Salesian Journal of Humanities & Social Sciences, Vol. IV, No. 1 (May 2013)
ISSN: 0976-1861 | DOI: 10.51818/SJHSS.04.2013.162-173 | Page No: 162-173 | Section: Article

Biomass Briquetting from the Residues of Tea Pruning

Abstract

The paper discusses about the potential for utilization of waste as obtained from tea industry as a source of energy by converting the loose waste materials into compact briquettes or pellets for better storage and combustion. It also discusses the various technical requirements for the above along with the feasibility analysis, environmental benefits and some options that are applicable for energy utilization in a medium or a large sized tea plantation industry.

Keywords: Biomass, Source of energy, Briquetting, Pelletization, Tea, Waste

Introduction : The Problem

It is nearly 40 years since the first oil shock in 1973. Since then the words 'energy crisis' and 'energy security' continue to dominate the news. Added to these worries now are the issues of climate change. In spite of efforts to promote and develop renewable sources of energy and other new sources, fossil fuels (coal, oil and natural gas) continue to dominate the energy scene. While the need for alternative sources of energy is recognized, no set alternatives have emerged which can take over the role played by fossil fuels. Meanwhile, the price of oil continues to rise ominously and has crossed $ 100 per barrel![1]

There is a classical difference between the conventional, non-conventional and renewable, non-renewable source of energy. The sources of energy which have been in use since long time is classified as conventional though it may be either renewable like hydropower or non-renewable like fossil fuel. However the sources of energy that are relatively new in technology and proper dissemination have not taken place is non-conventional which again is classified as renewable like wind or solar and non-renewable like nuclear.

In the past few years, it has become obvious that fossil fuel resources are fast depleting and that the fossil fuel era is gradually coming to an end. This is particularly true for oil and natural gas. Besides, the combustion of fossil fuels has caused serious air pollution problems in many areas because of the localized release of large amounts of harmful gases into the atmosphere. It is also the main contributor to the phenomenon of global warming which is now a matter of great concern. According to the latest report of the Intergovernmental Panel on Climate Change (IPCC), the atmospheric concentration of carbon dioxide has increased from a pre-industrial era value of about 280 ppm to a value of 398.35 ppm in 2013[2] primarily due to fossil fuel use. This along with increases in the concentration of methane and nitrous oxide has resulted in an increase in the global average temperature. Measurements indicate that the global

[1] P. Suhas, Sukhatme and J . K. Nayak, *Solar Energey - Principles of Thermal Collection and Storage*, Third Edition, New Delhi, Tata Mc Graw-Hill Publication.

[2] As on May 2, 2013 taken from Mauna Loa Observatory, Hawaii.

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average temperature has increased by about 0.8°C over the last 150 years and that it is currently increasing at the alarming rate of 0.2°C per decade. Consequences of these increases are already evident through the increase of the global average sea level and the decrease in the Northern Hemisphere snow cover.

Scope of Biomass as a source of Energy

Plant matter created by the process of photosynthesis is called biomass. Photosynthesis is a naturally occurring process which derives its energy requirement from solar radiation. In its simplest form, the reaction of this process can be represented as follows:

$$H_2O + CO_2 \rightarrow CH_2O + O_2$$

The term 'biomass' includes all plant life - trees, agricultural plants, bush, grass and algae, and their residues after processing. The residues include crop residues (such as oilseed shells, groundnut shells, husk, bagasse, molasses, coconut shells, saw dust, woodchips, etc.).

There are various biomass conversion routes to produce energy efficient biofuels. The conversion routes are broadly divided in 4 categories and are outlined as follows: (i) Physucal: Densification of biomass into solid briquettes. (ii) Agrochemical: Fuel (solid or liquid) extraction from freshly cut plants (iii) Thermo chemical: Combustion, carbonization, pyrolysis, gasification, liquefaction, anaerobic digestion to methane. (iv) Biochemical: Ethanol fermaentation, Hydrogen formation for fuel cell.[3]

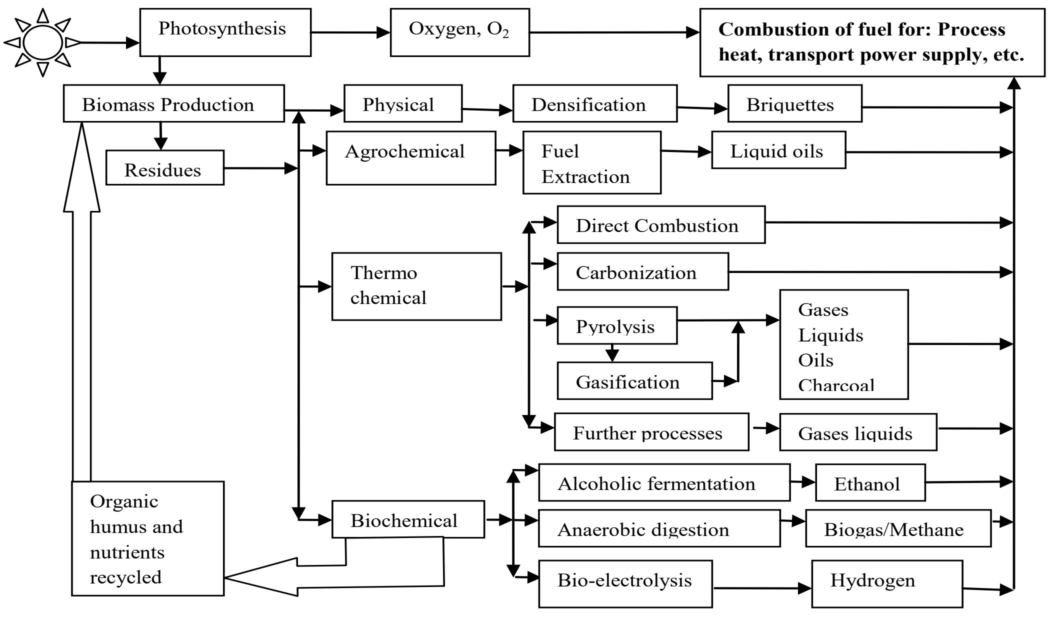

Fig. 1: Biofuels production processes[4]

[3] G. N. Tiwari and M. K. Ghosal, *Renewable Energy Sources*, New Delhi, Narosa Publishing House, 2007.

[4] *Ibid.*

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Physical Method of Bioconversion

The simplest method of physical conversion of biomass is through the compression of combustible material. As bulkiness of the biomass adds to its transportation cost, it is densified by compression through the processes called briquetting and pelletization.

Briquetting

Briquetting is a well known technique. This brought about by compression bailing i.e. by squeezing out moisture and breaking down the elasticity of the wood and bark. If elasticity is not sufficiently removed, the compressed wood tends to regain its pre-densifying volume. Densification is carried out by compression under a die at high temperature and pressure. The phenolic compounds in wood aid in densification by acting as natural glues under conditions of high temperature and pressure. Sometimes waxes (from external sources) are used to bind the wood. Commercially useful briquettes are produced by two types of machines. These are of reciprocating ram type press and screw press. The screw press briquettes are more homogeneous, have better crushing strength and better storage properties with extraordinary combustion properties due to large surface area per unit weight.

Pelletization

Pelletization is process in which wood is compressed and extracted in the forms of rods (5 - 12 mm dia and 12 mm long) facilitating its use in steam power plants and gasification systems. The purpose of pelletization is to reduce the moisture contents and increase the energy density of wood, making it more feasible for longer transportation haulage. Pelletizing reduces the moisture content to about 7 to 10 % and increases the heat values of the biomass. Pellets are more uniform fuel and have better and more efficient combustion characteristic than directly burned chips.

Biomass Briquetting (Refuse Derived Fuel, RDF) & Pelletization

Briquetting and Pelletization are the biomass loose residues/ waste to solid fuel production by compacting it using the mechanical methods. Using raw, unprocessed biomass specially the agricultural residues or MSW (Municipal Solid Waste) as a fuel gives problems due to the heterogeneous nature of the material which varies from suburb to suburb and season to season. It also has a low heat value and high ash and moisture content. This makes it difficult for plant designers and operators to always provide acceptable pollution free levels of combustion. Processing of the biomass/ waste to briquettes/ RDF partially overcomes these problems and the fuel can then be used more successfully in either chain grate water-tube boilers or in circulating fluidized beds. Waste with high organic (carbon) content is suitable for briquetting and pelletizing after non-combustible and recyclable materials have been separated. These processes involve the compaction of the waste at high temperatures and very high pressures. The organic matter is compressed in die to produce briquettes or pellets. It is important to note that using processed waste (where recyclable and non combustible components have been removed), for power generation will dramatically increase the efficiency of the waste to energy process, but at an increased cost due to the increased handling of the product.

Process and Technologies[5]

Densification essentially involves two parts; the compaction under pressure of loose material to reduce its volume and to agglomerate the material so that the product remains in the compressed state. The resulting solid is called a briquette if, roughly, it has a diameter greater than 30 mm. Smaller sizes are normally termed pellets though the distinction is arbitrary. The process of producing pellets is also different from the typical briquetting processes.

The compaction of the material may be changed from low to moderate pressure (0.2 - 5 MPa), to the intra molecular distance of the particles. Increasing the pressure will, at a certain stage particular to each material, collapse the cell walls of the cellulose constituent; thus approaching the physical, or dry mass, density of the material. The pressures required to achieve such high densities are typically 100 MPa plus. This process of compaction is entirely related to the pressure exerted on the material and its physical characteristics.

The ultimate apparent density of a briquette from nearly all materials is to a rough approximation constant; it will normally vary between 1200-1400 kg/m3 for high pressure processes. Lower densities can result from densification in presses using hydraulic pistons or during the start-up period of mechanical piston presses (which can last several minutes) whilst even higher densities are sometimes achieved in pellet presses. The ultimate limit is for most materials between 1450 - 1500 kg/m^3. The relation between compression pressures, briquetting process is given as

- Low pressure up to 5 Mpa with a binder
- Intermediate pressure 5 - 100 Mpa with a heating device
- High pressure above 100 MPa

The lowest bulk densities are around 40 kg/m3 for loose straw and bagasse up to the highest levels of 250 kg/m3 for wood residues. Thus gains in bulk densities of 2 - 10 times can be expected from densification.

Briquetting is the process of densification of biomass to produce homogeneous, uniformly sized solid pieces of high bulk density, which can be conveniently used as a fuel. The densification of the biomass can be achieved by any one of the following methods:

[5] SEES, DAVV, M. Tech (Energy Management) Notes on 'Biomass Conversion Technologies', Indore, 2007 [Hereafter SEES].

1. Pyrolysed densification using a binder;
2. Direct densification of biomass using binders; and
3. Binder less briquetting.

Binder-less technologies and their merits/demerits

Die and punch technology

In the die and punch technology, which is also known as ram and die technology, biomass is punched into a die by a reciprocating ram with a very high pressure thereby compressing the mass to obtain a compacted product. The standard size of the briquette produced using this machine is 60 mm, diameter. The power required by a machine of capacity 700 kg/hr is 25 kW. The ram moves approximately 270 times per minute in this process.

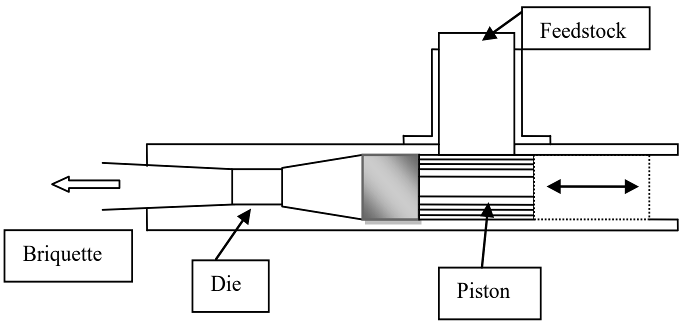

Fig 2.1: Hydraulic or mechanical piston drive[6]

Screw Press technology

In this process, one extrudes the biomass continuously or more screws through a taper die, which is heated externally to reduce the friction. Here also, due to the application of high pressures, the temperature rises fluidizing the lignin present in the biomass, which acts as a binder. The outer surface of the briquettes obtained through this process is carbonized and has a hole in the center, which promotes better combustion. The major parts of the machine are a driving motor, screw, die, die heaters and power transmission system. Pulley and belts were used to transmit power from the motor to the screw. An electrical coil heater is fixed on the outer surface of the die, to heat it to about 300°C. This temperature is required to soften the lignin in the biomass, which acts as a binder. The electrical heater is thermostatically controlled, to maintain the temperature at all times. When the motor is started and raw material is fed to the screw, it gets compressed and extruded through the die.

[6] SEES, *op. cit.*

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The cylindrical die has five grooves lengthwise, on the inner surface, which serves to prevent the densified material from rotating with the screw. The briquettes often get partially pyrolysed at the surface and cause quite a lot of smoking during briquetting. The design of the screw results in the formation of a central circular hole in the briquette; this acts as an escape route for steam formed during briquetting.

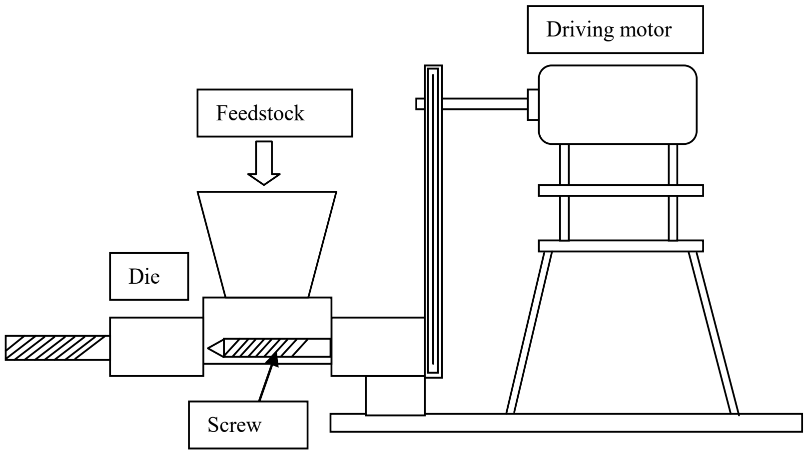

Fig 3: Screw press type briquetting[7]

Hydraulic press based technology

This process consist of first compacting the biomass in the vertical direction and then again in the horizontal direction. The standard briquette weight is 5 kg and its dimensions and 450 mm x 160 mm x 80 mm. The power required is 37 kW for 1800 kg/h of briquetting. This technology can accept raw material with moisture content up to 22%. The process of oil hydraulics allows a speed of 7 cycles/ minute (cpm) against 270 cpm for the die and punch process. The slowness of operation helps to reduce the wear rate of the parts. Further, the relative movement of the material within the die is only for a limited length. The wear and tear of the machine will be lower than those currently available machines in the Indian market.

Comparison of Screw extruder and a piston press[8]

Optimum moisture content of raw material	**Piston Press**	**Screw extruder**
	10-15%	8-9%
Wear of contact parts	Low in case of ram and die	High in case of screw
Output from the machine	In strokes	Continuous
Power consumption	50 kWh / ton	60 kWh / ton

[7] S. C. Bhattacharya, M. Augustus Leon and Md. Mizanur Rahman, "A Study on Improved Biomass Briquetting", Energy Program, School of Environment, Resources and Development, Asian Institute of Technology, Klong Luang, Pathumthani 12120, Thailand.

[8] P. D. Grover & S. K. Mishra, "BIOMASS BRIQUETTING: Technology & Practicing", Food & Agricultural Organisation of United Nations, Bangkok, April 1996 [Hereafter Grover & Mishra].

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Density of briquette	1-1.2 gm/cm^3	1-1.4 gm / cm^3
Maintenance	high	Low
Combustion performance of briquettes	Not so good	Very good
Carbonisation to charcoal	Not possible	Makes good charcoal
Suitability in gasifiers	Not suitable	Suitable
Homogeneity of briquettes	Non-homogeneous	homogeneous

The Tea Industry

Tea is the most important beverage crop of India. It is considered a stimulating yet cheap drink. Tea bush is a tropical and sub-tropical plant. There are mainly three varieties of tea available: (i) Black tea; (ii) Green tea; and (iii) Oolong Tea.

The various processes in the preparation of tea involve:

Harvesting: Plucking of Tea leaves

Pruning of the tea plant is essential because of two reasons:

1. Removal of the central stem encourages the quick development of lateral branches and periodical pruning also does not allow the plant to grow more than about 40 cm. This facilitates hand plucking which is done mostly by women.
2. Pruning also helps in growing new shoots bearing soft leaves in plenty. Tea leaves are ready for plucking in about 3 - 4 years. Tea leaves plucking is a very skilled job and is usually done, by women. A skilled tea plucker can pluck almost 50 kg of leaves/ day. The women work their way along the tea bushes plucking the tender leaves and tossing them in baskets tie at their back.

The finest tea is obtained from the young shoots comprising two leaves and a bud known as fine plucking. Bud is an unopened leaf found between first and second leaf. Plucking should not be done below this standard as it results in obtaining coarse tea. Tea crop is labor intensive requires abundant of supply of cheap and skilled labor.

Process

Processing of black tea involves five operations :

1. Withering: The tea leaves when green contain a lot of moisture. To remove this moisture, the leaves are spread over racks and heated air (generally electrical resistance heaters are used to heat the air, which can be replaced by the briquettes produced) is passed through them. After they become soft they are sent for rolling.
2. Rolling: It gives the twist to the leaf, breaks the leaf cells and the natural juice is exposed to the atmosphere for fermentation to set in. This is an energy intensive process, which uses electrical energy to run the motors.

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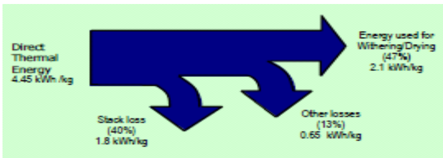
3. Fermentation: After rolling, the tea leaves are spread out in special trays on cement tables for fermentation. During this process, the tannin in tea is partly oxidized and the tea leaf changes its color to copper red.
4. Drying or Fixing: After fermentation, the leaves are put on a conveyor belt and are passed through an oven at a very high temperature. The heating requirement over here is generally done by coal or electrical resistance heating, which could be replaced by the briquettes.
5. Sorting: After drying, the leaves are sorted out in various grades.

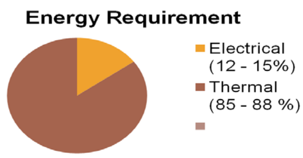
Energy Consumption in a Tea Industry[9]

The tea industry is one of the energy intensive food-processing sectors consuming both electrical and thermal energy. About 85 - 88% of the total energy requirement is in the form of thermal energy and the rest is electrical energy. The electrical energy is used to run the machineries and the thermal energy is used to reduce the moisture content of the leaves from 70-80% down to 3%. Most of the thermal energy requirement is derived from firewood, lignite, coal and fuel oil and ultimately they contribute to direct emission of carbon dioxide (CO2). For example on average, about 7.1 kWh of energy is required to produce one kilogram of black tea in Sri Lanka[10] which more or less is equivalent to the energy requirement of steel production.

The fermented tea particles are dried or fired to arrest the fermentation and also to reduce the moisture to about 3%. Clean and odorless hot air is passed through the fermented tea particles in dryers. The temperature of the hot air varies between 90-160°C depending on the type of dryer. Drying or firing is a thermal energy intensive operation that also consumes electrical energy to drive blowers and dryers.



Typical energy flow for the withering and drying processes in tea production



Waste Products (to energy)

Pruning of the tea bushes is done during the month of November and December for the growth of the new tea leaves. The pruned material from the tea bushes contains mainly the leaf, twig of the tea branches. Depending upon the condition of the bushes in a block, the following three types of pruning is done:

9 School of Energy, Resource and Development, "Small & Medium Scale Industries in Asia: The Tea Sector", Thailand, Asian Institute of Technology.

10 Sri Lanka Sector Report, Haskoning, 1989.

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1. Light Pruning: 2, 4 and 6 feet from the upper layer of the ground.
2. Middle Pruning: 2 feet from the upper layer of the ground.
3. Deep pruning 1 - 1½ foot from the upper layer of the ground.

These pruned materials usually remain scattered in the garden, which can be converted into the densified briquettes for better storage and combustion using suitable briquetting techniques.

The following processes are involved in the briquetting/ pressing:

- After the raw pruned tea stalks are passed through a vibratory screen it is grounded using a grinder or a hammer mill, to a size of 6 - 8 mm so that the densification occurs better.

This is followed by preheating the biomass feed up to a temperature of about 100^{oC} (higher may cause burning of the biomass) using a thermic fluid heater which results in relaxing the inherent fibers in the biomass and apparently softening its structure resulting in release of some bonding or gluing agent (usually the lignin) on to the surface and reduces the pressure required for briquetting, resulting in reduced power consumption;

- Pressure is then applied to the briquetting material in the briquetting press;
- Temperature goes up because of the friction between the particles of briquetting materials and the friction between the press and the briquetting material;
- As a result of the high temperature and pressure during the process, the wooden plants cellular structure breaks;
- Because of the heat the lignin contained in the material softens and glues the particles of the material together.[11]
- The finished briquette is than cooled and stored or packaged for further use.

Table 3.1: Proximate/ Ultimate Analysis of some waste biomass found in the Hills of Darjeeling

Sl. No.	*Name of the Biomass*	*Moisture content (%)*	*Ash content (%)*	*Volatile Matter Content (%)*	*Fixed Carbon content (%)*	*Carbon (%)*	*Hydrogen (%)*	*Oxygen (%)*	*Calorific value in Kcal/kg*
1.	Banmara	9.56	1.99	80.79	17.22	47.73	5.9	43.69	4511
2.	Titepati (Mugwort)	6.82	2.11	72.01	16.32	43.16	5.31	39.24	4100
3.	Tea Prunings		5.19	60.27	27.72	48.4	5.56	39.83	4200

[11] Jüri Olt, Mihkel Laur, "Briquetting different kinds of herbaceous biomaterial", *Jelgava*, 28-29 May 2009, Estonian University of Life Sciences, Kreutzwaldi [Hereafter Olt & Laur].

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Cost & Benefit Analysis[12] for a typical Briquetting Plant Setup

Sl. No.	Equipment	Number	Motor Power rating (hp)	Cost (Rs. in Lacs)
1.	Screw Feeder	1 (one)	2	0.50
2.	Hammer Mill	1 (one)	50	1.50
3.	Dryer	1 (one)	15	2.00
4.	Silo with feeder	1 (one)	2	2.00
5.	Main Screw Conveyor	1 (one)	3	1.00
6.	Return Feeder	1 (one)	2	1.00
7.	Preheater	1 (one)	3	1.00
8.	Machines with heaters	1 (one)	52	10.00
9.	Cooling conveyor	1 (one)	3	2.00
10.	Furnace	1 (one)		1.50
11.	Fluid system	1 (one)	5	1.50
12.	Fume exhaust	1 (one)	2	0.50
13.	Auxillaries			0.50
	TOTAL	**15**	**200**	**25.00**

Average Production:

Size of the tea garden:	500.00 acres
No. Of Tea Bushes: (2023450 m2/] $3m^2$/bush)	670000
Average amount of waste from medium prunning:	2 kg per mature bush
Total amount of waste generated (taking 300000 mature bushes):	600000 kg per annum = 600 tonnes per annum
Amount of briquette produced (considering 10% loss of moisture)	540 tonnes per annum
Total heat value in the waste material: (GCV x total waste):	2.3 x 109 kCal per year
GCV of Indian Coal:	5000 kCal/kg
Equivalent amount of Coal	
Saved per year:	453.6 tonnes (appx)
Energy required for Production of briquettes:	
(a) Electrical Energy (@ 50 kWh per tonne):	30000 kWh
Cost of Electricity per year (@ Rs 10/kWh):	Rs 300000
(b) Thermal Energy (@ 20 kCal per kCal tonne): 20 x 4200 x 600	= 5.04 x 107 kCal = 10.1 tonnes of coal (12 tonnes of briquettes)

[12] Grover & Mishra, *op. cit.*

If the thermal energy required for drying and preheating the biomass feed is provided by the final products itself (briquettes), amount of briquette left (540 - 12) = 528 tonnes annually.

Now if the thermal energy requirement in the industry for drying, withering, etc is provided by the final products, considering

Average yield of tea per acre: 200 kg

Average annual production (taking 350 acres of productive area): 70000 kgs

The drying process has a specific thermal energy consumption of about 3.24-5.00 kWh/kg of made tea. It is about 75-85% of the thermal energy requirement and about 50-75% of total energy consumed, depending of the type of tea produced.

Total thermal energy required for drying + other purpose (@ 5.3 kWh/kg):
= 371000 kWh

= 3.18 x 108 kCal per year

= 64 tonnes of coal (75.7 tns of briquettes)

(Assuming Combustion efficiency of 60% for drying) = 106 tns (126.2 tns briquettes)

Average Cost of Indian Coal: = Rs 3000 per tonne

Cost of Coal saved for drying purpose: = Rs. 318000

Simple Pay Back:
(Initial Investment + Electrical cost for briquette prodution/ yearly savings)

= (2500000 + 300000) / 318000 = 8.8 yrs

The above simple pay back obtained using the cost of coal saved for drying and withering reflect the proposed project unsuitable. However, if the remaining briquettes (total briquette produced - briquettes used for drying up of biomass feed - briquettes used for thermal energy requirement in the factory) is sold at a nominal value of Rs 2 per kg then the earnings in selling (540 - 12 - 126.2) = 400 tonnes(appx) of briquettes:
= Rs 8 Lacs

Yearly Benefits (Cost of Coal saved + selling of briquette) = Rs 11.18 Lacs

Simple Pay Back: (Total Cost/ yearly savings) (2500000 + 300000) / 1118000

= 2.5yrs

= 2 yrs 6 months

Also, the utilisation of biomass as fuel is considered as a eco friendly technology, since the amount of CO2 emitted during the combustion of biomass is again taken up by the crops that grow in the next season. Thus,

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Total Amount of Coal replaced: = 453.6 tonnes per year

CO2 saved: 1663.2 tonnes per year

Carbon Credits earned: (5 euros = @ Rs 400 per tonne of CO2 reduction):

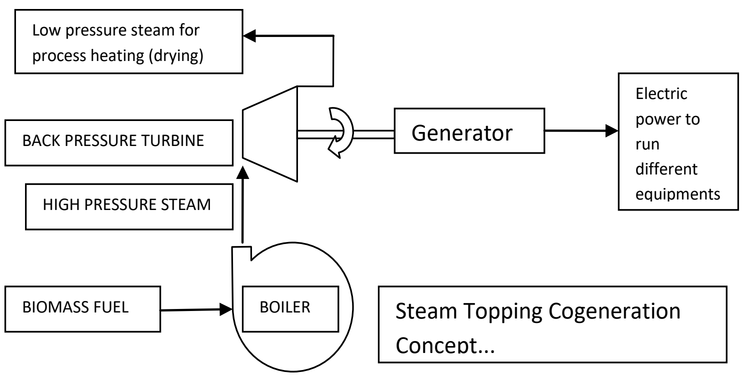
= Rs 665000/- per year

Conclusion: The benefits

As the material dries during briquetting, the energetic value of the fuel produced by briquetting increases. Pressed fuels of herbaceous origin have the following advantages over the unprocessed herbaceous material:

- Because of low humidity and high calorific value the pressed herbaceous material is cheaper to transport and store;
- Dry fuel will not decompose biologically because of fungus and microorganisms, and can therefore be preserved for a longer time;
- Equable moisture and size of the piece allow regulating the burning regime more precisely and thus ensuring higher efficiency.[13]

The same briquettes or pellets could be used during the tea processing to produce hot air to dry out the freshly plucked leaves, which could reduce the otherwise conventionally used coal or electricity thereby reducing the energy cost for production. In addition to the above, this would also reduce the dependence on the scarce fossil fuel and thereby decrease the CO2 emission (since biomass being renewable, the CO2 emitted during its combustion would account for the growth of next generation crops) and a possible claim for carbon credits.



Since, tea industry requires both mechanical power for driving equipments like motors, fans, conveyors, etc as well as thermal heating for drying and withering process, cogeneration (derivation of mechanical power and thermal power) from the same fuel (finished biomass) with a steam topping cycle could also be a very positive concept.

13 Olt & Laur, *op. cit.*