Journal of Mechanical Engineering Research and Developments
ISSN: 1024-1752
CODEN: JERDFO
Vol. 43, No. 3, pp. 246-261
Published Year 2020

Development, Optimization and Performance Evaluation of Indigenous Piston Press Briquetting Machine for Crop Residue

Hafiz M. Safdar[†], Abdul Nasir[†], Haroon Rashid[†], Shanawar Hamid[‡], Mohsin Noor[†] & M. Azhar Ali[†]

[†]Department of Structures and Environmental Engineering, University of Agriculture Faisalabad, 38000, Pakistan

[‡]Department of Agricultural Engineering, Khwaja Fareed University of Engineering and Information Technology, Rahim Yar Khan, 64200, Pakistan

*E-mail: Muhammad.safdar@uaf.edu.pk

ABSTRACT: Pakistan produces massive amount of crop residue with high bulk volume and low density. This low density, high volume agro residue is difficult to handle, transport, and store. Only a little amount of energy is recovered due to inefficient techniques while remaining is wasted. Farmers often use on-site disposal via burning to get rid of this stuff which results in release of enormous amount of harmful gases to the environment due to incomplete combustion. There is need to have modern technologies to convert loose biomass residue into dense, well-shaped product like briquettes that would be easy to burn and sustainable to the environment. Moreover, these energy blocks in the form of briquettes have the opportunity to utilize in energy extraction systems as an alternative of wood and expensive fossil fuels (crude oil, natural gas and coal). Specially, deployment in electricity power generation plants can provide huge relieve from the energy shortage in the country. The present study shows the development, optimization and performance evaluation of intermediate pressure briquettes forming machine, working on mechanical piston press technology with production capacity ≈300 kg/m3 and produces 85 mm diameter briquettes. To develop this, we utilized locally available material, technology and indigenously skilled man power to reduce the cost of machine. Concavity of machine's die was optimized at 200 tapered. Economical and good quality briquettes were produced with mixture of wheat straw, slurry and starch in 12:3:1 on weight basis, respectively. Payback period and benefit to cost ratio (BCR) of briquettes formation plant were calculated as eight months and 1.25 respectively.

KEYWORDS: Briquetting Machine; Crop Residue; Renewable resources; Energy recovery; Payback period; Benefit to cost ratio

INTRODUCTION

Being agriculture based economy, Pakistan produces enormous amount of crop residue. For example, about 225,000 tons of different crops residue is produced in the country on daily bases [1]. A small amount is fed to animals or used as fuel in households while remaining is burnt in open fields. An enormous amount of harmful gases are added to the environment by this activity. It is reported that approximately 250 million tons (MT) of agriculture biomass is burnet annually in Asia which adds 379 MT CO_2, 23 MT CO, 0.96 MT NOX, 0.68 MT CH_4 and 0.1 MT SO_2 to the environment [2]. In addition to this, incomplete combustion of crop residue also generates hazardous carbon black which is the second largest contributor in global warming after CO_2 [3, 4]. Total global emission of black carbon is 7500 Gg per year [5]. Black carbon and numerous types of aerosols in combination with greenhouse gases absorb radiations from sun and enhance the atmospheric solar heating which results in global warming [6]. Recently, the phenomenon of smog occurred in Indo-Pak border region which severely affected the vast population residing in major cities e.g., Lahore, Delhi, Amritsar etc. NASA released the satellite images of the affected regions and claimed that the burning of crop residue in open fields by the farmers of both countries across the Indo-Pak Punjab border was the main reason of smog [7].

On the other hand, fast population growth, improvement in living standards and rapid industrialization has tremendously enhanced the energy demand and supply gap. The conventional sources of energy i.e., oil, coal and gas are rapidly depleting from the world, indicating that renewable resources of energy must be explored for a sustainable development [8, 9]. According to International Energy Agency(IEA), there will be a 50%

energy shift from non-renewable to renewable sources in 2050 in developed world [10]. Pakistan is facing huge energy crises as 30% of its population has no access to electricity and remaining 70% is bearing electricity shortage [11]. It is reported that Pakistan can fill about 76% of its electricity demand from cumulative crops residue produced in the country. Even, considering thermal power plant efficiency as a low as 30% [12]. Hence, wastage of crops residue in this scenario is a great loss in addition to environmental issues as stated above [13]. One and perhaps the only example of crop residue utilization in Pakistan is its direct use for heating purposes in domestic sectors without any processing. However, the utilization of crop biomass per house is only about 1160 kg annually. Furthermore, the crop residue is generally utilized by conventional household stoves which are only 12-28% efficient. Due to, low density of crop residue, less calorific value per unit volume, variation in quality and rapid burning [14]. In addition to this, it is also difficult to collect, transport, store and handle in loose form [15].

The main processes by which energy may be obtained from crop biomass include direct combustion, pyrolysis, gasification, liquefaction, anaerobic digestion, alcoholic fermentation and densification. Each technology has its own advantages, depending on the source, the form of energy needed and locally available skill level [16]. Conversion of crops residue to well-shaped and densified briquettes can be achieved through a process known as briquetting technology [17]. Briquetting technology is advantageous as compared to aforementioned technologies because it offers 1) socially adoptable as alternative of wood and coal 2) no requirement of additional apparatus to burn 3) stable production rate as it is not affected by weather 4) vast range of production i.e., low to high capacity production 5) faster processing time 6) less required skill level and 7) easy handling, storing and transportation of final product.

Traditionally, there are two types of high pressure briquettes forming machines, i.e. 1) piston or ram press and 2) screw press. In piston press machines a piston moves (by mechanical or hydraulic force) to and fro and pushes the biomass into a die to form briquettes while in screw press, biomass is extruded continuously by a screw through a die to form logs having hole at the center [18]. Pressure on the top of piston is the most important factor to transform residue into the required density and to overcome friction [19]. There is eccentric concavity which reduces in diameter continuously to increase the density of the product by decreasing the pore spaces between the particles. Configuration of die is most important in addition to pressure development at piston top because it compresses bulk material into densified form of briquettes. For continuous operation, die configuration requires optimization for compatibility with the properties of raw material and pressure [20]. It was reported by that quality of briquettes improved gradually with increase in the conicalness angle of pressing chamber [21]. However, the pressure required for compression also increased.

The high pressure binder less machines require a heavy die, high strength material and high power motor which increases the overall cost of machine. Due to this, an early wear and tear occurs resulting in short life span of the briquetting machine. These machines require very high pressure in die so that lignin comes out from the material as a result of high temperature due to friction and pressure in die. Lignin in material, acts as a natural binder and material particles are interlocked firmly. Briquetting process, carried out by these machines is more convenient but calls for sophisticated and expensive compactor and drying apparatus [22]. On other hand, low pressure machines are inexpensive but require artificial binder to increase mechanical properties, e.g. strength and durability of briquettes to withstand the final product for longer period of time. Different binders can be used in low pressure briquettes machines e.g., tar, clay, asphalt, pitch water, sodium silicate, starch, cow dung etc., depending on the availability, compaction technique and material properties [23].

The specific objectives of this study are 1) to develop a briquetting machine utilizing indigenous materials and skills to make it economical for local farmers 2) optimization of operational parameters for stable, high density and durable briquettes, 3) use of locally available binders to enhance machine life and 4) evaluation of economic factors i.e., payback period and benefit to cost ratio (BCR) of the machine.

MATERIAL AND METHODS

Main parts of briquitting machine

Main parts of machine are main frame, feeding hopper, feeding conveyer, a taper die, two flywheels, piston, connecting rod, main motor (for transmission of power to one of the flywheel via flat belt) and a 10 feet long air coolant line as shown in (Figures. 1& 2) and Table 1.

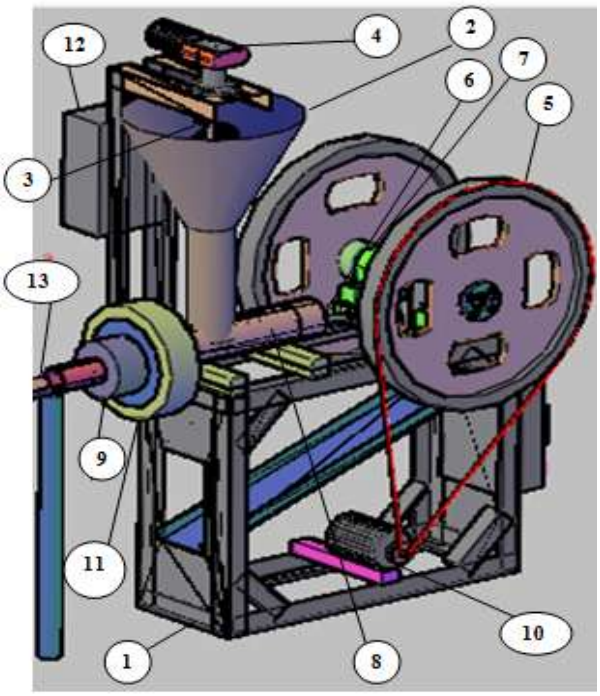

Table 1Parts of the briquetting machine

Item No.	Item Description	No. Off
1	Frame	1
2	Feeding Hopper	1
3	Feeding Conveyer	1
4	Conveyer Motor	1
5	Fly Wheel	2
6	Crank Shaft	1
7	Piston Rod	1
8	Piston	1
9	Tapper Die	1
10	Main Motor	1
11	Electric Heater	1
12	Electrical Panel	1
13	Air Coolant Line	1

Figure 1. Isometric view of machine

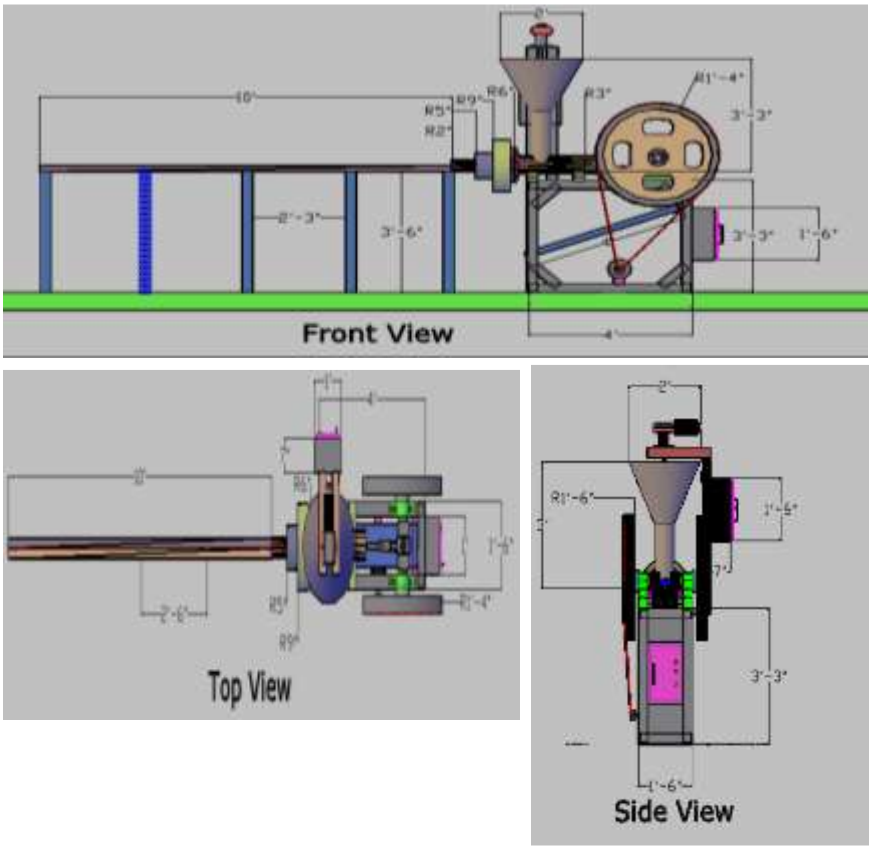

Figure 2. Orthographic views of machine

Materials

Mild steel (purchased from local mild steel market, Faisalabad) was preferred for manufacturing of machine parts due to its easily availability, low cost, high machine ability, strength, high resistance to temperature and stress. Die and piston were also manufactured with mild steel but inner surface of die and upper surface of piston were coated with steel to reduce the friction between these two and also for smooth flow of material. Machine was manufactured in agriculture machinery workshop, university of agriculture, Faisalabad. Initially, machine was tested only for wheat crop residue due to its abundant availability in Pakistan. However, other agriculture materials such as rice husk, maize straw, cotton stalk and rice straw etc. will be briquetted in future by optimizing its die and altering minor parts for example diameter of belt pulleys etc. according to material properties.

Laboratory setup to determine input material properties

Bulk density of raw material

Density of the chopped wheat crop residue was determined according to ASABE Standard S269.4 using a cylinder of known volume [29]. Using this method material was dropped on to the cylinder over a standard height of 20 cm. The height was taken from the bottom of cylinder. Once the cylinder was overflowed, the excess material was removed by straight edge. For determining the tapped density, cylinder was dropped five times from a specific height of 10 cm on the laboratory bench. Filling and tapping process was repeated until container was not required any material more. Difference of weight, before and after input was noted. A simple formula was used to find out the density of raw material.

$$Density\ (kg/m^3) = \frac{Mass\ (kg)}{Volume\ (m^3)} \tag{1}$$

The average density of five dry samples of crushed wheat straw was ≈110 kg/m^3.

Moisture content of raw material

A digital moisture meter TK100S available in laboratory facility of the university was used for determination of raw material moisture content. Moisture meter works on electrical resistance method. Moisture meter has two parallel prongs which are inserted into raw material and acts as terminals. Moisture content level is directly shown on digital screen and was noted. If the material was found to be higher than the required moisture level, it was simply dried in open sun and brought it to the required level otherwise water was sprayed if it was below the requirement.

Particle size of raw material

In this study an already available shredder in department of structures and environmental engineering was used. This shredder has the capacity of 200 kg/h. Shredder contains a steel drum with a rotating shaft on which hammers are mounted. The rotor at the center is spun at a high speed and feeds the material to feed hopper. The material is impacted by the hammer bars attached to rooter and is thereby shredded and expelled through screens in the drum of a selected size. We can attain different sizes of particles by changing the screen size. A variety of screens with different sizes are also available in local market to get required particle size.

Designing of important components of the machine

Working drawings of each part of machine were prepared by using Auto CAD software and all the machine parts were developed and fabricated according to prescribed specifications. For example required pressure, theoratical density of briquettes, manufacturing material, frame dimentions, fly wheel size, size of electric motors etc. were determined on the basis of lab experiments, design formulas and availability of parts in local market.

Main Frame Design

Main frame is the body structure prepared by the mild steel bars to accommodate the other parts including electric motor, fly wheels, crank shaft along with bore hole and piston, feeding hopper, feeding conveyer with conveyer motor, and electric and heating panel. The area of main frame can be calculated by eq. 2.

$$Area = L \times W \qquad (2)$$

Where:

L = length of frame

W = Width of frame

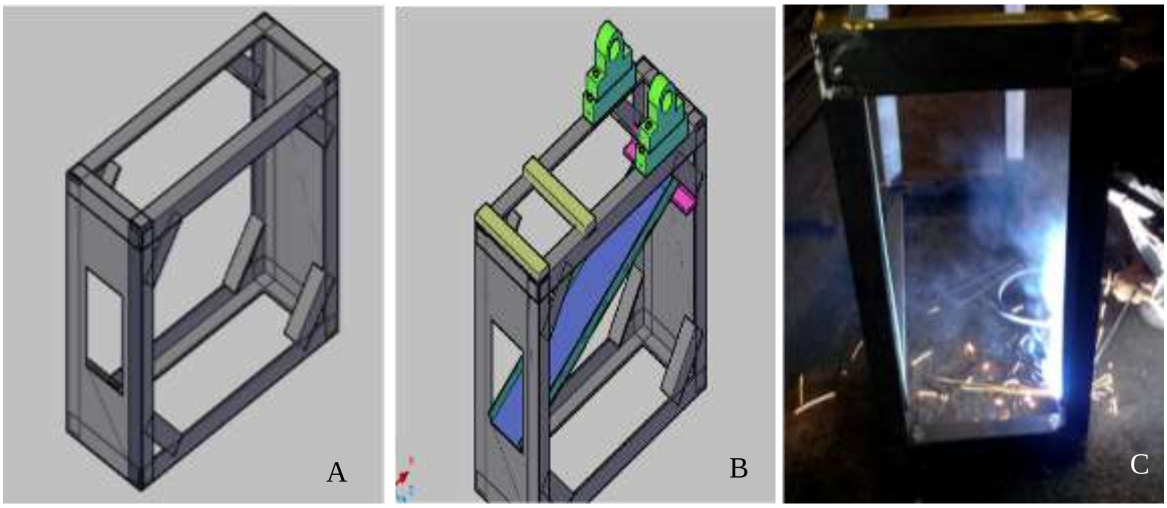

Figure 3. CAD drawing of main frame (A and B) and manufacturing in workshop (C)

Feeding hopper Design

A feeding hopper is a container that keeps the raw material supplier into the machine and also acts as a reservoir Figure.4.

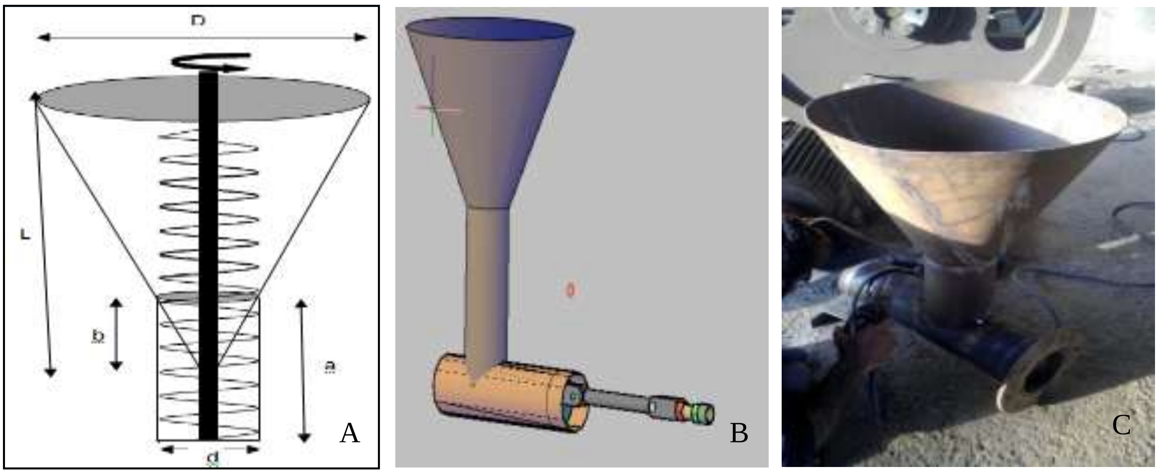

Figure 4. 2D (A) and 3D (B) views of hopper and its manufacturing in workshop (C)

It feeds the input material to centrally rotating conveyer. It is important to design a proper hopper because under sized hopper may led to improper briquettes due to insufficient input of raw material while oversize will increase the cost of machine. The size of hopper is designed in such a way that 2/3 volume should always be filled during operation. It was designed using eq.3.

$$V_t = \left(\frac{1}{3} \times \frac{\pi D^3}{4} \times L\right) - \left(\frac{1}{3} \times \frac{\pi d^3}{4} \times b\right) + \left(\frac{\pi D^2}{4} \times a\right) - \left(\frac{\pi (\mathrm{d1})^2}{4} \times (L + a - b)\right) \qquad (3)$$

Here: V_t is the total volume and d_1 is the diameter of rotating shaft

Design of feeding conveyer

An auger conveyer, centrally rotated in hopper was used to feed the raw biomass to compression chamber. Auger conveyer consisted of a shaft with belt pulley system rotated by a motor (Figures. 1&2). Conveyer speed could be controlled by adjusting diameter of the drive or driven belt pulley. As if, there is more diameter of driven pulley, less will be the speed of conveyer, which could result in less volume input and vice versa. The designing of an auger conveyer mainly depends on the characteristics of input biomass (such as class of material, practical size, initial density etc.) and also on material flow rate (volume per unit revolution).

Conveyer size and speed determination

We have set the following design parameters to design auger conveyer: residue feed rate was300 kg/h (equal to machine capacity) and density of crop biomass was 110 kg/m^3 (from section 2.3.1). Firstly, we determined the actual calculated volume using following eq. 4.

$$Actual\ calculated\ volume = \frac{actual\ capicity\ required}{density\ of\ material} = \frac{300\ kg/h}{110\ \ kg/m^3} = 2.73\ \frac{m^3}{h}$$

$$= 90.34 \frac{ft^3}{h} \qquad (4)$$

The selection capacity was determined as:

$$Selection\ capacity\ (SC) = Capacity\ in\ cubic\ feet\ per\ hour\ (CFH) \times Capacityfactor\ (CF) \qquad (5)$$

$$\text{capacity factor (CF)}$$
$$= \text{ pitch capacity factor } \times \text{ pitch capacity factor factors for conveyers with puddles}$$
$$\times \text{ ribbon conveyer capacity factor} \qquad (6)$$

Above factors were adopted from standard tables given in by considering auger conveyer having slandered pitch (pitch = diameter of screw), ribbon flight with 45% loading from materials table in material characteristics section for wheat residue, none paddle on conveyer and ribbon type conveyer [24]. Ribbon flight was selected from different types of flights suggested by a researcher according to our requirements [25]. Putting the values of all factors in (eqs.5& 6) we have

$$CF = 1 \times 1.81\ \times 1\ \times 1.5 = 2.72$$

$$SC = 90.34\ \times 2.72 = 245.72$$

Above calculated selection capacity factor (SC) was used as reference to determine the diameter of conveyer and per revolution volume to be delivered from conveyer capacity table for wheat crop residue. Best suitable diameter and per revolution capacity were found to be equal to 15.24 cm and 2.27ft^3/h respectively.

From this, actual conveyer speed can be calculated using eq. 7.

$$Conveyer\ speed\ (CS) = \frac{SC}{CFH\ at\ 1\ rpm} = \frac{245.72}{2.27} \approx\ 108\ rpm \qquad (7)$$

Stroke length determination

Length of stroke was determined using capacity of machine as 300 kg/h, for raw material density equal to 1100 kg/m^3 (calculated in section 2.3.1) and machine was designed for 60 rpm speed of piston. For example, 60 strokes per minute, about quarter of traditional speed of machines 240-270 rpm, to reduce the wear and tear by decreasing load on die of machine. So,

$$mass\ in\ one\ strock = \frac{300}{60 \times 60} = 8.33\ \times 10^{-2}\ \ kg \qquad (8)$$

$$volume\ in\ one\ strock = \frac{mass}{density} = \frac{0.083\ kg}{11\ {}^{kg}/_{m^3}} = 7.58\ \times 10^{-3} m^3 \tag{9}$$

$$Cross\ section\ area\ of\ bore\ hole = \frac{\pi a^2}{4} = 3.14\ \times 10^{-2} m^2 \tag{10}$$

Here a is cross sectional area of bore hole and equal to 0.2 m.

$$length\ of\ strock = \frac{volume\ in\ one\ strock}{Cross\ section\ area\ of\ bore\ hole} = \frac{7.58\ \times 10^{-3}}{3.14\ \times 10^{-2}} = 0.24\,m \tag{11}$$

Main motor pulley diameter

Motor RPM was 900 and available diameter of pair of fly wheel in market was equal to 0.81m. So, drive pulley diameter of main electric motor was designed using eq. 12.

$$D_2 = \frac{D_1 \times R_1}{R_2} = \frac{0.81\text{ m} \times 60\text{ rpm}}{900\text{ rpm}} = 0.054\,m \tag{12}$$

Note: Above design and equations were referenced by (Khurmi and Gupta 2005).

Main motor power required

There are complex internal forces/ stresses produce in compaction chamber due to tapered die and it is difficult to calculate electric power requirement to overcome these internal frictional forces. There is a general formula given in food and agriculture organization of United Nations by a researcher for the motor power requirement (P) of mechanical piston press briquettes formation machines in relation to capacity of machine (Q) shown in eq. 13 [26]. The following eq. 13 was developed on the basis of results of electric power requirement of a number of briquettes forming machines working on engineering principle of mechanical piston press technology. It may not give accurate results for electric power requirement; still we have the idea that the use of 26 kW electric motor would be economical to produce 300 kg/h as shown in eq. 13.

$$\text{P(kW)} = 0.58 * (Q)^{\frac{2}{3}} = \text{ 26 kW} \tag{13}$$

Here Q is the capacity of machine in kg/h.

Die of machine

The die has three sections, i.e., (1) Cylindrical/Heating section, (2) Conical section (3) Calibration section as shown in Figure.5.

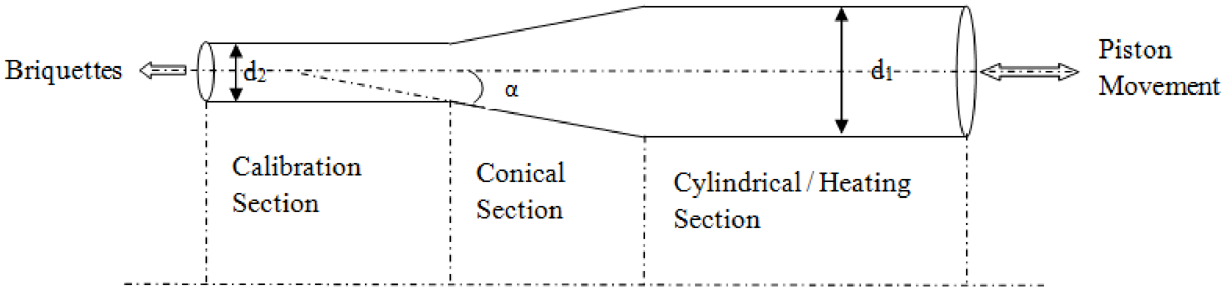

Figure 5. Die sections of piston press briquettes forming machine

Heating section starts from the top dead center of piston as shown in Figure. 5. It contains three heaters with 2 kw capacity and are wrapped round the upper surface to heat up the inner material. The heat sensors are also installed to indicate temperature of die. Any value of temperature can be adjusted within the range of 0^0C-500^0C. In 2^{nd} section (also known as conical section) the density of raw biomass increases gradually as diameter is reduced. In this section voids between the particles are reduced gradually along the length of this section and particles locked with each other reducing the spaces between them. Although at the end of second section required density is achieved, however, material is very warm and it will tend to swallow if suddenly exposed to air. This will severely affect the durability of the briquettes. So, a third section (also known as calibration section) is necessarily added to hold the newly formed briquettes for additional time so that particles are firmly attached to each other by cohesive forces.

After designing the other parts of machine, die concavity was firstly optimized using three different conical angles (15^0, 20^0 and 25^0) as shown in Figure. 6 was fitted to machine and check for formation and quality of briquettes in terms of two physical parameters density and durability of briquettes. Results are shown in results and discussion section (Table 2).

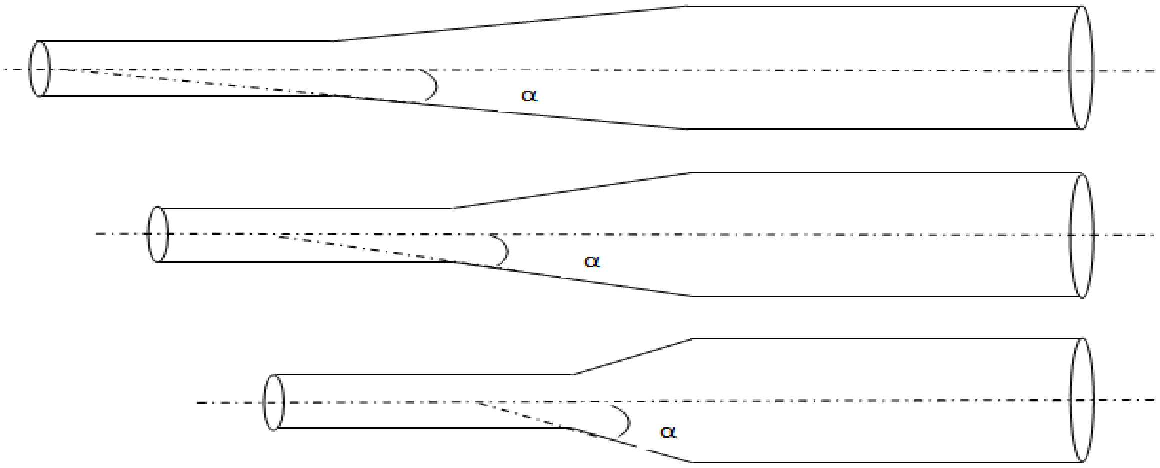

Figure 6. Variation of conical angle (α) for optimization of die. (a) $\alpha = 15^0$, (b) $\alpha = 20^0$ and (c) $\alpha = 25^0$

Air Coolant line

The newly formed briquettes are required to slowly cool down for a stable shape and size. To achieve this purpose, we added a 10 ft long semicircular air coolant line right after the calibration section of die (Figures. 1 & 2). After formation, the briquettes travel on it and cools down due to natural air flow.

Determination of density and durability of briquettes

Density of briquettes

For determination of density, first volume of an individual briquette was measured by water displacement method. In this method wax was coated on the surface of briquette to prevent water penetration. Weight of briquette was calculated before and after coating wax. Wax coated briquette was then merged into a water containing cylinder and volume of water displaced by briquette was noted. Density was then measured by dividing initial weight of briquette before applying wax to the volume of briquette after subtracting the volume of wax [27].

Durability of briquettes

In this study drop resistance test was used for the determination of durability of briquettes [28]. In drop resistance test first weight of the briquette is noted and it is dropped freely from a selected height of 1.85m on a concrete floor. Some of the weight is shattered in small pieces. Weight retained by the largest piece of briquette to its initial weight in percentage is taken as durability.

Procedure of briquette forming by briquetting machine

First of all wheat straw was collected from the fields of PARS (Post Graduate Agriculture Research Station), new campus, University of Agriculture, Faisalabad. Material was then shredded to required particle size by varying sieve size of shredder. Available binders (optimization of binder is given in results and discussion section) in specific amount were mixed in chopped material. This process material was then added to machine for the formation of long rods which ultimately cut into a specific length using a cutter. Following, Figure. 7 shows the step wise procedure of briquettes formation.

Figure 7. Flow diagram of briquette formation from raw materials content

RESULT AND DISCUSSION

Die optimization

Table 2 shows the quality of briquettes in terms of density and durability against the three angles (i.e., **α** = 15^0, 20^0 and 25^0) of die concavity. There were unacceptable results for both parameters of density and durability as 435 kg/m^3 and 34 % respectively at concavity angle **α** = 15^0. It may be due to less compaction and more spaces between particles. In contrast to this, an increase of 5^0 (i.e., **α** = 20^0) resulted in smooth operation of the briquetting machine with giving well shaped briquetting logs. The density and durability results showed that 20^0 angle gave a density of 845 kg/m^3 and enhanced durability of briquettes as 65 % Table 2. It indicates a gain to about two folds in density and durability with 5^0 more concavity. However, a further increase of 5^0 (i.e., **α** = 25^0) at highest contraction, raw material was stuck in the die and resulted in choking of the briquetting process. It indicates that a very high concavity angle could hinder the flow of the biomass material through conical section. The results from this experiment show that too high concavity causes the loss in flow to biomass while too small concavity may cause very lose binding of particles due to pressure area distribution. We selected **α** = 20^0 as optimal concavity angles due to its highest density and durability results.

Table 2. Specifications of conical section and its effect on density and durability of briquettes

Sr. No.	α (degrees)	d_1 (mm)	$H=d_1/2$ (mm)	Conical section length (mm)	Density Kg/m^3	Durability (%)	Remarks
1	15	200	100	214.5	435	34	Lower density & stability
2	20	200	100	275	845	65	Highest density & stability
3	25	200	100	373	No briquettes formed	No briquettes formed	Material was stoked in die

Binder selection

It should be noted that dense briquettes were found at optimal **α** = 20^0 however, durability was not satisfactory. One of the reasons was the fact that the particles may have been compressed due to piston force however, they lack to bind each other permanently. We added binder to further enhance the quality of product. The binders were selected on the basis of assumptions that it should be economical and locally available. For this we selected two different binders i.e., 1) slurry form a biogas plant and 2) starch from a local corn processing plant. In this study firstly experiment was started by adding 3 kg of slurry in to 50 kg of grinned wheat straw residue by keeping the other variables of machine i.e. temperature, particle size and moisture content kept constant. Slurry was added in increasing order (3,6,9,12,15, 18kg) in same amount of wheat residue 50kg. As the results shows in (Figures. 8&9) that durability was increased with increasing rate up to some extent and further increment decreased the quality of briquettes. Briquettes were formed but their highest durability was not acceptable of this class (Figures.8&9).

In 2nd phase starch was used as binder taking 50kg chopped wheat residue as previously was taken. Starch was added as (2, 2.5, 3, 3.5, 4, 4.5, 5kg). With the increase in the amount of starch quality of briquettes became better and better. The reason behind the better results was the excellent adhesive properties of starch. Starch forms adhesive bond around the biomass particles to binds them together and to increase the strength of briquettes. The highest quality of briquettes was formed at the highest amount of starch shown in Figure. 8. Further increment in starch quantity may increase the durability of final product more. On the other hand local price of starch is 50 Rs/kg. So, addition of more than 4 kg of starch in 50 kg of crop residue will not be viable economically. So, in 3rd phase it was decided to add slurry + starch in 3:1 as (slurry: starch= 1.5:0.5, 3:1, 4.5:1.5, 6:2……) in same sample size as 50kg of wheat residue. Highest quality of results of this specific class was obtained with the mixture of 50kg of wheat straw + 12 kg slurry + 4 kg starch ≈ 12:3:1 on wt basis. Results of durability of briquettes were intermediate between 1st and 2nd classes but acceptable both economically as well as quality wise as shown in (Figures. 8&9).

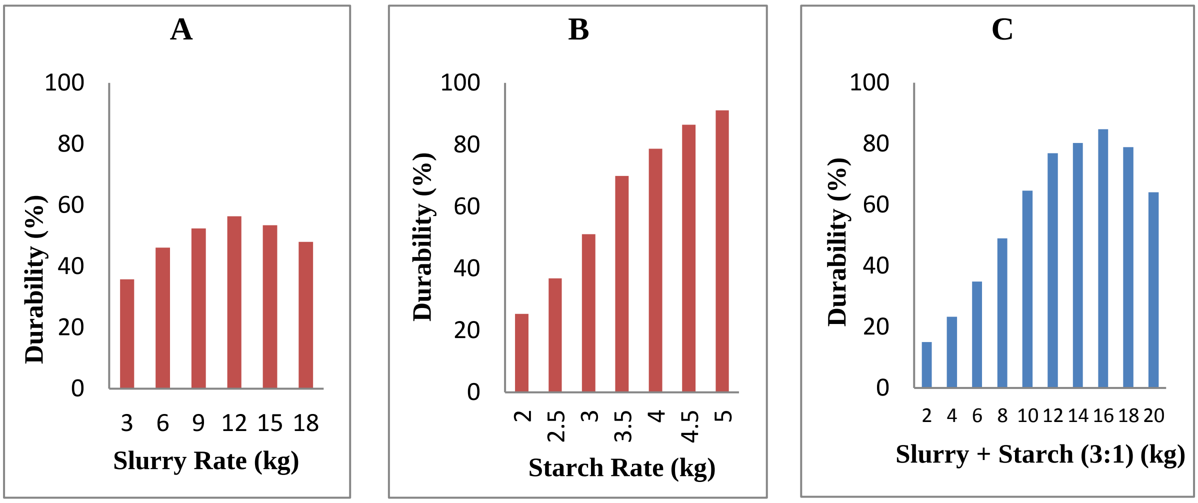

Figure 8. Durability Vs different classes of binders (A= Slurry, B= Starch and C=Slurry+Starch

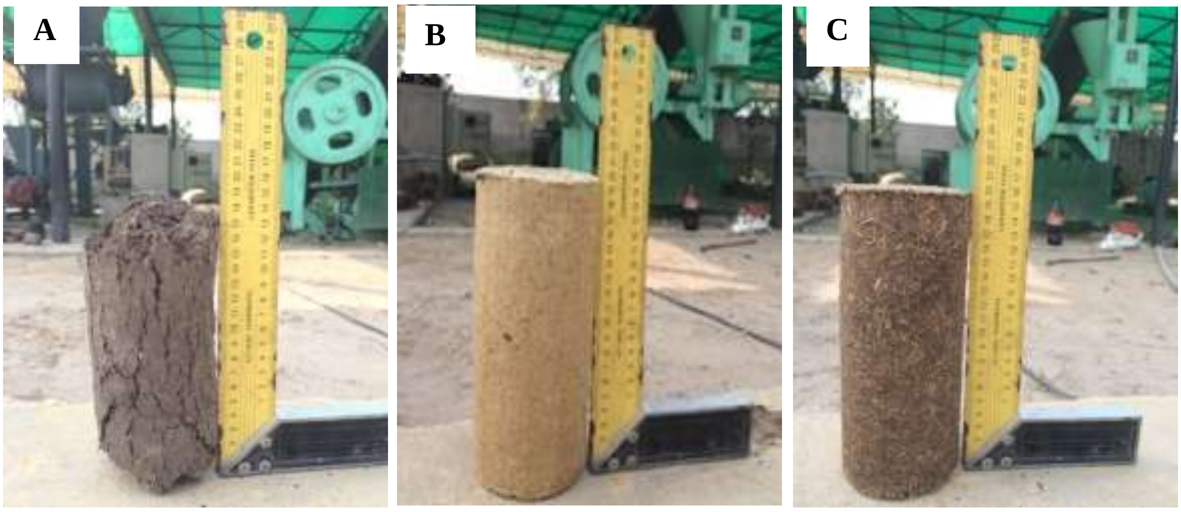

Figure 9. Wheat straw briquettes using different binders (A= Slurry, B= Starch and C=Slurry+Starch)

Effect of pretreatments (temperature, moisture content, particle size) of raw biomass

Once the binder type and ratio was selected the next step was to determine the effects of three most important parameters for example die temperature, moisture level and particle size of input material. Die heaters are actually the addition in the machine as compare to similar types of piston press machines. Traditionally, those machines have a heavy weight die, operated at a high speed of piston about 270 rpm, elevated pressure is required and high power electric motors are used. Due to large friction and heat in die, lignin's come out from material and acts as a binder in those machines. But in our case we have used locally prepared light weight die, less speed of piston only 60 rpm. So, moderate pressure is developed in die and less power of motor is required for comparatively high diameter of briquettes. Hence, manufacturing cost of machine was reduced and also has less chance of burst of die. Because, there is less friction in die and heat from external source warmed the inner material. So, natural binder in form of lignin's along with artificial binder (starch and slurry) binds the raw biomass. Temperature also softens the material which is easy to move further in die.

Firstly, durability of briquettes was increased with increase in temperature but increasing rate was very slow after 250 ^{0}C Figure. 10. It shows once the upper surface of briquette is formed, more heat is utilized to penetrate towards the middle of briquette but this penetration is a very slow process as compare to traveling speed of briquette and does not have significant impact on strength of briquettes. Secondly, we determined the effect of moisture content which shows the highest quality of briquettes were prepared at 20% moisture content level while results were decreased before and after this as shown in Figure. 10. May be the reason behind it was the binder showed the best performance at middle due to more stickiness. On other hand particle size showed an inverse relationship for example highest durability was obtained at lowest particle size shown in Figure. 10. Because as we go on increasing the particle size, total surface area of the particles is decreased, this not only reduces the chance of bond formation by binder but also creates the pore spaces among the particles.

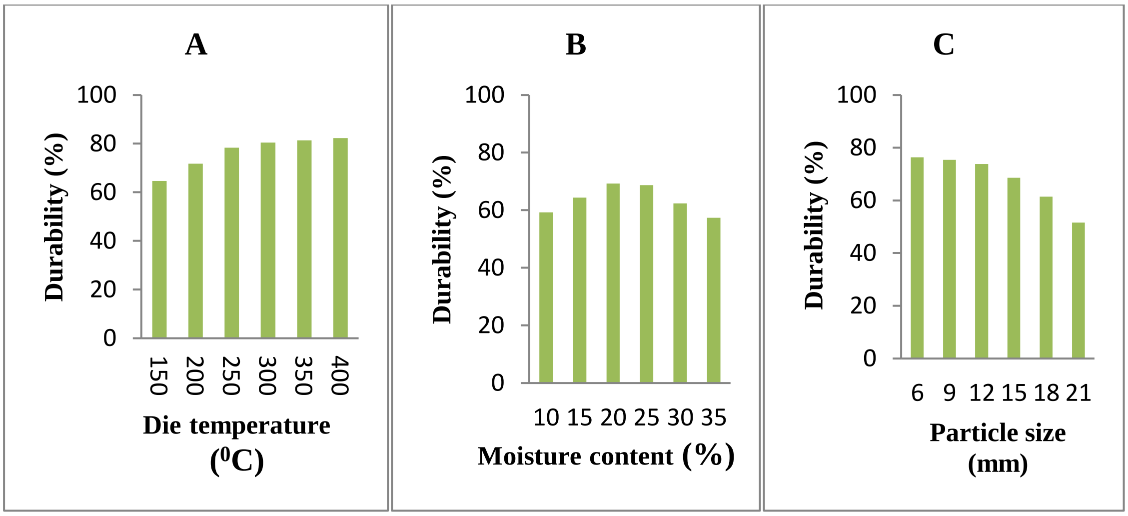

Figure 10. Durability results after pretreatment (A= Die temperature, B= Moisture content C= Particle size)

Economic evaluation

Important considerations for cost analysis

Cost analyses is highly site specific and a number of factors for example, manufacturing and input material cost, cost of electricity, labor, binder, machinery maintenance etc. affects the overall cost of a briquetting plant [29]. Considering the local scenario there are few important considerations those need to be mentioned before cost analysis. It was estimated that total cost on machinery was about 1 million and life period was assumed to be ten years. Cost of housing and installation of plant were 0.1 million and 0.025 million respectively. Salvage value and interest rate was taken as 10 % for each. Average cost of raw material including harvesting, collection and transportation cost was considered to about 3000 Rs/ton. It was assumed that machine will work 25 days in a month and 8 hours in a day with production capacity to about 300 kg/h. Two workers are required @ 12000 Rs/worker/month salaries. Operational cost including electricity cost was calculated @ 16 Rs/unit considering commercial meter rates in country. Operational cost for compactor, shredder and conveyer was calculated as 1000 Rs/h. Maintenance and cost of coolant were taken as 250 Rs/hr. Cost of binder was at the rate of 50 and 2 Rs/kg for starch and slurry was included. Purchase cost of briquettes per ton was assumed to about 1200 Rs/ton, equal to rate of wood in local market.

Payback Period

Payback period is the length of time taken to recover an investment. It is a good tool for the economic evaluation of machine adaptation. A period of one year was taken and a graph was drawn between total costs verses total benefit shown in Figure. 11. Total cost includes; machine manufacturing cost, binder cost, operational cost (electric cost, labor cost, maintenance cost) and raw material cost (collection, transport and grinding). Green line shows the profit by selling the briquettes at the rate of 12 Rs/kg. Payback period of this machine was near about8 months shown in Figure. 11. Payback period was two months more as determined by for binder less piston press machine, may be due to extra expense on addition of binder, less capacity of machine and a reduced amount of initial cost [30].

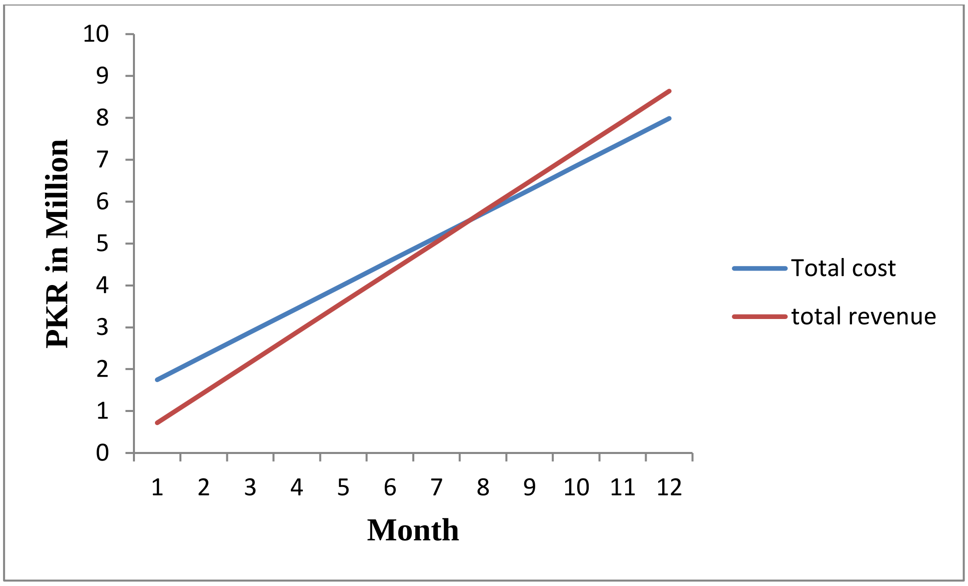

Figure 11. Payback period of machine

Benefit to cost ratio (BCR)

Benefit to cost ratio was calculated using eq. 20 which is the ratio between the gross revenue to the production cost. For determination of BCR following equations used by a researcher are written along with calculations.

$$Annual\ depriciation\ (D) = \frac{P - S}{L} = \frac{1 - 0.1}{10} = 0.09\ million \tag{14}$$

Here,

P= purchase or manufacturing cost of machinery

S= salvage value @ 10%,

L= useful life of machinery

$$Interest\ on\ investment\ (I) = \frac{P + S}{2} \times i = \frac{1 + 0.1}{2} \times +0.10.055\ million \tag{15}$$

i = interest rate @ 10 %

$$Total\ fixed\ cost\ (TFC) = D + I + cost\ of\ \text{housing}\ (CH) + installation\ cost\ (IC)$$

$$= 0.09 + 0.055 + 0.01 + 0.0025 = 0.16\frac{million}{year} \tag{16}$$

$$Total\ variable\ cost\ (TVC)$$

$$= Repair\ and\ maintance\ cost + labor\ cost + cost\ of\ electricity$$

$$+ cost\ of\ raw\ material + cost\ of\ binder = 0.6 + 0.29 + 1.6 + 1.04 + 3.24$$

$$= 6.77\frac{million}{year} \tag{17}$$

$$Total\ cost\ (TC) = TFC + TVC = 0.1575 + 5.73 = 6.93\frac{million}{year} = \frac{2887.5Rs}{h} \tag{18}$$

$$Production\ cost\ \left(\frac{Rs}{kg}\right) = \frac{Production\ cost\ per\ hour\ \left(\frac{Rs}{h}\right)}{production\ rate\ of\ briquettes\ \left(\frac{kg}{h}\right)} = \frac{\frac{2887.5}{300}Rs}{kg}$$

$$= 9.63\frac{Rs}{kg} \qquad (19)$$

$$Gross\ revenue = selling\ rate\ of\ briquettes\ \left(\frac{Rs}{kg}\right) = 12\frac{Rs}{kg}$$

$$Benifit\ cost\ ratio\ (BCR) = \frac{Gross\ revenue}{Production\ cost} = 1.25 \qquad (20)$$

From the results calculated above it is concluded that by investing 1 Pakistani rupee, a farmer can earn 1.25 Rs with and can save 0.25 Rs with saving of priceless environment.

CONCLUSION

A relatively low pressure 85mm diameter briquettes forming machine was designed indigenously. The briquetting machine is working on the mechanical piston press technology. Die concavity was optimized at 20^0 tapered angle on the basis of density and durability. Rather than similar machines binder was added to increase the quality of product. Wheat straw + Starch + slurry in 12:3:1 gave the durable (85%) and dense (1100 kg/m^3) briquettes. Machine's payback period and BCR were approximately eight months and1.25 respectively. By adopting this machine farmers can get some additional money from crop residues which the presently wasting and polluting the environment. This technology is highly economical and viable in rural areas of Pakistan.

ACKNOWLEDGEMENT

The authors would like to thank Higher Education Commission, Pakistan for funding of this project No. 320.We would also like to show our gratitude to both technical and non technical staff of university those assisted us during development of machine and especially to the lab staff helped us in the provision of lab equipments and other lab facilities.

REFERENCES

[1] Uqaili, M. A., et al. Prospects of Renewable Energy for Meeting Growing Electricity Demand in Pakistan, *American Institute of Physics*. 941: 53-61, 2007.

[2] Streets, D. G., et al. "Biomass burning in Asia: Annual and seasonal estimates and atmospheric emissions." *Global Biogeochemical Cycles* 17(4), 2003.

[3] Kante, B. "Benefits of black carbon mitigation for developing countries. Black carbon-e bulletin, 1, 2, 2009.

[4] UNEP. "A major study on black carbon intercomparison. Black carbon-e bulletin, 1,2, 2009.

[5] Bond, T. C., et al. "Bounding the role of black carbon in the climate system: A scientific assessment." *Journal of Geophysical Research: Atmospheres* 118(11): 5380-5552, 2013.

[6] Nakajima, T. "New demands on black carbon sciences. *Black carbon-e bulletin*, 1: 2, 2009.

[7] NASA. "(Online). Available at http://www.bashaoorpakistan.com/reports/nasa-satellite-image-suggests-crop-burning-india-lahore-smog/. Downloaded at 23-07-2017, 2016.

[8] Shukla, S. and V. Savita. "Study of Biomass Briquettes, Factors Affecting Its Performance and Technologies Based on Briquettes." *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)* 9(11): 37-44, 2015.

[9] Olivia, E. I. N. and W. J. O. Oti. "The design and fabrication of a briquette press using locally available raw materials in Nigeria: An approach towards briquette technology sustainability in Nigeria." IAJPS. *Indo American journal of pharmaceutical sciences* 4(2): 450-456, 2017.

[10] IEA. "Internation Energy Agency. Biomass for Power Generation and CHP, [Online]. Available: https://www.iea.org/publications/freepublications/publication/essentials3.pdf, 2007. [Accessed 08-09-2015].

[11] WEO. World Energy Outlook. IEA. International Energy Agency. [Online]. Available:http://www.oecdilibrary.org/docserver/download/6113131e.pdf?expires=1390164356&id=id&accname=ocid177514&checksum=A920D8DE85A3EE017819CAF75735609D, 2013. [Accessed 02-06-2016].

[12] Saeed, M. A., et al. Agriculture waste biomass energy potential in Pakistan. International bioenergy exhibition and Asian bioenergy conference. Shanghai P. R. China, 2015.

[13] Butt, S., et al. (). "Bioenergy potential and consumption in Pakistan." *Biomass and bioenergy* 53: 379, 2013.

[14] Mirza, U. K., et al. "An overview of biomass energy utilization in Pakistan." *Renewable and Sustainable Energy Reviews* 12(7): 1988-1996, 2008.

[15] Batidzirai, B., et al. "Current and future technical, economic and environmental feasibility of maize and wheat residues supply for biomass energy application: Illustrated for South Africa." *Biomass and Bioenergy* 92: 106-129, 2016.

[16] Deepchand, K. "Energy from Sugar Cane Bagasse on a Commercially Sustainable Basis." Paper Presented to the Parliamentarian Forum on Energy Legislation and Sustainable Development, Cape Town, South Africa (5-7 October 2005), 2005.

[17] Kaliyan, N. and R. V. Morey. "Binding mechanisms of corn stover and switchgrass in briquettes and pellets." *(ASABE) American Society of Agricultural and Biological Engineers*. 7: 4388-4410, 2008.

[18] Grover, P. D. and S. K. Mishra. Biomass Briquetting: Technology and Practices, Regional Wood. Energy Development Programme. FAO, Bangkok, 1996.

[19] Yadong, L. and L. Henry. "High-pressure densication of wood residues to form an upgraded fuel." *Biomass and Bioenergy* 19: 177-186, 2000.

[20] Redivivus, E. "(online). Available at http://www.redivivus.co.il/briquetting-press/biomass-briquetting-press/ram-press.aspx. 2017. Accessed at 24-07-2017.

[21] Peter, K. and M. Milos. "Impact of pressing chamber conicalness on the quality of briquettes produced from biofuels in briquetting machines." FUELS 4: 122-127, 2012.

[22] Tabil, L. G. "Binding and Pelleting characteristics of alfalfa: An Unpublished Ph.D diss. Saskatoon, Saskatchewan, Canada: - University of Saskatchewan, *Department of Agricultural and Bio-resources Engineering*, 1997.

[23] Birwatkar, V. R., et al. "Physical and thermal properties of biomass briquetted fuel." *Ind. J. Sci. Res. and Tech.* 2(4): 55-62, 2014.

[24] Kase, C. C. "Engineered Bulk Material Handling, Bulk Material Handling Equipment, Screw Conveyor Engineering Guide.". Retrieved 15-04, 2017, from http://www.kaseconveyors.com, 2017.

[25] Amey, K. Design and fabrication of a feedstock delivery system for a 3kw solar gasification reactor. Faculty of graduate school of university of Minnesota, University of Minnesota, 2013.

[26] Khurmi, R. S. and J. K. Gupta. A Text Book of Machine Design. Ram Nagar, New Delhi-110 055, Eurasia Publishing House (Pvt.) Ltd, 2005.

[27] Sengar, S. H., et al. "Performance of Briquetting Machine for Briquette Fuel." *International Journal of Energy Engineering* 2(1): 28-34, 2012.

[28] Al Widyan, M. I. and H. F. Al Jalil. "Stress–density relationship and energy requirement of compressed olive cake." *Applied Engineering in Agriculture* 17: 749-753, 2001.

[29] ASABE. American society of agricultural and biological engineers. S269.4. Cubes, Pellets and crumbles. definitions and methods for determining density, durability and moisture content. St. Joseph, Mich. ASABE, 2007.

[30] Saha, K. K., et al. "Feasibility study of coconut coir dust briquette " *J. Bangladesh Agril. Univ.* 12(2): 369-376, 2014.

[31] Maninder, K.S. Rupinderjit and G. Sonia. Using Agricultural Residues as a Biomass Briquetting: An Alternative Source of Energy. *IOSR Journal of Electrical and Electronics*, 2012.