A TECHNO-ECONOMIC EVALUATION OF BIOMASS BRIQUETTING IN INDIA

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Abstract—A financial analysis of biomass briquetting technology in India has been undertaken. Simple cost functions for briquetting machines have been developed. Unit cost of briquette production for various types of raw materials and different capacities of briquetting units have been calculated. Role of different factors affecting the cost of production of briquettes have also been analysed.

Keywords—Biomass; briquetting machines; financial analysis; agricultural residues.

1. INTRODUCTION

In India about 46% of total energy consumption is estimated to be met from various biomass resources, i.e. agricultural residues, animal dung, forest waste, firewood, etc.[1] India produces a huge quantity of agricultural residues and a major part of it is consumed in traditional uses (such as fodder for cattle, domestic fuel for cooking, construction material for rural housing, industrial fuel for boilers, etc). The direct burning of agricultural residues in domestic as well as industrial applications is very inefficient. Moreover, transportation, storage and handling problems are also associated with its use. One of the approaches that is being actively pursued worldwide towards improved and efficient utilisation of agricultural and other biomass residues is their densification in order to produce pellets or briquettes. The briquetting of biomass improves its handling characteristics, increases the volumetric calorific value, reduces transportation costs and makes it available for a variety of applications.[2]

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

In the present paper an attempt has been made to analyse the role of various factors affecting the unit cost of production of biomass briquettes in India. A simple framework for estimating the unit cost of the production of briquettes has been developed and results of some calculations are briefly presented and discussed.

2. RAW MATERIALS FOR BRIQUETTING

Essentially all agricultural residues, woody biomass, sawdust from timber mills, etc. can be briquetted. Agricultural residues which do not pose collection and drying problems are also suitable for briquetting.[2] The factors that mainly influence the selection of raw materials are moisture content, ash content, flow characteristics and particle size. Moisture content in the range 10–15% is preferred because grinding of high moisture content materials is problematic, and more energy is required for drying. The ash content of biomass affects its slagging behaviour togehter with the operating temperature and mineral composition of ash. Biomass feedstock having up to 4% of ash content are preferred for briquetting. The granular (preferably 6–8 mm in size) homogeneous materials which can flow easily in conveyors, bunkers and storage silos, are suitable for briquetting.[2]

Commonly used raw materials for briquetting in India include sawdust, groundnut shells, cotton stalks, maize stalks, rice husks, tamarind shells, coir pith, coffee husks, mustard stalks, sunflower stalks, bagasse, wood chips and forest residues. A combination of raw materials can also be used. The raw materials suitable for briquetting can be broadly divided into three categories: (i) fine granulated; (ii) coarse granulated; and (iii) stalky. In each of these categories it is possible to make use of both dry and wet raw materials. Another classification stems from the fact that besides raw biomass, briquettes of pyrolysed biomass are also made. Finally, briquettes can also be categorised on the basis of whether or not a binding material is used in briquetting. Briquetting of raw biomass without binder is more commonly practised in India.

3. BRIQUETTING TECHNOLOGIES

The briquetting technologies used for biomass without binder include briquetting machines based on screw- and piston-press technology. In screw-press technology the biomass is extruded continuously by a screw through a taper die, which is heated externally to reduce friction. The outer surface of briquettes obtained through this technology is carbonised and has a hole in the centre. With piston-press technology biomass is punched into a die by a reciprocating ram by high pressure. The briquettes obtained through this technology have neither the central hole nor carbonised outer layer. In both the piston- and screw-press technologies the application of high pressure increases the temperature of the biomass, and lignin present in the biomass is fluidised and acts as binder. In the present work attention has been focused on piston-press technology, which is commercially available in India.

4. BRIQUETTING PROCESS

The briquetting process (Fig. 1) primarily involves drying, grinding, sieving, compacting and cooling operations. Any moisture in the raw material is first removed in a dryer, and the dried material is ground in a hammer-mill grinder. The ground material is then passed through a screen for sieving and thereafter stored in a bin placed over the briquetting press to ensure a regular flow of materials into the press. The ram in the press continuously packs the material through a taper die and the briquettes are produced.

5. BRIQUETTING PLANT AND MACHINERY

The configuration of various equipment and machinery required in a briquetting process depend largely on the type of raw materials used for briquetting. For example, a dryer will be required for raw materials with high moisture content and for coarse and stalky materials a grinding unit will be necessary. The stalky materials also require a cutting/clipping

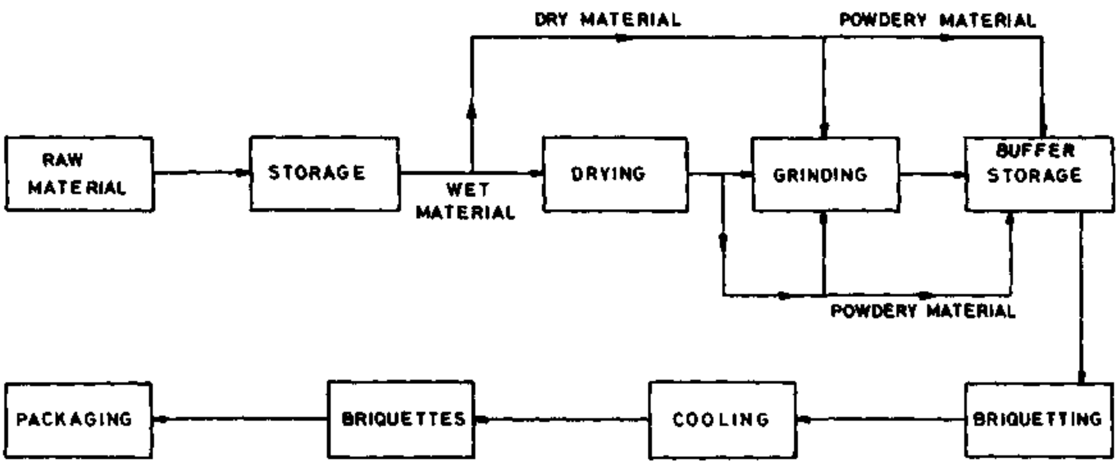

Fig. 1. Flow diagram of briquette production process.

Table 1. Equipment matrix of briquetting units for six categories of raw materials

Components	Fine granulated material		Coarse granulated material		Stalky material	
	Dry	Wet	Dry	Wet	Dry	Wet
Cutter clipper	—	—	—	—	—	+
Turbo dryer	—	+	—	+	—	+
Hammer-mill grinder	—	—	+	+	+	+
Material handling equipment	—	—	+	+	+	+
Inclined screw feeder	+	+	+	+	+	+
Briquetting press	+	+	+	+	+	+

Note: +: used; — not used.

mechanism and so on. Based on the three categories of raw materials, i.e. fine granulated, coarse and stalky the equipment matrix for different possible combinations of briquetting machines is presented in Table 1.

The components of a typical briquetting unit can be divided into three groups: (a) pre-processing equipment; (b) material-handling equipment; and (c) briquetting press. Pre-processing equipment includes cutter/clipper drying equipment (flash dryer, hot-air generator, pneumatic fans, cyclone seperator and drying column) and hammer-mill grinder. Material handling equipments are screw conveyors, pneumatic conveying system and holding bin. A briquetting press is the main machine used in briquette production. A schematic diagram of the plant and machinery set-up of a briquetting unit is shown in Fig. 2, and typical costs (for 1996) of the equipment suitable for various sizes of briquetting units are given in Table 2.

6. FINANCIAL ANALYSIS

6.1. *Capital cost*

The capital cost of a biomass briquetting unit essentially comprises the costs of pre-processing equipment, material-handling equipment and the briquetting press depending on the type of raw material. In the present analysis attention is focused only on the plant and machinery costs, although the cost of land and building should also be included in the total cost of a briquetting unit.

Table 3 presents the estimates of total capital cost of briquetting units of various production capacities for three different categories of raw materials, i.e. fine granulated, coarse granulated and stalky, for both dry and wet raw material conditions. The cost-related data have been provided by M/s Solar Sciences Consultancy (P) Ltd., New Delhi, a leading manufacturer of biomass briquetting machines in India. M/s Solar Sciences manufacturers the

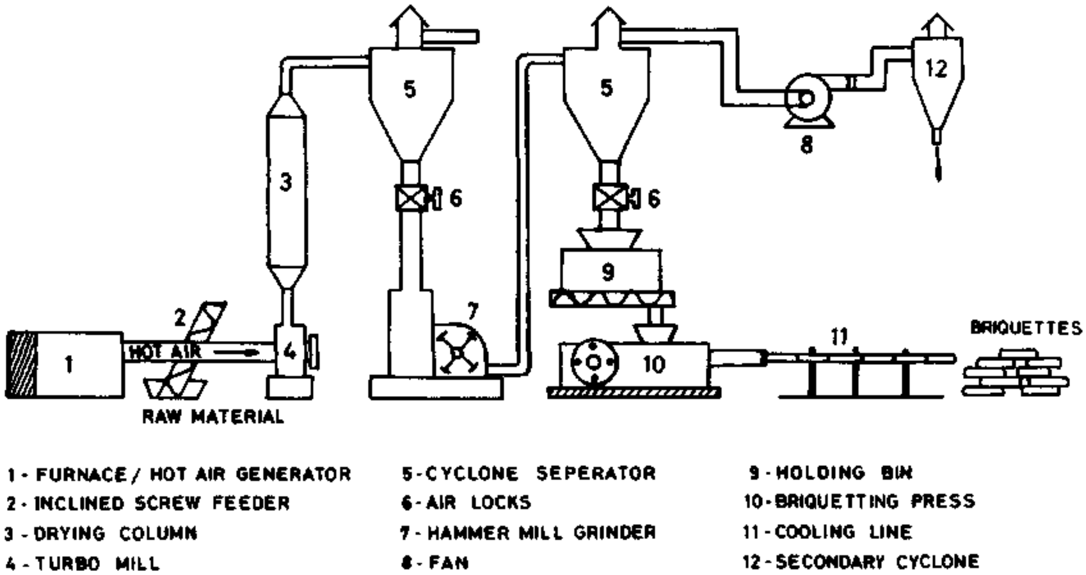

Fig. 2. Schematic diagram of the plant and machinery set up of a briquetting unit.

Table 2. Cost of various equipment in a briquetting unit

Components	Cost of components (Rs)Briquette production capacity (kg/hr)					
	250	500	750	1000	1500	2250
Cutter cliper	82 500	45 000	148 500	148 500	148 500	1,48,500
Turbo dryer	255 000	255 000	255 000	385 000	385 000	3,85,000
Hammer-mill grinder	109 000	109 000	120 000	142 000	198 000	1,98,000
Material handling equipment	150 000	150 000	150 000	208 000	208 000	2,08,000
Inclined-screw feeder	25 000	82 500	45 000	90 000	90 000	1,35,000
Biquetting press	315 000	525 000	750 000	1 050 000	1 500 000	2 250 000

US$1 = 36.00 Indian Rs in April 1997.

modules of briquetting presses for briquette production capacities of 250, 500 and 750 kg/hr. Combinations of one or more of these briquetting presses are used for higher capacities (up to 2250 kg/hr). However, other equipment (i.e. cutting, drying, grinding, etc.) are available in several capacity ranges. The component cost break-up of briquetting units (as a percentage of total capital cost) for different raw materials is given in Tables 4–6.

The economy of scale in the capital cost of briquetting units of the production capacity range 250–2250 kg/hr may be noted from Fig. 3. A cost function of the following form has been attempted to represent the total capital cost of briquetting units:

$$C = \alpha K^{\beta} + \gamma \quad (1)$$

where C represents the capital cost and K the briquette production capacity in kg/hr. α, β and γ are coefficients obtained through regression. Six cost functions have been obtained for six different types of raw materials (Table 7).The annualised capital cost A_{cc} can be calculated as:

$$A_{cc} = (\alpha K^{\beta} + \gamma)^{*}CRF \quad (2)$$

where CRF is the capital recovery factor defined as:

$$CRF = d(1+d)^{t}/\{(1+d)^{t}-1\} \quad (3)$$

with d representing the discount rate, and t, the useful lifetime of the briquetting unit.

6.2. *Installation cost*

The various equipment employed in a briquetting unit is erected on the site itself for which a fixed cost may sometimes be charged by the equipment supplier. The costs given in Tables 2 and 3 do not include the erection and commissioning costs, which range from Rs35 000 to 70 000 depending on the production capacity of the unit.

6.3. *Operating costs*

The operating costs of the briquetting unit include the cost of various inputs viz. raw biomass material, oil and lubricants and electricity as well as the cost of manpower required to operate the unit. The cost of biomass also includes the transportation cost. The daily operation of the unit includes jobs relating to preparation of raw materials, such as through cutting (for stalky materials only), drying, sieving and grinding operations. Manpower is required mainly at the sieving unit, dryer, hammer-mill grinder, material-handling system and inclined-screw feeder, etc. depending on the raw material type and the configuration of the unit.

Other routine jobs prior to starting the unit include checking of oil temperature and pressure in the briquetting press, monitoring of

Table 3. Capital cost of briquetting units for various briquette production capacities and different raw materials

Briquette production capacity (kg/hr)	Capital cost of briquetting units (Rs)					
	Fine granulated material		Coarse granulated material		Stalky material	
	Dry	Wet	Dry	Wet	Dry	Wet
250	340 000	595 000	599 000	854 000	681 500	936 500
500	570 000	825 000	829 000	1 084 000	911 500	1 166 500
750	795 000	1 050 000	1 065 000	1 320 000	1 213 500	1 468 900
1000	1 140 000	1 525 000	1 490 000	1 875 000	1 638 000	2 023 000
1500	1 590 000	1 975 000	1 996 000	2 381 000	2 144 500	2 929 000
2250	238 5000	2 770 000	2 791 000	3 176 000	2 939 000	3 324 000

US$1 = 36.00 Indian Rs at April 1997.

Table 4. Component cost break-up of briquetting units, for dry and wet fine granulated raw materials

	Cost break-up as % of total cost for fine granulated material Briquette production capacity (kg/hr)											
	250		500		750		1000		1500		2250	
Components	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Cutter clipper	—	—	—	—	—	—	—	—	—	—	—	
Turbo dryer	—	42.9	—	30.9	—	24.3	—	25.3	—	19.5	—	13.9
Hammer-mill grinder	—	—	—	—	—	—	—	—	—	—	—	—
Material handling equipment	—	—	—	—	—	—	—	—	—	—	—	—
Inclined-screw feeder	7.4	4.2	7.9	5.5	5.7	4.3	7.9	5.9	5.6	4.8	5.7	4.9
Briquetting press	92.6	52.9	92.1	63.6	94.3	71.4	92.1	68.8	94.4	75.9	94.3	81.2

Table 5. Component cost break-up of briquetting units for dry and wet, coarse granulated raw materials

	Cost break-up as % of total cost for coarse granulated material Briquette production capacity (kg/hr)											
	250		500		750		1000		1500		2250	
Components	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Cutter clipper	—	—	—	—	—	—	—	—	—	—	—	—
Turbo dryer	—	29.8	—	23.5	—	19.3	—	20.5	—	16.2	—	12.1
Hammer-mill grinder	18.2	12.8	13.2	10.1	11.3	9.1	9.5	7.6	9.9	8.3	7.1	6.2
Material handling equipment	25.0	17.6	18.1	13.8	14.1	11.4	14.0	11.1	10.4	8.7	7.5	6.6
Inclined-screw feeder	4.2	2.9	5.4	4.2	4.2	3.4	6.1	4.8	4.5	3.8	4.8	4.3
Briquetting press	52.6	36.9	63.3	48.4	70.4	56.8	70.4	56.0	75.2	63.0	80.6	70.8

Table 6. Component cost break-up of briquetting units for dry and wet, stalky raw materials

	Cost break-up as % of total cost for stalky material Briquette production cpacity (kg/hr)											
	250		500		750		1000		1500		2250	
Components	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Cutter clipper	12.1	8.8	9.1	7.1	12.2	10.1	9.0	7.3	6.9	5.9	5.0	4.5
Turbo dryer	—	27.2	—	21.9	—	17.4	—	19.0	—	15.2	—	11.6
Hammer-mill grinder	16.0	11.6	12.0	9.3	9.9	8.2	8.7	7.0	9.2	7.8	6.7	5.9
Material handling equipment	22.0	16.1	16.5	12.9	12.4	10.2	12.7	10.3	9.7	8.2	7.1	6.2
Inclined-screw feeder	3.7	2.7	4.9	3.8	3.7	3.1	5.5	4.5	4.2	3.6	4.6	4.1
Briquetting press	46.2	33.6	57.5	45.0	61.8	51.0	64.1	51.9	69.9	59.3	76.6	67.7

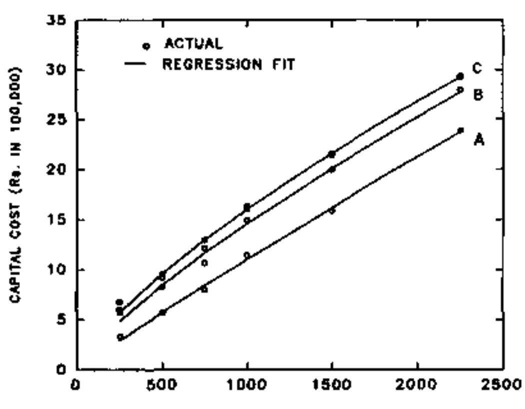

Fig. 3. Capital costs of briquetting units. (A) Fine granulated material (dry), (B) coarse granulated material (dry), (C) stalky material (dry).

temperatures of die holder and water coming out of the die holder, dryer temperature, etc. The manpower requirement for the operation of briquetting units is worked out on the basis of detailed discussions with M/s Solar Sciences Pvt. Ltd., and is given in Table 8. The annual operation cost, A_{cc} of the briquetting unit can thus be calculated as;

$$A_{oc} = 8760*\mathrm{CUF}(C_l m + C_b r_b K + C_e P_w) \quad (4)$$

where CUF represents the capacity utilisation factor of the briquetting unit, C_l the cost of manpower required, m the number of workers hired, C_b the cost of raw material, r_b the correction factor for estimating the requirement of raw material from the production capacity of briquetting unit (to account for the moist-

Table 7. Regression coefficients for the cost functions

Raw materials	Regression coefficients α	β	γ	Maximum r.m.s. error (%)
Fine granulated (dry)	1257	0.97	41 232	7.3
Fine granulated (wet)	1761	0.94	240 834	8.9
Coarse granulated (dry)	1407	0.97	267 487	7.1
Coarse granulated (wet)	2405	0.91	430 540	9.4
Stalky (dry)	2588	0.90	271 544	5.8
Stalky (wet)	4411	0.84	414 649	7.5

ure loss during drying and briquette production), K the rated production capacity of the briquetting unit, C_e the unit cost of electricity, and P_w the net power requirement of the unit. Estimated power requirements, P_w, for six different briquetting units is given in Table 9.

6.4. *Repair and maintenance costs*

Briquetting units require appropriate maintenance on daily, weekly, monthly and six-monthly basis. Briquetting press requires daily maintenance which includes removal of accumulated dirt from the bottom chamber of the tank, checking of oil level in the press and cleaning of sieves. Weekly maintenance of the press requires cleaning of oil filter, replacement of filter cartridge (if necessary), making oil up to the required level, cleaning air filter, checking ram seal, cleaning die holder cooling circuit and tightening all screws and nuts. Maintenance of vertical screw gearbox and change of oil is necessary at 6-month intervals. The regular maintenance of all other moving parts of the equipment, motors, belts, etc. (as per manufacturer's instructions) is also necessary.

The major wearing parts of a briquetting unit are hammer-mill screen, ram, scrapper ring, wear ring, tapper die and spilt die. Occasional wearing of screws, cutter, belts and bushes has also been observed. Besides these the periodic change of gear oil and lubricating oil is also required. The average working life and unit cost of major wearing parts based on the available data and discussions with plant users and manufacturer is given in Table 10. The annual replacement cost of major wearing parts including lubricating oil and gear oil can be worked out as sum of the product of the cost of each part and corresponding annual frequency of replacement. Besides replacement of these major parts, the cost for routine maintenance (bushes, belts, hose pipes, nut-bolts, washers, etc.) of the entire briquetting unit has been taken as 2% of its capital cost.

Table 8. Manpower requirement in operation of briquetting units

Briquette production capacity (kg/hr)	Manpower requirement (number): Fine granulated material, Dry	Fine granulated material, Wet	Coarse granulated material, Dry	Coarse granulated material, Wet	Stalky material, Dry	Stalky material, Wet
250	3	4	4	5	5	5
500	3	4	4	5	5	5
750	3	4	4	5	5	5
1000	5	5	5	6	6	6
1500	5	5	5	6	6	6
2250	7	7	7	8	8	8

Table 9. Power requirement of briquetting units

Briquette production capacity (kg/hr)	Power requirement (kW): Fine granulated material, Dry	Fine granulated material, Wet	Coarse granulated material, Dry	Coarse granulated material, Wet	Stalky material, Dry	Stalky material, Wet
250	17.5	26.5	36.0	45.0	43.5	52.5
500	25.0	34.0	43.5	52.5	51.0	60.0
750	32.5	41.5	58.5	67.5	73.5	82.5
1000	50.5	65.5	101.0	116.0	116.0	131.0
1500	65.5	80.5	108.5	123.5	123.5	138.5
2250	98.0	113.0	141.0	156.0	156.0	171.0

Table 10. Average working life and component replacement cost of briquetting units

No. (i)	Component/ material	Frequency of replacement F_i (hr)	Cost of replacement of components in Rs (C_i) Briquettes production capacity (kg/hr) 250	500	750	1000	1500	2250
1	Gear oil	5000	3000	3000	3000	6000	6000	9000
2	Lubricating oil	1000	1875	2250	3000	4500	6000	9000
3	Hammers	500	500	750	1000	1500	2000	3000
4	Mill screen	800	400	400	400	800	800	800
5	Ram	300	700	1400	1500	2800	3000	4500
6	Scrapper ring	300	250	300	400	600	800	1200
7	Wear ring	300	100	300	300	600	600	900
8	Taper die	500	800	1250	1750	2500	3500	5250
9	Split die	500	600	1000	1250	2000	2500	3750

The annualised repair and maintenance cost, A_{rm} can, therefore, be expressed as:

$$A_{rm} = \sum_{i=1}^{9} [8760*\text{CUF}*C_i/F_i] + 0\cdot02(\alpha K^{\beta} + \gamma) \quad (5)$$

where i (varying from 1 to 9) refers to different components as explained in Table 10, F_i represents the frequency of replacement of ith part and C_i its cost of replacement.

The total annualised cost would comprise the annualised capital cost, A_{cc}, annual operation costs, A_{oc}, and annual repair and maintenance cost, A_{rm}. Thus:

$$U_{BP} = [A_{cc} + A_{0c} + A_{rm}]/A_{BP} \quad (7)$$

Substituting the expressions for A_{cc}, A_{oc}, A_{rm} and A_{BP} (eqns 2, 4–6) in eq. (7), the following expression is obtained for the unit cost of briquettes:

$$U_{BP} = \frac{(\alpha K^{\beta} + \gamma)(CRF + 0\cdot02) + 8760*\text{CUF}[C_l m + C_b r_b K + C_e P_w + \sum_{i=1}^{9} C_i/F_i]}{8760*\text{CUF}*K} \quad (8)$$

7. UNIT COST OF BRIQUETTE PRODUCTION

The unit cost of briquette production, U_{BP}, can be obtained as the ratio of the total annualised cost of the briquetting unit to the annual production of briquettes. The annual production of briquettes A_{BP} can be expressed as:

$$A_{BP} = 8760*\text{CUF}*K \quad (6)$$

8. KEY ASSUMPTIONS AND INPUT PARAMETERS

The assumptions made in the present analysis regarding the base values of various input parameters used in eqns (1)–(8) are presented in Table 11. Although the useful lifetime of different components in a briquetting unit may be somewhat different from each other, in the present analysis these have been assumed to be the same. The installation

Table 11. Base values of input parameters used in calculation of unit cost of briquette production

Input parameters	Symbol	Unit	Value
Discount rate	d	%	12
Capacity utilisation factor	CUF	%	60
Useful life of briquetting unit	t	Year	10
Raw material correction factor (wet)	r_b	—	1.10
Raw material correction factor (dry)	r_b	—	1.05
Cost of raw materials	C_b	Rs/t	500
Cost of manpower	l	Rs/man-hr	8.00
Cost of lubricating oil	—	Rs/l	75
Cost of gear oil	—	Rs/l	100
Cost of electricity	C_e	Rs/kWh	2.25
Repair and maintenance cost as fraction of briquetting unit cost	R_m	—	0.02

charges also have not been included in the present analysis.

Though the cost of raw materials used for briquettes production may vary, an average base value cost of raw materials has been taken as Rs 500/t.

9. RESULTS AND DISCUSSION

The simple framework presented in this paper for financial evaluation of biomass briquetting units is quite general and may be used to determine the unit cost of briquette production for almost all design variations of briquetting machines commercially available in India. However, to exemplify the procedure for calculating the unit cost of briquettes, the typical values as provided by M/s Solar Sciences Pte Ltd., New Delhi (who are currently the largest manufacturer of piston-press type briquetting machines in India) have been used in the present work.

It is worth mentioning that briquetting technology in India has not yet reached maturity and there is considerable scope for design improvements, leading to increased reliability and reduced costs. Moreover, the number and scale of operation of the suppliers of the briquetting machines is rather too small to offer competitive prices. Therefore, the cost figures presented in this work should be considered merely as indications of the emerging trend in briquetting technology in India.

Figure 3 shows a comparison of actual values of capital cost of briquetting units of different daily briquette production capacities with those obtained from the regression expressions. The economy of scale in the capital cost noted in this figure can be seen explicitly in Fig. 4. For the 1000 kg/hr production capacity unit a little deviation from the economy of scale is observed because from 1000 kg/hr capacity onwards the capital costs have been arrived at for a combination of two or more briquetting presses, along with a suitable and corresponding capacity enhancement in the other equipment.

As mentioned earlier the unit cost of briquettes depends on a variety of factors, including the type and cost of raw materials, the production capacity of briquetting unit, its capacity utilisation, repair and maintenance costs, useful life of the unit, manpower costs and unit cost of electricity, etc. besides the discount rate used in the financial evaluation.

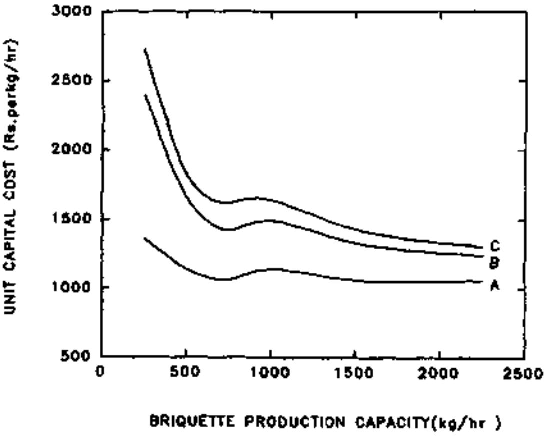

Fig. 4. Unit capital costs of briquetting units. (A) Fine granulated material (dry), (B) coarse granulated material (dry), (C) stalky material (dry).

Results of some typical numerical calculations are shown in Fig. 5 for dry raw materials. As expected the costs are minimum for dry, fine granulated raw materials. Moreover, the use of higher production capacity units leads to considerable reduction in the cost of production of briquettes.

Figure 6 shows a break-up of the cost of production of briquettes to facilitate a comparison of the relative contribution of different factors to the unit cost of briquettes. It may be noted that for a 250 kg/hr briquetting unit, the cost of raw materials accounts for about 41% of the total cost of briquettes, whereas for a 2250 kg/hr unit it accounts for about 67%. The cost of electricity is the second most important input followed by the operation, repair and maintenance costs and the contribution of capital cost. For briquetting units

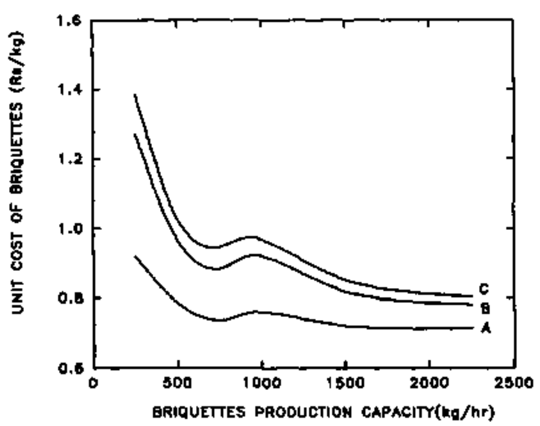

Fig. 5. Unit cost of briquette production. (A) Fine granulated material (dry), (B) coarse granulated material (dry), (C) stalky material (dry).

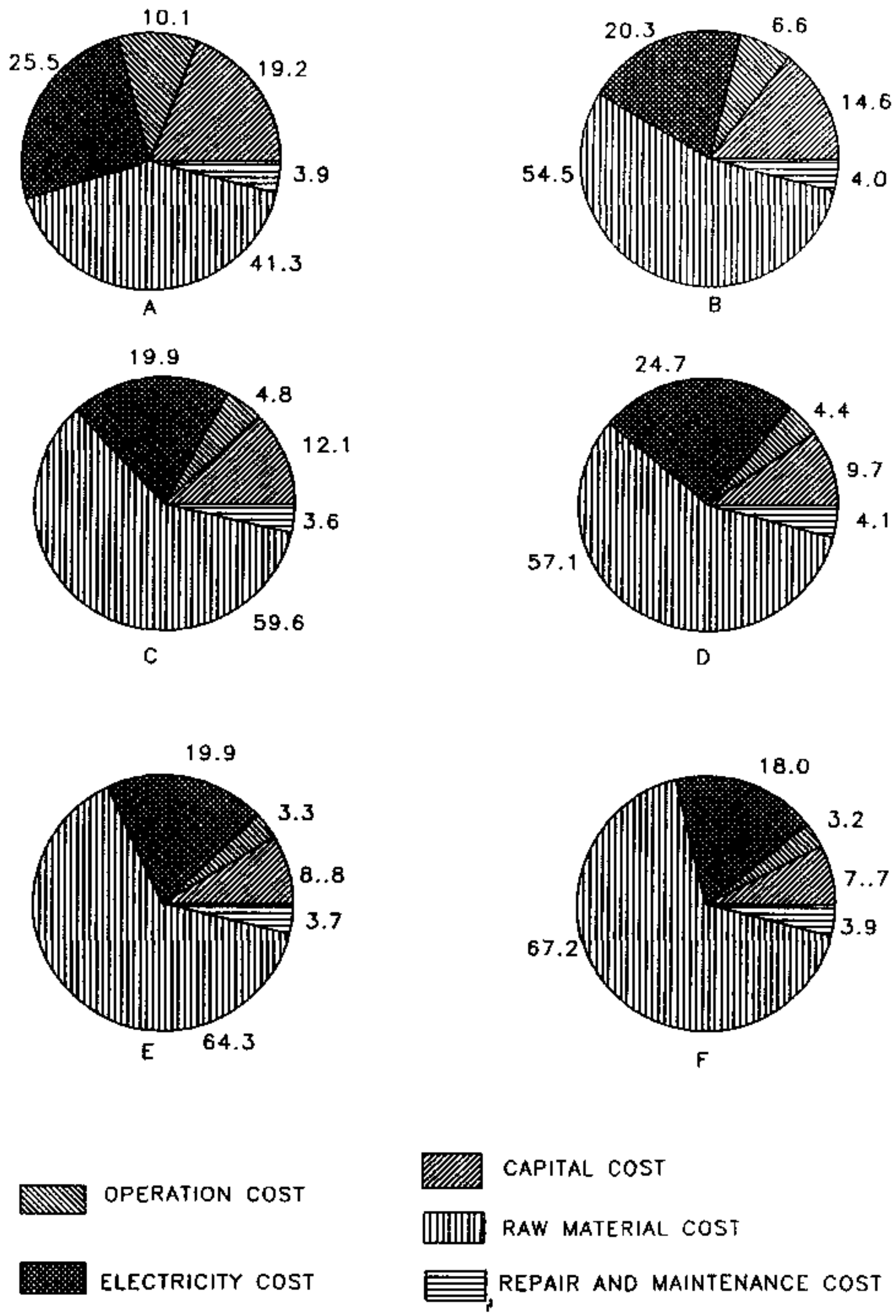

Fig. 6. Contribution of input cost components in unit cost of briquette for various briquette production capacities for coarse granulated wet, materials. (A) 250 kg/hr, (B) 500 kg/hr, (C) 750 kg/hr, (D) 1000 kg/hr, (E) 1500 kg/hr, (F) 2250 kg/hr.

with higher production capacities, the relative contribution of the cost of raw materials further increases, primarily due to a reduction in the contribution of capital cost (due to economics of scale) and reduced electricity consumption per unit of briquette production.

The sensitivity of the unit cost of briquettes to different factors is given in Fig. 7. It may be noted that the cost of raw materials and the capacity utilisation of the briquetting units considerably affect the unit cost of briquettes production.

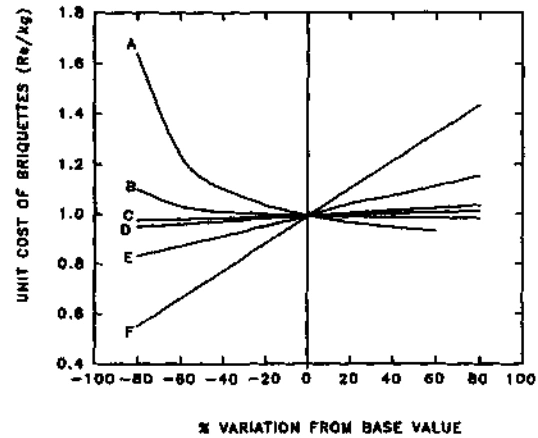

Fig. 7. Sensitivity analysis for unit cost of briquette production for a briquetting unit (750 kg/hr) using coarse granulated wet material. (A) Capacity utilisation factor, CUF. (B) Useful lifetime, *t*. (C) Discount rate, *d*. (D) Manpower cost, C_l. (E) Unit cost of electricity, C_e. (F) Raw material cost, C_b.

Table 12. Unit cost of briquette production for various raw material categories

	Cost of briquette production[a] (Rs/t)				
	Raw material cost (Rs/t)				
Raw material	100	300	500	800	1000
Fine granulated (dry)	291–467	501–677	711–887	1026–1202	1236–1412
Fine granulated (wet)	333–748	553–968	773–1188	1103–1518	1323–1738
Coarse granulated (dry)	361–850	571–1060	781–1270	1096–1585	1306–1795
Coarse granulated (wet)	403–1106	623–1326	843–1546	1173–1876	1393–2096
Stalky (dry)	383–964	593–1174	803–1384	1118–1699	1328–1909
Stalky (wet)	419–1174	639–1394	860–1615	1189–1944	1409–2164

[a]Lower values correspond to briquette production capacity of 2250 kg/hr and higher value for 250 kg/hr.

Table 12 presents the ranges for the cost of briquettes for the six different combinations considered in the present work. As expected, the highest value corresponds to a production capacity of 250 kg/hr and the lowest for the 2250 kg/hr briquetting unit.

10. CONCLUDING REMARKS

Notwithstanding some of the technology-related problems yet to be resolved the option of briquetting raw biomass materials appears to be quite attractive from the financial standpoint. It is expected that with increasing fossil fuel costs, the net zero carbon emitting biomass briquettes may find large-scale application in industry and commercial installations besides their domestic uses.

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