Analysis for the Financial Viability of the Rice Husk Briquette Production by Increasing Screw Life and Reducing Fuel Cost

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Abstract: Nepal is predominantly an agricultural based country whose 98% of energy consumptions based on biomass material. The energy demand increased by 10% each year.

Direct briquetting system of the rice husk is chosen for the densification of the loose biomass material. In this system replacement of the old briquette dies heating system by the electric heater die heating system reduce cost of power used for the briquette production by NRs. 4.95 per kg of briquette production. From the risk analysis of the system by using the Monte Carlo simulation software crystal ball, the certainty of obtaining 39.97 annual returns on investment is only 43.33% but in the case of the electric heater heating system certainty is 97% for the 100 % annual return on the investment.

Mixing of loose biomass material (saw dust and Sal leaves) with the rice husk also increase the running life time of the direct briquetting screw and increase the rate of the production of the briquette. Which also reducer the production cost of the briquette and improves the heating value of the briquette.

Keywords: Briquette; GIS; Sal; Rice husk; Bomb calorimeter; Saw dust

1. Introduction

Biomass densification represents a set of technologies for the conversion of biomass into a fuel.

The technology is also known as briquetting and it improves the handling characteristics of the materials for transport, storing etc. This technology can help in expanding the use of biomass in energy production, since densification improves the volumetric calorific value of a fuel, reduces the cost of transport and can help in improving the fuel situation in rural areas. Briquetting is one of several agglomeration techniques which are broadly characterized as densification technologies. Agglomeration of residues is done with the purpose of making them denser for their use in energy production. Raw materials for briquetting include waste from wood industries, loose biomass and other combustible waste products. On the basis of compaction, the briquetting technologies can be divided into:

1.1 High pressure compaction

Medium pressure compaction with a heating device

Low pressure compaction with a binder.

In all these compaction techniques, solid particles are the starting materials. The individual particles are still identifiable to some extent in the final product. Briquetting and extrusion both represent compaction i.e., the pressing together of particles in a confined volume. If fine materials which deform under high pressure are pressed, no binders are required. The strength of such compacts is caused by van der Waals' forces, valence forces, or interlocking. Natural components of the material may be activated by the prevailing high pressure forces to become binders. Some of the materials need binders even under high pressure conditions. Figure below shows some of the binding mechanisms.

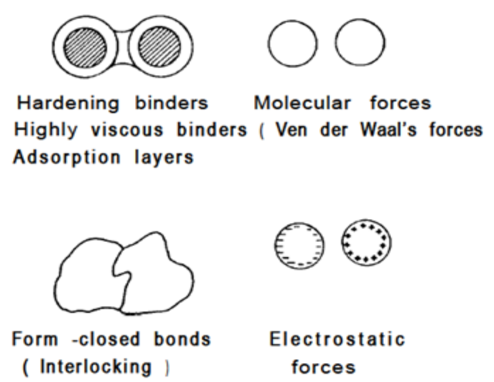

Figure 1: Binding mechanism

1.2 Binding Mechanisms of Densification

In order to understand the suitability of biomass for briquetting, it is essential to know the physical and chemical properties of biomass which also influence its behavior as a fuel.

Physical properties of interest include moisture content, bulk density, void volume and thermal properties. Chemical characteristics are importance include the proximate and ultimate analysis, and higher heating value. The physical properties are most important in any description of the binding mechanisms of biomass densification. Densification of biomass under high pressure brings about mechanical interlocking and increased adhesion between the particles, forming intermolecular bonds in the contact area. In the case of biomass the binding mechanisms under high pressure can be divided into adhesion and cohesion forces, attractive forces between solid particles, and interlocking bonds.

High viscous bonding media, such as tar and other molecular weight organic liquids can form bonds very similar to solid bridges. Adhesion forces at the solid-fluid interface and cohesion forces within the solid are used fully for binding. Lignin of biomass/wood can also be assumed to help in binding in this way. Finely divided solids easily attract free atoms or molecules from the surrounding atmosphere. The thin adsorption layers thus formed are not freely movable.

However, they can contact or penetrate each other. Softening lignin at high temperature and pressure conditions form the adsorption layer with the solid portion. The application of external force such as pressure may increase the contact area causing the molecular forces to transmit high enough which increases the strength of the bond between the adhering partners. Another important binding mechanism is van der Waals' forces. They are prominent at extremely short distances between the adhesion partners. This type of adhesion possibility is much higher for powders. Fibres or bulky particles can interlock or fold about each other as a result forming interlocking or form-closed bonds. To obtain this type of bond, compression and shear forces must always act on the system. The strength of the resulting agglomerate depends only on the type of interaction and the material characteristics.

1.3 Mechanism of Compaction

In a screw extruder, the rotating screw takes the material from the feed port, through the barrel, and compact it against a die which assists the build-up of a pressure gradient along the screw.

During this process the biomass is forced into intimate and substantially sliding contact with the barrel walls. This also causes frictional effects due to shearing and working of biomass. The combined effects of the friction caused at the barrel wall, the heat due to internal friction in the material and high rotational speed (>600 rpm) of the screw cause an increase in temperature in the closed system which helps in heating the biomass. Then it is forced through the extrusion die, where the briquette with the required shape is formed. At this stage just before entering the die, the pressure exerted is maximum. If the die is tapered the biomass gets further compacted.

Usually the die is heated for the smooth extrusion of the briquette. Some of the heat of the heated die is also transmitted to the biomass and the screw surface.

A simple extruder features three distinct zones: feed, transport, and extrusion zones. The important forces that influence the compaction of biomass play their role mostly in the compression zone. When the biomass is fed into a screw extruder and force is applied due to the restriction in the form of a die, compaction occurs due to the following mechanisms:

Before reaching the compression zone (a zone usually formed by tapering of the barrel) the biomass gets partially compressed. This leads to closer packing and increased density. Energy is dissipated to overcome particle friction.

At the compression zone, the biomass material becomes relatively soft due to high temperature (200-250°C). In the process, due to loss of elasticity, it is pressed into void spaces and as a result, the area of inter-particle contact increases. When the particles come together they form local bridges which selectively support and dissipate the applied pressure. Interlocking of particles may also occur. The moisture gets evaporated to steam at this stage and helps in moistening the biomass.

The biomass gets further compressed in the tapering die (temperature 280°C) to form the briquette. In this section, removal of steam and compaction take place simultaneously; the pressure exerted transmits throughout the material giving uniform pressure, and therefore, uniform density throughout the briquette.

In the compression zone the occluded air is pushed back to the feed section and thermal conductivity is improved due to compaction. During its passage through the compression zone the biomass absorbs energy from friction so that it may be heated and mixed uniformly through its mass. Brittleness, plasticity, and abrasively are some of the important factors for pressure compaction.

The speed of densification determines the relative importance of the various binding mechanisms. The aim of compaction is to bring the smaller particles closer so that the forces acting between them become stronger which subsequently provides more strength to the dandified bulk material. The product should have sufficient strength to withstand rough handling.

If uniform pressure is not applied throughout the entire volume of the material, it causes variations in compact density in the product.

The properties of the solids that are important to densification are:

a. Flow ability and cohesiveness (lubricants and binders can impart these characteristics for compaction)

b. Particle size (too fine a particle means higher cohesion, causing poor flow)

c. Surface forces (important to agglomeration for strength)

d. Adhesiveness

Hardness (too hard a particle leads to difficulties in agglomeration)

Particle size distribution (sufficient fines needed to cement larger particles together for a stronger unit).

2. Methodology

2.1 Stages of Research

Every research needs systematic tools and methods in order to make remarkable achievements. At the first stage raw material required for the production of the biomass briquette is plotted by using the GIS map. Then production process is conducted at factory by using the rice husk only and mixing the rice husk in different proportion.

In this research also the basic stages occurred during the development and experimentation of the rice husk direct briquetting occur:

Plotting the rice husk production area by using the GIS map of Nepal.

Rice husk briquetting (by replacing the briquette die heating system by the electric die heating system) and by mixing the rice husk in different proportion.

Proximate analysis of the raw material and find out the heating value of the product.

Financial analysis of system by using the Monte Carlo simulation software crystal ball.

2.2 GIS mapping of paddy cultivated area and production

Software that is used to create, manages, analyze and visualize geographic data, i.e. data with a reference to a place on earth. Typical applications for GIS software include the evaluation of places for the location of new stores, The management of forests, parks and infrastructure, such as roads and water ways, as well as applications in risk analysis of natural hazards, and emergency planning and response. For this multitude of applications different types of GIS functions are required and different categories of GIS software exist, which provide a particular set of functions needed to fulfill certain data management tasks [26].

2.3 Determination of volatile matter of Sal leaves

The dried sample left in the crucible was covered with a lid and placed in an electric furnace (muffle furnace), maintained at 750 ± 20℃ for 7 minutes. The crucible was cooled first in air, then inside desiccators and weighed again. Loss in weight was reported as volatile matter on percentage basis.

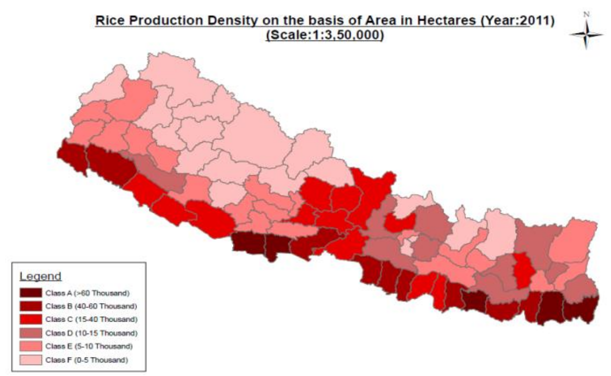

Figure 2: Paddy production area of Nepal

2.4 Calculation for the ash content

The residual sample in the crucible was heated without lid in a muffle furnace at 900 ± 50℃ for one 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.

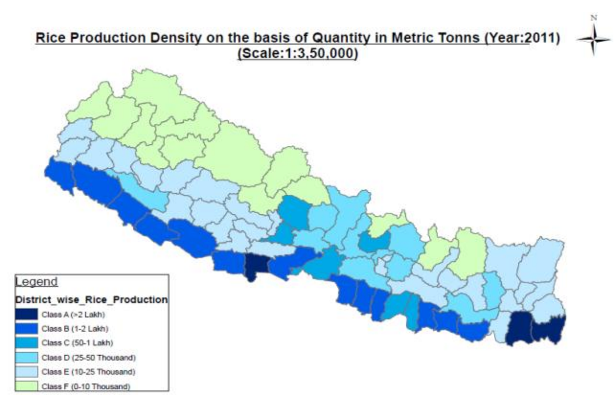

Figure 3: GIS map of paddy production in Nepal

This data shows that Nepal has capacity to produce 4.3 million metric tons of paddies annually. Paddy contains about 20 % of rice husk that means Nepal have potential of produce 0.86 million metric tons of rice husk. If, 50 % of total rice husk is used for the production, 0.375 million Metric tons of the rice husk briquette will be produce, having heating value more than 15.151 MJ/kg.

Most of the jungle of the southern part of the Nepal is occupied by the thick Sal forest. It changes its leaves annually and the heating value of the Sal leaves is higher than that of the rice husk.

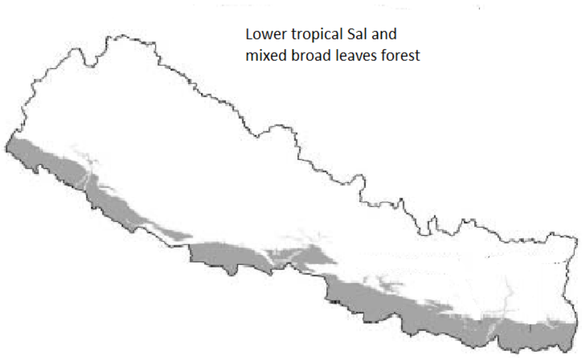

Figure 4: Sal and broad leaves (Source: Department of Forest, HMG/Nepal)

2.4 Proximate analyses

The proximate analysis of coal was developed as a simple means of determining the distribution of products obtained when the biomass sample is heated under specified conditions. As defined by JIS 8821, proximate analysis separates the products into four groups:

a. Moisture content of water in biomass
b. Volatile matter, consisting of gases and vapors driven off during pyrolysis
c. Fixed carbon, the nonvolatile fraction of coal
d. Ash, the inorganic residue remaining after combustion

Proximate analysis is the most often used analysis for characterizing biomass to find out the type and quality.

JIS 8821 standard

Proximate analysis of raw material is conducted at the Centre for Energy and environment Nepal (CEEN) by following the Japanese industrial standard, 8821 (JIS 8821).

2.5 Proximate analysis of the rice husk saw dust and Sal leaves

The moisture content of raw biomass was determined by calculating the loss in weight of material using hot air oven dying method at 105℃ to 110℃ for one hour and up to constant weight loss.

$$Moiture\ content\ (\%) = \frac{w1-w3}{w2-w1} * 100\%$$

Where,

w1 = weight of crucible (g)

w2 = weight of crucible + sample (g)

w3 = weight of crucible + sample, after heating (g)

3. Result and Discussion

3.1 Analysis of proximate analysis test

Plotting the result of the proximate analysis of the rice husk saw dust and Sal leaves.

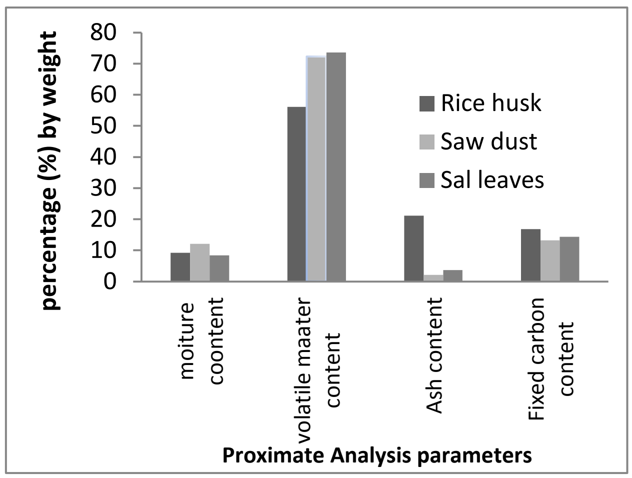

Figure 5: Proximate analysis of the Sal leaves, Rice husk and Saw dust.

Figure 5 shows that ash content of the rice husk is higher than that of the other biomass material such as saw dust and Sal leaves. Mixing the saw dust and Sal leaves with rice husk ash content of the mixture reduces then wear and tear of the screw also reduces which gives the higher life time for the biomass briquette production.

Mostly the friction between loose biomass material and screw is due to the silica content of the rice husk which appeased in the ash content. Percentage of the silica in the mixture also reduces on mixing the rice husk with other biomass material.

Volatile matter content and fixed carbon content of the Sal leaves and saw dust is higher. Mixing saw dust and

Sal leaves with rice husk give the higher heating value and lesser the ash content. High silica content in rice husk cause greater wear and tear in the screw and die. Mixing saw dust and Sal leaves reduces the percentages of the silica content which ultimately reduce wear and tear of screw and die.

3.2 Wear and tear of the screw thread

After 4-5 hours production of the briquette the screw is wear out. Mostly only three threads from exit of the briquette wear out quickly. Wear of the thread is tabulated in table 1.

Average of three times recover screw threat wear and tear of the thread is tabulated below: Screw thickness before and after the use.

Table 1: Wear and tear of screw thread

screw Number	Before use thread height (mm)	After use thread height (mm)	Before use thread Thickness (mm)	After use thread Thickness (mm)
1	9.5	7.4	9.5	4.5
2	10.15	8.5	10.95	5.85
3	11.05	8.55	11.85	9.25
4	12.5	9.8	11.45	10.6
5	12.45	12.4	10.35	10
6	12.4	12.35	12.35	12.25
7	12.5	12.45	11.75	11.65
8	12.5	12.45	12.15	12.10
9	12.4	12.4	11.90	11.90
10	12.3	12.3	12.00	12.00

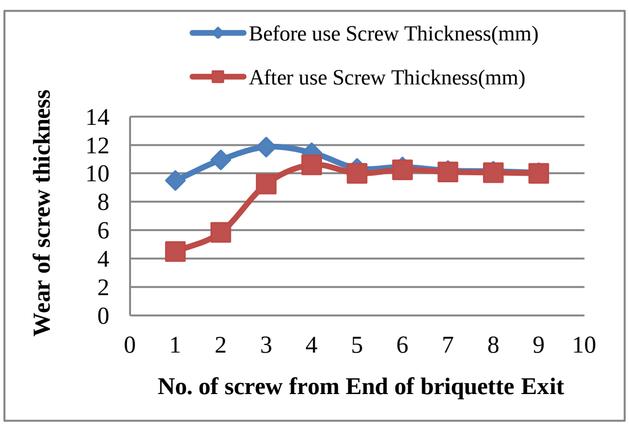

Figure 6: Wear of the screw thread thickness

Figure 6 shows first three thread wear highly than that of the rest screw thread. Only the first three thread required regular maintenance.

Expressing the wear and tear of the screw thread in the term of percentage:

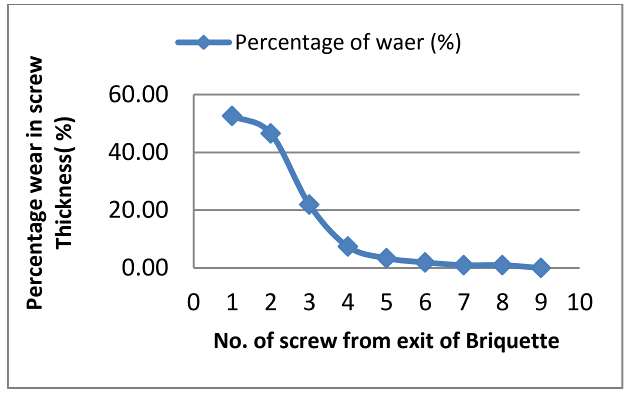

Figure 7: Wear percentage of screw thread thickness

Figure 7 shows that first thread wear out more than 50% second thread wear out more than 40% but in case of the last five threads the wear and tear percentage is nearly zero.

Screw height before and after the production:

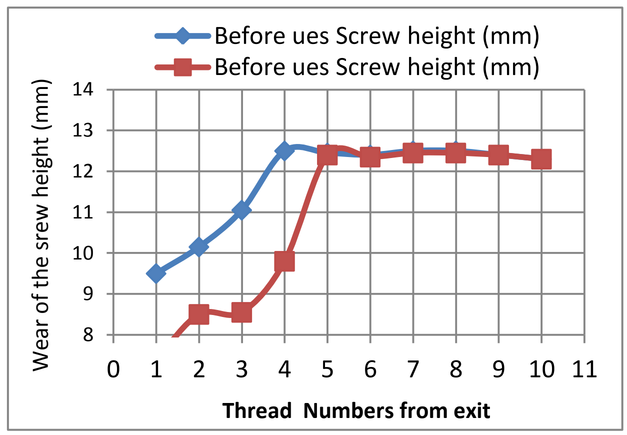

Figure 7: Wear of the screw thread thickness

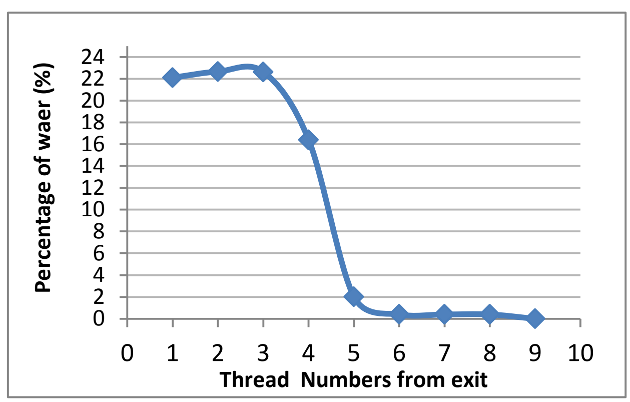

Figure 8: Percentage wear and tear of the screw thread height

Wear and tear of screw height is directly related with position of the thread in the screw. First three four screw height are rapid wear and tear than that of the rest six threads. So the only front threads need the regular maintenance.

From the above graph the wear and tear rate of the initial three threads is more comparative to the rest screw. On the special hardening of the screw by the heat treatment or by using hard material can improve the screw life. High investment is required for the surface hardening and replacing the thread by the harder material. For this process skillful and highly qualified technical worker is required.

Main causes of the wear and tear of the screw are higher silica content in rice husk. Mixing the rice husk with other loose biomass material decrease the percentages of silica content in the loose biomass.

3.3 Variation of the die temperature

Table 2: Die temperature variation

Time at End of (Hrs)	Die Temperature by briquette heating (°C)	Die Temperature by electric heater with controller (°C)
0.5	330	330
1	328	328
1.5	325	327
2	322	328
2.5	325	329
3	322	328
3.5	320	327
4	325	328
4.5	320	329

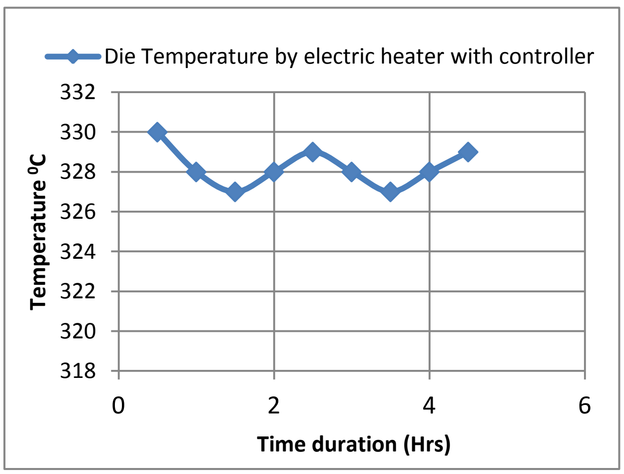

Figure 9: Die Temperature by using electric heater with controller

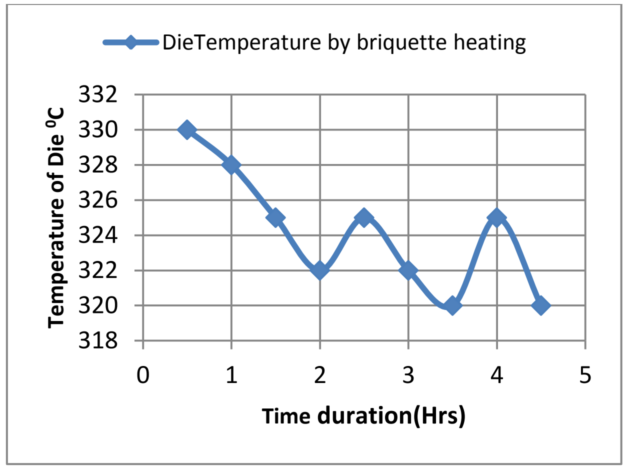

Figure 10: Temperature of die by briquette heating with time period

From the above, in case of the electric die heating system temperature varies from 327 0C to 330 0C . This shows lesser fluctuation in the temperature, which provides the smoother die temperature for the production. Smooth temperature improves the pyrolysis surface of the briquette and improves the quality of the briquette.

In case of the briquette burning die heating system temperature varies from 3200C to 330 0C. This differs on the surface pyrolysis of the briquette and carries on the dissimilarities in the produced product.

3.4 Calculation of heating value

DIN 51900-1 standard test method for solid fuel, liquid fuel and biomass fuel determine the heating value by using Bomb calorimeter.

Bomb Calorimeter is used to determine the heat of combustion of a gas, liquid, or solid. Combustion is an exothermic reaction with oxygen. We prepare the sample in an oxygen-charged bomb and detonate it under water. The change in temperature (ΔT) of the water, combined with the mass of the sample, is used to calculate the heat of combustion in °C/g. For gases and liquids, the units can be converted to heat per volume such as BTU/scf. Different oxygen pressures can be used to simulate combustion under oxygen-poor or oxygen-rich operating conditions. For determining heating value we use a **Parr Oxygen Bomb Chamber and Calorimeter**.

Heating value of the different sample is calculated at the CES laboratory by using the Parr Oxygen bomb calorimeter Model No. 1341. The result is tabulated below table 3.

Table 3: heating Value of briquette at different ratio

SN	Biomass Material	Heating Value (MJ/kg)
1	Pure Sal leaves	20.521
2	RH only by electric heater	15.475
3	SD & RH (1:1)	16.82
4	SD & RH (1:2)	16.48
5	SD & RH (1:3)	15.811
6	RH & Sal Leaves (1:2)	19.511
7	RH & Sal Leaves (1:3)	17.830

4. Financial analysis

For the financial analysis of single unit of the rice husk direct briquetting plant is tabulated below comparing the cost for the production of the briquette by using the electric heater of the 2900 watt and by using briquette for the die heating.

4.1 Net Annual profit on electric die heating system and briquette die heating system

Table 4: Annual cash flow

Items	Die heating by Heater (NRs)	Die heating by briquette (NRs)
Fixed Cost		
Equipment & Machinery (15 years life)	400,000	400,000
Building (25 years life)	300,000	300,000
Annual component of fixed cost	114,810	114,810
Annual Expenses		
Administrative cost	172,000.00	172,000.00
Labour 3 person @ NRs. 8000	252,000.00	252,000.00
a. Electricity lighting		
i. 6 lamp @ 40 W @ 3 Hrs/day (300 working day)	1,360.80	1,360.80
ii. 2 lamp @ 100w @ 3 Hrs (300 working day)	1,134.00	1,134.00
b. Electricity Machinery	0	
i. Motors for feeder 2 @ 2HP (10 % running time)	4,511.81	4,511.81
ii. Motor rice husk Dryer @5 HP (1 Hrs/Day)	7,049.70	7,049.70
iii. Screw driving motor @ 11.125 kW (8 Hrs/Day)	2,6700.00	2,6700.00
iv. Temperature controller (for 3 month) @ NRs 2600	10,400.00	0.00
v. heater @ 2.9 kW and box	3,000.00	500.00
vi. Die Heater @ 2.9 kW (8.333 Hrs/Day)	7,247.10	0.00
vii. Screw Cost (for every 5 hrs maintenance)	120,000	127,200
c. Rice husk 238000 kg @ NRs 5 /Kg.	1,190,839.69	1,071,755.73
d. cost of briquette for die heating	0	1,080,000
Maintenance cost 15 % of machinery cost	60,000	60,000
Revenue from Briquette @ NRs 18 /kg	4,800,000	4,320,000
Net Annual profit	2,828,946.90	1,401,477.97

figure 4 calculation shows that, Net annual profits for the electric heater die heating system plant has NRs. 28, 28,946 and for the briquette die heating plant Net annual profit NRs.14,01,477. On the replacement of the briquette die heating system by the electric die heating system saves the NRs.14,01,477 per year which increase the rate of the return of the investment of the plant.

4.2 Payback period for electric die heating and briquette die heating system

Table 5: Monthly cash flow Electric heater die heating system

	Electric heater die heating system			
Date	Monthly cash out flow (NRs)	Monthly cash flow (NRs)	Net Cash Flow (NRs)	cumulative cash flow (NRs)
1-Jan	700,000	0	-700,000	-700,000
1-Feb	100,000	0	-100,000	-800,000
1-Mar	154,686	450,000	295,314	-504,686
1-Apr	154,686	450,000	295,314	-209,372
1-May	154,686	450,000	295,314	85,942
1-Jun	154,686	450,000	295,314	381,256
1-Jul	154,686	450,000	295,314	676,570
1-Aug	154,686	450,000	295,314	971,884
1-Sep	154,686	450,000	295,314	1,267,198
1-Oct	154,686	450,000	295,314	1,562,512
1-Nov	154,686	450,000	295,314	1,857,826
1-Dec	154,686	450,000	295,314	2,153,140

Table 6: Monthly cash flow briquette heater die heating system

	Briquette die heating system			
Date	Monthly cash out flow (NRs)	Monthly cash flow (NRs)	Net Cash Flow (NRs)	cumulative cash flow (NRs)
1-Jan	700,000	0	-700000	-700,000
1-Feb	100,000	0	-100000	-800,000
1-Mar	243,251	360,000	116,749	-683,251
1-Apr	243,251	360,000	116,749	-566,502
1-May	243,251	360,000	116,749	-449,753
1-Jun	243,251	360,000	116,749	-333,004
1-Jul	243,251	360,000	116,749	-216,255
1-Aug	243,251	360,000	116,749	-99,506
1-Sep	243,251	360,000	116,749	17,243
1-Oct	243,251	360,000	116,749	133,992
1-Nov	243,251	360,000	116,749	250,741
1-Dec	243,251	360,000	116,749	367,490

Simple Payback period = Investment / Annual benefit

From table 5 payback period for the Electric dies heating system type briquette production system has payback period less the 5 months. But in the case of the briquette die heating system has the payback period 9 months.

Monthly rate of return on the investment:

With help of excel sheet the monthly internal rate of return of the electric die heating briquette 16.95% this value is very high internal rate of return. But in case of the briquette die heating system it is only 2.92% which lesser in comparison to the electric die heating system.

Figure 10 shows the power cost for the unit mass production of the briquette. The production cost of the briquette die heating system is more than the electric heater dies heating system.

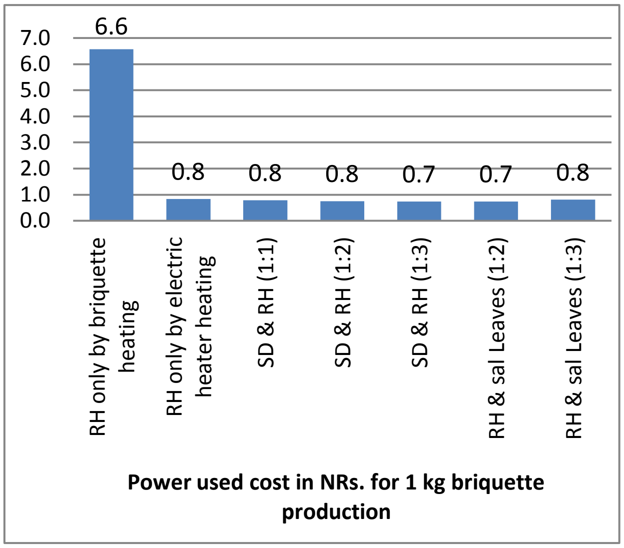

Figure 10: Cost of briquette for unit production

5. Conclusion

Replacing by electric heater die heating system with the temperature controller provides the smoother die heating temperature and improves the surface of produced briquettes. Improved outer surface quality increases the rate of production by reducing the frictional force between briquette and inner die surface.

Die heating by briquetting heating system consumes 125 kg briquette for 8 hours which costs about Rs. 450 per hour. But the electric die heating system consumes 3 kW per hour which cots Rs. 18.90 as per Unit industrial rate of the electricity, which saves NRs. 431.10 per hour. Since the installation cost of the electric heater and temperature controller system is NRs. 6,000 which means instillation cost of new heating system returns within 14 hours of production excluding the fact of increased production rate.

From the proximate analysis of rice husk, Sal leaves and saw dust tested at the laboratory of CEEN, volatile matter and fixed carbon content of saw dust and Sal leaves are relatively higher than rice husk. On mixing them with rice husk improves the heating value of briquette produced which was also verified from test result obtained by using bomb calorimeter at CES..

As a natural resource, rice husk, Sal leaves etc. and saw dust (which will be wasted otherwise) could be sustainably managed and economically exploited --via briquetting – to overcome the rising energy crises in countries like Nepal where such resources are abundantly available and wasted.

On mixing Sal leaves and rice husk in ratio 1:2 screw life increase by 30 minutes and mixing Saw dust and rice husk screw life increase by 20 minutes.

Ignition time of the briquette also improve on mixing the Sal leaves and saw dust with the rice husk due to the higher volatile matter content in Sal leaves and Saw dust.

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