\theta = 7.9 \text{ degree}$$

Determination of theoretical screw volume per pitch

The theoretical screw volume was given by

$$V_s = \text{Area} \times \text{Pitch}$$

$$V_s = \frac{\pi}{4} (D^2 - d^2) \times S$$

$$= \frac{\pi}{4} (0.16^2 - 0.03^2) \times 0.07$$

$$=$$

$$= 1.35 \times 10^{-3} \text{ m}^3$$

Determination of screw revolution

Speed of screw was dependent on mass flow rate, product density, theoretical screw volume per pitch (V_s) and filling and it was calculated by using formula.

$$m = \frac{Q}{N}$$

$$= \frac{2 \text{ kg m}}{60}$$

$$= 0.033 \text{ m}$$

$$N = \frac{m}{V_s(f)}$$

Where, ρ is the density of biomass = 160.75 kg/m^3 and θ is the filling efficiency = 5 %. From above formula the revolution required was estimated

$$= 2 / (1.35 \times 10^{-3} \times 160.75 \times 0.05)$$

$$N_1 = 200 \text{ rpm}$$

Determination of drive power

The power required to transfer the material from first flight to the die was estimated by the formula given below.

$$P_d = m \times L \times g$$

Neglecting gravitational effects (g) and considering the drive efficiency as 5.5%, Drive power calculated was

$$P_d = 2 \times 0.50 \times (0.4/0.55)$$

$$P_d = 0.72 \text{ kw}$$

After considering the correction factor = 0.72×1.01

$$P = 0.73 \text{ kw}$$

Torque on the screw, $T = \frac{P_d}{\omega} = \frac{0.72 \times 30000}{200 \times 3.14}$

$$= 34.87 \text{ Nm}$$

$$= 35 \text{ Nm}$$

Pulley shaft power

Shaft Power (P_s) required for briquetting machine after considering the pulley efficiency

$$P_s = \frac{P}{\eta}$$

$$= \frac{0.73}{0.55}$$

$$= 1.32 \text{ kw}$$

$$= 1.32 \text{ kw}$$

Where, η = Efficiency of pulley, %

Motor power

Motor power P_m was estimated from the given equation.

The factor S was the allowances made for motor efficiency. Motor allowance factor for 1.32 kw motor was selected from Appendix II. ($S = 0.4$)

$$\begin{aligned}P_m &= P_s (1 + S) \\P_m &= 1.70 (1 + 0.1) \\&= 1.85 \text{ kw}\end{aligned}$$

Thus the available motor power 2 hp was adopted for the design operation

Actual motor speed

The actual motor speed (n) was given by selected slip factor "s".

From Appendix III slip factor for 1.85 kw motor was 7.0 %.

Actual motor speed estimated is,

$$\begin{aligned}n &= N (1 - S) \\&= 900 (1 - 0.07) \\&= 837 \text{ rpm}\end{aligned}$$

Design of pulley

Saverin's empirical formula was used to determine the diameter of smaller pulley. Pulley design was mainly depends on the power to be transmitted and required revolution of the machine. The simple drive mechanism was selected for the design. Small pulley diameter was estimated

$$\begin{aligned}d_2 &= 630 \frac{i/P_m(kW)}{\sqrt{27T_r|_{\max}}} \\d_2 &= 630 \sqrt{[1.85/(2 * 3.14 * 837)]} \\&= 630 \times 0.080 = 44.1\end{aligned}$$

Thus small pulley of standard diameter was selected as $d_2 = 75\text{mm}$

Driven pulley diameter

Now, the big pulley diameter was estimated by substituting the calculated values of rated motor speed, actual motor speed and diameter of big pulley in following formula

$$N_i = \frac{d_1}{d_2}$$

$$837 = \frac{d_1}{200 - 75}$$

$$= 313.8 \text{ mm}$$

Thus small pulley of standard diameter was selected as $d_2 = 300\text{mm}$

Design of conveyer flight

Sectional flights with right hand flights on a single screw were selected in the design. As shown in the plate 2 (b). This flight section was butt welded to form the complete screw. Now over all conveyer length = $0.5\text{m} + 2 \times \text{pitch}$
of conveyer flight = $500 + 2 \times 100$

$$= 700 \text{ mm}$$

$$\text{No. of flights} = 700/100 = 7 \text{ flights}$$

It is proposed to take all right handed flights from inlet end of trough to outlet.

Thickness of flight = 3 mm. Material = Mild steel (MS).

APPENDIX II

Data for typical allowances made for motor efficiency

<i>P_m</i> (kW)	
	5
0.4 0.75 1.5	0.4
2.2 3.7	0.4 - 0.25
5.5 7.5 11 15 18.5 22 30 37	0.25 - 0.15
45	0.15 - 0.10

APPENDIX III

Data for percent slip of different types of electric motors

kW	<i>s</i> (%)					
	2P		4P			
		E		E		E
0.2	9.5	10.0	10.0	10.5		
0.4	8.0	8.5	8.5	9.0	9.5	10.0
0.75	7.0	7.5	7.5	8.0	8.0	8.5
1.5	6.5	7.0	7.0	7.5	7.5	8.0
2.2	6.0	6.5	6.5	7.0	6.5	7.0
3.7	5.5	6.0	6.0	6.5	6.0	6.5
5.5	5.5	6.0	5.5	6.0	5.5	6.0
7.5	5.5	6.0	5.5	6.0	5.5	6.0
11	5.0	5.5	5.5	6.0	5.5	6.0
15	5.0	5.5	5.0	5.5	5.5	
19	5.0		5.0		5.0	
22	4.5		5.0		5.0	
30	4.5		5.0		5.0	
37	4.5		5.0		5.0	

APPENDIX - IV

Cost of operation of shredder cum briquetting machine

Assumptions made:

Initial cost of shredder cum briquetting machine, Rs	: 57000
Life of shredder cum briquetting machine, years	: 8
Salvage value, per cent	: 10
Interest rate, per cent	: 15
Shelter and insurance, per cent	: 2
Price of electricity, Rs kW ⁻¹	: 8
Operator charge, Rs h ⁻¹	: 37.50
Annual use of shredder cum briquetting machine, h	: 400
Depreciation	: Straight line method

I. Cost of operation for shredder cum briquetting machine

a. Annual fixed cost

i) Depreciation (D):

The annual depreciation value can be calculated by the following expression

$$D = \frac{Z - S}{L \times H}$$

Where,

D = depreciation, Rs h⁻¹

P = purchase price, Rs h⁻¹

S = salvage value, 10 per cent of purchase price

L = life of the machine in years

H = number of working hours per year

$$D = \frac{57000 - 5700}{8 \times 400} = 16.03 \text{ Rs h}^{-1} \quad \dots (i)$$

ii) Interest (I):

Annual interest is calculated on an average investment by using the prevailing interest rate by the following formula:

$$I = \frac{P + S}{2} \times \frac{i}{100} \times H$$

Where,

I = annual interest charge, Rs h⁻¹

i = interest rate, per cent

$$I = \frac{57000 + 5700}{2} \times \frac{0.15}{100}$$

$$I = 11.75 \text{ Rs h}^{-1} \quad \dots \text{ (ii)}$$

iii) Shelter and Insurance:

Insurance and shelter charges together are taken @ 2 per cent of the purchase price per year.

$$\text{Shelter and Insurance} = \frac{0.02 \times 57000}{100} \times H$$

$$\text{Shelter and Insurance} = \frac{0.02 \times 57000}{100}$$

$$= 2.85 \text{ Rs h}^{-1} \quad \dots \text{ (iii)}$$

$$\text{Total fixed cost} = i + ii + iii = 16.03 + 11.75 + 2.85 = 30.63 = 31 \text{ Rs h}^{-1} \quad \dots \text{ (a)}$$

b. Operating cost

i) Repair and maintenance costs:

Repair and maintenance costs are considered as an essential and significant part of machinery ownership. Repairs and maintenance cost was taken 10 per cent of the purchase price of the machine per year.

$$\text{Repair and maintenance costs} = \frac{57000 \times 0.1}{100} = 14.25 \text{ Rs h}^{-1} \quad \dots \text{ (iv)}$$

ii) Electricity cost:

Electricity cost was calculated on the basis of actual fuel consumption in tractor.

Cost of per kW electricity was taken Rs. 2.75.

Electricity required for 1 hour = 1.76 kW h⁻¹

Electricity cost = 8 x 1.76 = 14.08 Rs h⁻¹ . . . (v)

iii) Lubricants cost:

Charge of lubricant was taken 5 per cent of the electricity cost.

Lubricating cost = 14.08 x 0.05 = 0.7 Rs h⁻¹ . . (vi)

iv) Operator charge:

The cost of operator was calculated from the actual labor charges paid in rupees per day at the prevailing rates in the study area.

Rs. 300/day is paid for machine operator, 8 hour taken for one day

Operator charge = $\frac{300}{8} = 37.5 \text{ Rs h}^{-1}$. . (vii)

Total operating cost = iv + v + vi + vii = 14.25 + 14.08 + 0.70 + 37.5 = 66.53 Rs h⁻¹ . . . (b)

Total cost of operating the shredder cum briquetting machine = 31 + 66.53 = 97.53 = 87 Rs h⁻¹ . . . (c)

Market price of briquettes per kilogram, Rs kg⁻¹ = 4

Income from briquettes per hour = 5 x 45 = 180 Rs h⁻¹ Wet briquettes = 120

Dry briquettes = 45

Breakeven point, h per annum:

Annual fixed cost, Rs = Total fixed cost of shredder cum briquetting machine x

Annual usage of shredder cum briquetting machine in hrs.

Annual fixed cost, Rs = 31 x 400

Annual fixed cost, Rs = 12400

Break even point $\frac{\text{Annual fixed costs, Rs}}{\text{Income Rs h}^{-1} - \text{Total operating costs, Rs h}^{-1}}$

BEP $\frac{5200}{180 - 66.53}$

BEP, h annum⁻¹ = 109.27

Payback period, year : $\frac{\text{Initial cost of machine}}{\text{Average net annual profit}}$

Average net annual profit, Rs = Income, (Rs h⁻¹) — Total operating cost (Rs h⁻¹) X Annual usage

Annual usage of shredder cum briquetting machine = 400 h

Average net annual profit, Rs = (180 - 97.53) x 400

Average net annual profit, Rs = 32988

Payback period = $\frac{57000}{32988}$

Payback period = 1.72 year.

Benefit - Cost ratio (B - C) $\frac{\text{Total benefit}}{\text{Total cost of investment}}$

Total Benefit = Average annual net benefit (Rs.) x Life of the machine in years

Total Benefit = 32988 x 8

Total Benefit = 263904 Rs.

Total cost of investment for shredder cum briquetting machine = Rs. 57000

B-C Ratio = $\frac{263904}{57000}$

B-C Ratio = 4.6