"A STUDY ON ENERGY CONSUMPTION IN RICE MILLING USING ENERGY AUDIT PRINCIPLES"

M.Tech. (Agril. Engg.) THESIS

by

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"A STUDY ON ENERGY CONSUMPTION IN RICE MILLING USING ENERGY AUDIT PRINCIPLES"

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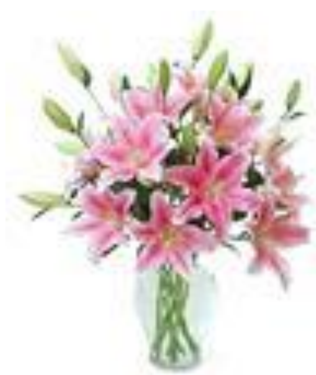

MY
BELOVED PARENTS
AND
Dr. M. R. Varma

CERTIFICATE – I

This is to certify that the thesis entitled **"A STUDY ON ENERGY CONSUMPTION IN RICE MILLING USING ENERGY AUDIT PRINCIPLES"** submitted in partial fulfilment of the requirements of the degree of **"MASTER OF TECHNOLOGY"** of the Indira Gandhi Agricultural University, Raipur, is a record of the bonafide research work carried out by **Mr. Suneel Kumar Goyal** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma (certificate awarded etc.) or has been published/Published part has been fully acknowledged. All the assistance and help received during the course of the investigations have been duly acknowledged by him.

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This is to certify that the thesis entitled **"A STUDY ON ENERGY CONSUMPTION IN RICE MILLING USING ENERGY AUDIT PRINCIPLES"** submitted by **Mr. Suneel Kumar Goyal** to the Indira Gandhi Agricultural University, Raipur in partial fulfillment of the requirements for the degree of M. Tech. (Agricultural Engineering) in the Department of Agricultural Processing and Food Engineering has been approved by the Student's Advisory Committee after oral examination in collaboration with the external examiner.

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Major Advisor ……….…………………………………………..

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Director of Instructions ……….…………………………………………..

Date:

LIST OF ABBREVIATIONS AND SYMBOLS

Agril.	:	Agricultural
Anon.	:	Anonymous
d. b.	:	dry basis, %
^0C	:	degree Celsius
E. E. U. I.	:	Electrical Energy Utilization Index
et al.	:	et alibi
Fig.	:	Figure
g	:	gram
h	:	hour
i. e.	:	that is
kg	:	kilogram
kWh	:	kilo-Watt-hour
m. c.	:	moisture content
C_p	:	Specific heat of the paddy, kcal/kg ^0C
C_w	:	Specific heat of the water, kcal/kg ^0C
E_1	:	heat required for soaking, kcal
E_2	:	heat gained by paddy in steaming, kcal
E_{dr}	:	heat required for drying of steamed paddy, kcal
m	:	final moisture content
m_0	:	initial moisture content
N. E. C.	:	Net energy consumption, kWh

Q	:	Capacity, t/h
q	:	sensible heat in dry flue gas
S. E. C.	:	Specific energy consumption, kWh/t
t	:	tonne
Δt_1	:	temperature difference of initial water and heated water for soaking, ^0C
Δt_2	:	temperature difference between steamed and soaked paddy,
Δt_3	:	temperature difference between atmospheric and heated air,
%	:	per cent
viz.	:	namely
w. b.	:	wet basis, %
W	:	Weight of water required for soaking, kg
W_d	:	Weight of paddy to be soaked, kg
W_{dp}	:	Weight of dry paddy, kg
W_{dr}	:	Weight of husk used for drying, kg
W_s	:	Weight of water in the soaked paddy, kg
W_{dp}	:	Weight of dry paddy, kg
W_p	:	Weight of water to fill the pore space of paddy, kg

CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

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CHAPTER - I

INTRODUCTION

In the present context of global energy crisis, every country has been exploring the possibilities of reducing the consumption of energy. Solutions for energy crisis are strongly dependent on the technology of how energy is used. The era of cheap energy has passed, but still there are industrial complexes that are highly energy intensive. The populace is becoming increasingly energy conscious because of dire consequences in placing additional stresses on our biosphere, already showing serious stings of strain.

Energy plays a key role in the socio-economic development of any country. Developing countries have a primary need to formulate strategies to achieve food self sufficiency which are energy efficient. India, with its typical socio-economic and not so sound energy situations, currently engaged in planned agricultural development, where the planners need information on the input requirements. Moreover, the bulk of energy consumed in processing of agricultural products is often being substantial. Hence, it has become essential that effort should be made to conserve energy by its efficient utilization in agricultural production in general and processing of farm produce in particular.

Rice contributes around 45 per cent of India's cereals production and is the main staple food for over 65 per cent population. Rice cultivated in about 43 million ha with a total production of 86 million tonnes (Singh *et al.,* 2001). The Chhattisgarh is a newly born state known as "rice bowl". Out of the total geographical area of 145.2 million ha, rice is sown in 40 million ha. The average yield of rice in Chhattisgarh is 12 q/ha (Anon, 2000).

Rice milling industry is the largest agro-based industry in India. In 1998, India had approximately 1,38,898 rice milling units. The number of hullers was 91,287, shellers 4,538 and huller-cum-shellers 8,385 respectively (Singh, 1999). Unlike other agro-based processing industries, there is a dearth of available information on the energy consumption level by the various utilities/services of commercial rice mills. From industrial point of view alone, such information is vital for developing work plan to acquire better control over production operations and to properly appraise energy consumption in production, planning and marketing.

The important utilities in a rice mill are water, air, steam, electricity and labour. In a rice mill some of the operations are done manually namely, feeding paddy to the bucket elevators and cleaning. So the man-hours should to be included in this energy accounting study. Water is used for soaking and steam generation. Electricity is used to run motors, pumps, blowers, conveyors, fans and light etc. The variations in the consumption rate of energy through the use of utilities during processing must also accounted for in the final cost of the finished product. The efficient utilization of energy is a great challenging task to the researchers.

There are two long range options that could permit supply of essentially unlimited amounts of energy, the nuclear and solar options. To build either of these options will require large amount of money and time. Energy audit principally involves following procedural steps:

- Objective determination
- Defining system boundary
- Process flow diagram design
- Identification of all mass and energy inputs
- Measurement of all mass and energy inputs
- Identification of all mass and energy outputs
- Measurement or estimation of all mass and energy outputs

Energy audit will help to understand more about the areas where the energy is being unknowingly wasted. With this, possible improvements are identified and corrective measures are recommended for adoption on short/long term duration so that the over all mill efficiency could be improved. While doing so a clear picture of financial involvement is given for each type of recommended measure supported by payback period to facilitate the easy adoption.

The energy audit would give a positive orientation to the energy cost reduction, preventive maintenance and quality control programmes which are vital for production and utility activities. Such an audit programme will help to keep alive variations which occur in the energy costs, availability and reliability of supply of energy, decision on appropriate energy mix, identification of energy conservation technologies etc.

The primary objective of the audit is to determine ways to reduce energy consumption per unit of product output or to lower operating costs. There can be two types of energy audit. Preliminary audit and detailed audit, the objective of preliminary audit is to set priorities for optimizing energy consumption. It can highlight energy costs and wastages in major equipments/ processes. While the objective of detailed audit are to quantify energy consumption/ utilization and evolve detailed engineering for options to reduce energy costs/ consumption (PCRA, 1991).

Rice industry is one of the most energy consuming industries. It uses rice husk as a fuel. The reduction in the use of rice husk would enable the rice industry to spare rice husk which is a valuable raw material for the manufacture of amorphous silica, silicon, ceramic materials, furfural etc. Saving of husk would also lead to co-generation of thermal energy in furnaces for boilers and dryers in the rice industry. Thus energy conservation in the rice industry would lead to reduction in the use of fuels and electricity. If measures suggested in energy audit are properly implemented, it would reduce the cost of milled rice simultaneously with increased availability of husk stepping up the production of amorphous silica, silicon, ceramic materials, furfural etc. would be possible.

Like capital, labour and material, energy is one of the production factor used to produce final product. In economic term, energy is demand-derived goods. The energy can be regarded as intermediate goods whose demand depends on the demand of final product.

Keeping the above discussion in view the objectives of present study were set as furnished below,

1. To study the energy consumption in converting paddy into rice by various milling methods.
2. To determine energy consumed in various processing machines of modern rice mills.
3. To compare the account of energy consumption at the rice mills under study with those studied by others.

CHAPTER – II

REVIEW OF LITERATURE

This chapter deals with the review of literature on the research work of energy consumption in different methods of rice milling and various milling machinery. Efforts have been made to include basic paddy processing operations.

2.1 Energy Requirements for Post Harvest Operations of Paddy

2.1.1 Parboiling

Tiwari (1980) estimated the energy requirement of various parboiling methods,

	Method	Energy requirement
(A)	RPEC method	9.54×10^5 J/kg of paddy
(B)	CFTRI method	16.4×10^5 J/kg of paddy
(C)	Pressure parboiling	3.75×10^5 J/kg of paddy

Not withstanding certain limitations, it had been concluded that RPEC method of paddy parboiling was the most economic process though the CFTRI method was used commercially.

Arora (1982) categorized the various operations in a rice mill and found out the energy requirement of various parboiling operations.

(a) Soaking

The hot water requirement for soaking one tonne of paddy was estimated to be 1200 kg. The heat required raising the temperature of water from 25^0C - 85^0C was calculated as 72,000 kcal (301.4 MJ).

(b) Steaming

The steaming operation, if carried out immediately after the soaking operation, needed about 21,000 kcal (87.92 MJ) per tonne of paddy.

(c) Drying

Drying operation required hot air at 80^0C to the extent of 50 m^3/min for 4 h to dry one tonne of paddy which means an energy requirement of 1,37,000 kcal (573.49 MJ) per tonne of paddy.

Hence the energy requirement for complete parboiling operation came to 2,30,000 kcal (962.9 MJ) per tonne of paddy produced.

Sehgal and Bhatnagar (1987) reported that the energy input per tonne of paddy processed ranged from 1261 to 3312 MJ. Non-uniform energy input trends were observed in eight different parboiling and drying processes. The parboiling and drying operations consumed more than 90 per cent of total energy required in a rice milling system. Integrated energy model of mini rice milling system indicated that surplus energy was available in raw paddy milling system; while in parboiling milling system extra energy had to be provided.

Dash *et al.* (1994) gave the opinion that most rice mills could be divided into two major sections, viz. parboiling section and milling section. They found that parboiling section utilized both electrical and thermal energy including the manual energy and the milling section mostly utilized electrical and manual energy. Parboiling and milling sections consumed 1.68×10^{10} and 6.70×10^8 MJ/year respectively. The total energy requirement for the rice industry was 1.75×10^{10} MJ/year.

Primary processing of rice basically involves removal of husk and the underlying bran layers from paddy in major rice milling systems such as hullers, shellers and modern rice mills. It was estimated that 50 per cent of paddy processed in India was parboiled by using various methods of parboiling. Drying was mostly done in the open sun while parboiling and drying operations mainly require thermal energy and the milling operations needed mechanical energy

(Kapur *et al*., 1994). The authors had tabulated different operations and energy demand as follows:

Table 2.1 Energy demand of rice processing operations

S. No.	**Operation**	**System/method**	**Energy demand, MJ/t**	
			Raw	**Parboiled**
1.	Milling*	Huller Sheller Modern rice mill	144.0 108.0 79.2	164 123 90
2.	Parboiling#	Single steaming Double steaming Open drum Hot soaking and steaming Pressure parboiling		241 391 391 425 271
3	Drying#			827

*Demand is for mechanical energy indicated in terms of electricity i.e. MJ/t.

Demand indicated is useful thermal energy demand in terms of MJ/t of paddy; in addition mechanical energy @ 28.8 and 86.4 MJ/t may be required for material handling during parboiling and drying operations respectively.

Kapur *et al*., (1997a) used 22, 30, 40 kWh/t of paddy as the mechanical energy intensity of raw rice milling for estimating the energy demand. Useful thermal energy intensity for parboiling was worked out to be 241, 391, 391, 425 and 271 MJ/t of paddy in case of single steaming, double steaming, open drum, hot soaking, steaming and pressure parboiling methods respectively. For drying of parboiled paddy the energy intensity was 827 MJ/t of paddy.

De (2002) reported that parboiling and drying operations required thermal energy. The useful thermal energy intensity for parboiling had been estimated to be ranged between 241 MJ/t and 425 MJ/t of paddy for different methods of parboiling. The traditional single steaming method requires minimum energy, while hot soaking and steaming method require the maximum energy as quoted by Kapur *et al*., 1997. The thermal energy intensity of drying had been estimated to be 827 MJ/t of paddy.

2.1.2 Energy requirement for milling

Anonymous (1966) studied the function of different modern rice mills i.e. Dandekar, Binny and Damodar having different mechanisms for husk separation, polishing and grading operations. The energy requirement for milling of paddy by Dandekar type rice mill was 5–6 per cent lower as compared to Binny type mill and 8–10 per cent less than that of Damodar type rice mill. The total rice recovery of Dandekar type mill was also higher as compared to other two rice mills.

Anwar and Kapur (1983) reported that the energy requirement in China for milling a tonne of rice was 25 kWh or 6.9 liter of diesel. The resulting of 0.25 tonne of husk from one tonne of rice can produce 100-104 kWh of electricity through a gas engine generator set yielding 85-115 kWh of surplus energy.

Nag and Bhole (1983) studied the power requirements of different types of rice mills i.e. Dandekar, Binny, Kisan and Satake mills. The milling capacities of these mills were 250, 400, 500 and 900 kg/h respectively and power requirements were 10, 15, 15 and 18 hp respectively. It was found that the Satake type rice mill was the best of all the rice mills in terms of capacity per unit power.

Ilyas and Nag (1984) estimated that 37 kW shaft power was required to mill one tonne of paddy per hour. In the rice mill, shaft power was provided for operating the equipment and process heat was provided by steam generated in boiler. The shaft power requirement for each individual component of the milling section of a 2 t/h rice mill amounted to 55.5 kW and for parboiling 20 kW.

Bakhara *et al.* (1991) studied the energy consumption in two commercial rice mills namely Vijay Laxmi rice mill and Shiba Durga rice mill of West Bengal. The total energy consumption was 1888.13 MJ and 2420 MJ/t of rice produced in the integrated and semi-mechanized mill, respectively.

Borah and Prasad (1993) studied the operations in milling section of three commercial rice processing plants of equal capacity and same make. The total power required at installed capacity of 2 t/h for raw paddy milling was found as 62.34 kW and on an average the same for parboiled paddy was found as 73.57 kW. The total energy required per tonne of raw and parboiled paddy milling was found as 31.17 kWh and 36.78 kWh respectively.

De (2002) reported that all the unit operations in rice milling required mechanical energy, which was mainly provided by electric motors. In huller mills dehusking and polishing were accomplished in one operation, other operations like material handling, separation of rice from husk were done manually. Mechanical energy requirement varies from 18-55 kWh/t in different types of rice mills. While the energy consumption in modern rice mills generally vary from 18-26 kWh/t for raw and 20-30 kWh/t for parboiled paddy, sheller and huller mills required higher energy. Rice mills having elevators for material handling consumed 7-10 kWh/t and 24-25 kWh/t of mechanical energy for parboiling and drying respectively.

2.1.2.1 Paddy separator

Gariboldi (1974) stated that paddy separator with adjustable stroke had given the maximum output of 110 kg of round grains and 67 kg of long grains per compartment per hour while the machine was being operated at 124 rpm and 144 mm stroke length. As a rule, compartment separators required about 1.119 kW/t–1.492 kW/t of husked rice.

2.1.2.2 Polisher

Bhole (1976) found that the major portion of the total energy consumed in milling of paddy was due to the polishing of rice and concluded that polisher with finer emery grains consumed less energy while the increase in speed and operating pressure resulted in higher energy consumption.

Gariboldi (1974) reported that power requirement of an individual polisher was proportional to the machine output i.e. to cone polisher, other factors such as design, manufacture, type of rest bearing etc. did not much affect the power requirement. The power required per tonne of rice varied with variety, with degree of polish and with number of polisher used.

Kapur (2002) reported that energy requirement for milling rice depends on number of grains, process, equipment and other parameters. These include grain quality, uniformity of grain size, grain hardness, form of rice and quality of output desired, type/capacity/age/combination of equipment used, fuel/power source, efficiency of driver and power transmission. with such a variety of factors affecting the energy requirement and rice milling being done largely in unorganized sectors, no comprehensive efforts appears to have been made for its assessment. He studied in isolated case. A summary of results of some such studies is given in table 2.1 it may be observe that there is a large variation in energy intensities (energy required to process unit mass of the input to the final product) of rice milling.

Kapur *et al*. (1997 a) reported the values of mechanical energy intensity for rice processing operations.

Table 2.2 - Reported values of mechanical energy intensity for rice processing operations

Sl. No.	Reference	Mechanical energy intensity, kWh/t*				Remark
		Rice milling		Parboiling	Drying	
		Raw	Parboiled			

1	Pathak *et al*., (1982)	25.6	-	9.4	-	2 t/h modern mill
2	Sehgal *et al*., (1983)	-	-	3.37 8.77 22.38 9.30 7.46 13.92 5.04 3.85	9.30 30.46 24.61 24.61 24.80 25.36 25.36 13.92	1, 1.5, 2 and 3 t/h parboiling plants using pressure parboiling method
3	Kumar *et al*., (1989)	46	50	-	-	1-2 t/h modern mill
4	Bakhara *et al*., (1991-92)	-	29.84	-	-	2 t/h modern mill
5	DSIR (1992)	18 25	20 22 55	-	-	1.5 t/h modern mills except the last which is an integrated complex
6	Bal (1992)	20 30 40	-	-	-	Modern mill Sheller Huller
7	Gupta (1993)	24.75	28.46	7.83	12.51	120 & 4 t/h modern mills

*t refers tonne of paddy initially at moisture content of 16 %

Energy in its different forms as biomass, human, fossil and electricity were used in each unit operation. Mechanized processing industry normally required direct fuel energy, steam and electricity. About 48 per cent of the total energy was used in the form of as direct fuel use, 13 percent was used in the form of as electricity, 29 percent as processed steam and 10 percent was in the form of hot water (Adolfson, 1982). About two-thirds of electricity was consumed in generating mechanical power to operate conveyer, pumps, compressors and other machinery. Other appliances as lighting etc. normally about 15 percent of electricity (De, 2002).

2.2 Energy Production System in Rice Mills

Basically there are two types of energy production systems commercially available,

(1) Gasification and

(2) Direct combustion

2.2.1 Gasification

The producer gas is a combustible gas mixture obtained by gasification of biomass. The gasification involves burning of biomass like rice husk, groundnut shell, stalks of pigeon pea etc. under restricted air supply. It involves:

(i) Oxidation of the carbon into carbon dioxide and carbon mono oxide and reduction of carbon dioxide into carbon monoxide,

(ii) Release of H_2 from chemical bond and

(iii) Formation of small quantities of methane gas (CH_4).

Andre *et al.*, (1980) reported that the efficiency of the gasification process was generally about 70-80 per cent. The thermodynamic efficiency of thermal engine was about 37 per cent. Engine was coupled to an alternator allowing electricity generation with an efficiency of 93 per cent. Each kWh (3.6 MJ) was obtained from 0.55 lb (25g) of diesel fuel and 2200 kcal (9.21 MJ) under gaseous form.

2.2.2 Direct combustion

The most commonly adopted method of burning the solid fuels is used in the direct combustion. The burning of solid fuel in a longer term results in the generation of gaseous substances (i.e. volatile matter) and a solid residue consisting of carbon and ash. The direct burning of solid carbon in the fuel bed and combustion of volatile gases in the furnace space over the fire bed occurs simultaneously in the furnace. For the burning of the fuel in a bed and of gaseous combustible matters in the furnace space air is supplied through fire grate and partly into the furnace space over the fire bed. To ensure complete combustion of solid fuel, excess air is always supplied to the furnace.

Kuppuswamy (1976) reported that rice milling industry generated more than that was consumed. It was found that approximately 200 kg of husk was obtained from milling of one tonne of paddy. It produced 660 kg of steam, which generated 100 kWh of electricity through steam turbine. But milling of one tonne of paddy required only 65 kWh of electricity, thus rendering 35 kWh as surplus energy.

Maheswari (1975) found that the various physical factors which affect the burning of rice husk and efficiency of furnace were:

(i) variety of rice husk,

(ii) particle size of husk,

(iii) moisture content of husk,

(iv) size grading,

(v) rate of air flow through the bed and height of fuel bed.

The average calorific value of paddy husk is 3000 kcal/kg (12.6 MJ/kg). Hence, one tonne per hour rice mill producing 200 kg of husk per hour is capable of generating 6,00,000 kcal (2520 MJ) of heat energy per hour. Thus, if an overall energy conversion efficiency of 41 per cent was assumed from the system, a surplus energy to the extent of 5, 00,000 kcal (2100 MJ) could be available with the mill where parboiling operations were not carried out (Arora, 1982).

Pathak (1999) studied that 4.5 kg pressure steam was produced from one kg of husk. In a co-generation plant the steam turbine extracted some energy from steam to convert and supply it as mechanical power to the mill. The exhaust steam supplied heat for parboiling. But for a rice husk fired fluidized bed furnace-boiler-steam turbine unit to function economically and efficiently it should be designed to produce at least 500 kW power and a matching amount of steam. Obviously a common 2 t/h mill would not meet this requirement. On the other hand a cluster of 5 such mills or a 10 t/h mill would be placed in the following comfortable position.

Husk production	1.5 t/h
Steam generation (medium pressure @ 4.5 kg/kg husk)	6.75 t/h
Mechanical power generation @ 1 kW/11 kg steam	610 kW
Availability of process steam	0.6 t/ paddy

One tonne of paddy produces 180 kg of husk, of which at least 150 kg could be recovered to be used as fuel. The heat value of husk was about 15 MJ / kg. 150 kg husk at an over all efficiency of 70 per cent in co-generation plant can supply 1575 MJ energy. In a ratio 1: 9 between shaft power and process steam about 44 kWh mechanical energy, which is much more than what is needed for milling, and sufficient heat energy would be available to produce parboiled rice.

2.3 Paddy Husk Fired Furnaces

2.3.1 Box-type furnace

Ilays and nag (1984) developed the box-type furnace utilizing rice husk as a source of fuel in rice milling industry for paddy. It is equipped with an inclined grate adjustable at 40^0, 45^0 and 50^0 and consists of cast iron bars arranged in a stair-case fashion.

2.3.2 Cyclone type husk fired furnace

Singh (1975) reported that principle of operation of cyclone of cyclone furnace was similar to that of vortex burner. The centrifugal force keeps the fuel particles rotating in fixed circles according to their size in equilibrium against the drag of inwardly spiraling air so that relative motion between air and the fuel accelerate combustion. The husk is carried in a stream of air and enters the cyclone chamber tangents with a whirling motion. Large particles of husk are thrown outwards by centrifugal force burn near the walls, while fine particles burn in suspension in the air.

With the husk feed rate of 25 kg/h the supply of 2100 cm^3 of heated air-flue gas mixture can be maintained at 90^0C or it can generate the steam at the rate of 42 kg/h. The furnace provides a perfect combustion with no traces of smoke in flue gas. The highest furnace efficiency of 80 per cent occurred at the feed rate of 20 kg/h and air flow rate of 2.83 m^3/min. The maximum temperature of flue gas was obtained 1000^0 C at husk feeding rate of 30 kg/h and an air flow rate of 2.8 m^3/min.

2.3.3 Fluidized bed husk fired furnace

Ravindran (1982) reported that with view to the improve the combustion efficiency, fluidized bed furnace was considered as the best suited. The furnace was a cylindrical hollow chamber with a concentric cylinder. The outer cylinder was provided with an entry for the husk air mixture at height of 0.3 m from inside the floor level. The fuel-air mixture enters the outer chamber tangentially in the annular space, the mixture takes a circular path in the outer chamber and raises upto the dome and enters in to the central cylinder to clear out the furnace in to the blower. The temperature of this zone is always above 600^0 C. At the husk consumption of 4 kg/min, heat out put is approximately 31.4 MJ/min. A constant temperature obtainable at the outlet of the furnace is 100^0 C. The internal temperature of the furnace reaches upto 1200^0 C. the actual efficiency of the furnace of higher capacity, the quantity of air required for combustion should be admitted into the furnace from multiple points.

2.4 Boilers used in rice mills

Bhatia (1974) studied that the efficiency of boilers ranges form 50-85 per cent. Straight electrical power generation brings the over all efficiency down to about 20 per cent. Husk consumption was calculated at 350 kg/h with an estimated at 9.21 MJ/kg recovery from the husk. Surface area was 46 m^2 and pressure was 7 kg/cm^2. This was a natural draft unit with a 18.28 m high stack.

2.5 Over all heat utilization efficiency of parboiling system (OAHU)

Tiwari (1980) studied that the over all heat utilization efficiency of parboiling system was the heat utilized for soaking and steaming divided by the total heat input. This was a dimensionless energy parameter which gives an idea about the performance of the system.

2.6 Manual energy

Bakhara (1988) reported that labour plays a very important in Indian rice processing industries as some of the operations were done manually and hence can not be avoided in any energy accounting process.

2.7 Reduction of energy consumption

Pathak et al. (1982) have estimated that the plants of 15 t/h can be self sufficient in energy supply form rice husk alone. Energy saving could be achieved by using efficient furnace-dryer systems, energy efficient electric motors, less long power chains as well as uniform quantity of raw material. Power requirement per tonne of raw rice reduced for plant capacity exceeding 4 t/h (De, 2000).

Pathak (1999) suggested that the contribution of processing waste and by products to captive power generation in agro processing industries would become more meaning full if simultaneous efforts were mode to conserve energy. Use of energy efficient processes and equipment, co-e\generation, recovery and recycling of thermal energy, proper insulation, etc. were some of the steps that could reduce gross consumption and allow and industry to move closer to energy self-sufficiency using its own renewable resources like process waste.

2.8 Reduction in parboiling time

Paillaiyar (1998) reported that soaking paddy for one hour at 70^0 C, draining water and tempering for 4 hour restricted the grain moisture and on steaming the moisture was 28 per cent. The paddy parboiled by short soaking tempering (SST) dried faster and saved 25 per cent drying time. In the sand parboiling technique, soaked paddy is mixed with hot sand at $150\text{-}180^0$ C. In a traverse time of 40-60 seconds through the commercial mechanical sand roster, the soaked paddy is gelatinized and dried to a moisture content of 16-18 per cent in a co-current process. In the recent thermic fluid parboiling system developed by Paddy Processing Research Center (PPRC), the soaked paddy is passed through a gelatinization unit and the parboiled paddy produced could be dried faster and save 40 per cent in drying time.

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the description of the rice processing plants that were selected for investigation, method of data collection and analysis. The chapter also describes various formulae used and assumptions made for the purpose of calculation. After carrying out initial survey of rice mills, a few were selected for the present study. It was decided to investigate energy consumption for milling of raw as well as parboiled paddy. To have comprehensive information, all modes of paddy processing i.e. modern rice mill, mini rice mill and hullers were considered. The selected paddy processing plants were:

(i) Modern rice mills

(a) M/s Shri Tara Mohan Agro. Pvt. Ltd. (raw rice, capacity-2t/h)

(b) M/s Jagannath Rice mill (parboiled rice, capacity -2 t/h)

(ii) Mini rice mill and (capacity -0.5 t/h)

(iii) Two hullers (capacity -0.6 and 0.5 t/h).

3.1 Modern rice mills

These rice mills use a different machine for each processing operation i.e. cleaning, shelling, separating, bran removal and grading. Bucket elevators are used to move the paddy from one machine to next.

3.1.1 Plant Description of Shri Tara Mohan Agro. Pvt. Ltd.

This rice processing plant is located at about 6 km distance from the Faculty of Agricultural Engineering. The mill processes only raw paddy which they procure from the Food Corporation of India, Raipur. The milling section consists of

(a) an oscillating type paddy cleaner,

(b) a destoner,

(c) a rubber roll sheller,

(d) a husk aspirator,

(e) an indented tray type paddy separator,

(f) a vertical abrasive whitening cone polisher and

(g) two vibrating sieve type rice grader

All machines are in series and interconnected by chutes that are fed by total of seven bucket elevators. The operations of weighing and bagging are done manually. Arrangement of various machines in milling section of mill is shown in Fig. 3.1. Initially the paddy is fed to the first bucket elevator which is of scooping type and delivers the paddy to the paddy cleaner. The paddy is then transferred with the help of second elevator in the destoner for removing the stones, mud pieces and other solid impurities. The paddy is then taken to the rubber roll sheller by the third elevator. The husk is aspirated by a husk aspirator which is connected with rubber roll sheller. Paddy and brown rice is then fed into the indented tray type paddy separator, to get the product as paddy and brown rice through two different outlets. The separated paddy is then fed back into the sheller by the fourth elevator and the brown rice is fed to the cone polisher by the fifth elevator. The sixth elevator picks the polished rice from the polisher and feeds it into the vibrating sieve type rice grader. The head rice obtained is picked up by the final elevator which delivers it into the chute which further delivers the polished rice into a different floor where weighing and bagging operations are carried out manually.

3.1.2 Plant Description of Jagannath Rice Mill

The mill is located at about 20 km distance from Faculty of Agricultural Engineering, Raipur. The plant processes only parboiled paddy. This mill has modern paddy processing plant employing steam boiler, L.S.U. (Lousiana State University, U.S.A.) dryer and bucket elevators.

The method suggested by Central Food Technology Research Institute for parboiling of paddy adopted here. Its milling section consists of a paddy cleaner, a rubber roll sheller, a husk aspirator, three cone polisher, an indented cylinder rice grader and nine bucket elevators.

3.1.2.1 Parboiling operation

The system consists of following subunits

(1) a furnace

(2) a boiler

(3) a hot water tank

(4) six soaking-cum-steaming tanks

The furnace used in this mill is a commercial grate type husk fired furnace. The grate is inclined at 45^0 from the horizontal and consists of cast iron bars arranged in staircase fashion. The effective width of grate is 2 m and inclined length 2.75 m. The roof and side walls of the furnace are made of refractory bricks to control heat losses and withstand high temperature. The feeding platform is provided at the top of the furnace. The lifting and feeding of the husk is done by a bucket elevator. Husk flows into the furnace through the hopper by the action of gravity when the slide gate is adjusted. The ash slides down due to gravity at the end of inclined grate from where it is disposed to ash pit. Flow chart of paddy, air and steam in this mill is given in Fig. 3.2.

Six soaking-cum-steaming tanks of 3.75 tonnes capacity are installed on a heavy reinforced cum iron angles platform. Fig. 3.3 shows hot water circulation pipes and steam distribution pipes which are laid out permanently and connected to each tank for hot soaking and steaming respectively. The hot water tanks is constructed on a raised platform and connected with a hot water pump for recirculation purpose.

Paddy is soaked in tanks for 6-7 h and temperature is raised from 27-85^{0}C, thereafter steaming is done for 30 minutes. The pressure of steam is kept as 4 kg/cm^2. The parboiled paddy is dried from 40-45 per cent moisture content to 14-16 per cent (w.b.) to obtain desirable condition for milling and storing.

3.1.2.2 Drying of paddy

A mechanical L. S. U. type dryer is used for drying the steamed paddy. Holding capacity of dryer is 12 tonnes. The hot air at 85^0 C for this dryer is provided by a tubular heat exchanger connected with a grate type husk fired furnace. A blower of 3600 m^3/h capacity is used to suck the hot air from the heat exchanger. The drying chamber contains inverted V-ports. Alternate rows of these ports were opened on the blower and closed on the exhaust end. Hot air enters the drying chambers through these ports. Mixing of hot air and steamed paddy occurs in this chamber while air was flowing across it in zigzag path and paddy flowing downwards in a similar fashion. Three fluted rollers were attached at the bottom exhaust ports, which were rotate at a slow speed.

3.1.2.3 Milling of parboiled paddy

The milling section consists of the following equipments and machineries

(a) a cleaner

(b) a rubber roll sheller

(c) a husk blower

(d) a paddy separator (Compartment type)

(e) three cone rice polishers

(f) three bran aspirators

(g) a cyclone bran collector

(h) an indented cylinder rice grader

(i) nine bucket elevators

All the machines are connected in series by bucket elevators. At different outlets different byproducts like husk, bran and small broken rice are obtained. At the end, head rice and broken rice is found as final products. Arrangement of various machines in milling section of this mill is given in Fig. 3.4.

3.2 Mini rice mill

The mini rice mill of 0.5 t/h capacity was used in this study, situated in College of Dairy Technology. Mini rice mill has the component of modern rice mill like rubber rolls, husk aspirator, paddy separator and improved polisher. In this mill shelling was done with rubber rollers, husk was aspirated by aspirator and bran was removed by friction polisher. Mill was operated with 7.46 kW motor.

3.3 Huller mill

The study was conducted at two hullers viz. Maha Laxmi huller and Jain huller near the Faculty of Agricultural Engineering, Raipur. The capacities of hullers were 0.6 and 0.5 t/h. The working element of these hullers was a ribbed cast iron roller. The roller rotates on its axis inside a concentric cylinder. On the inner cast iron roller, spiral ribbed strips are mounted to one fourth part of the length and on remaining three fourth part 4-6 straight ribbed strips are mounted. The outer cylinder was made in two parts. The bottom half was fabricated by perforated mild steel sheet. During hulling, the husk and bran removed through perforated portion.

Paddy was fed into the hopper and due to rotational direction of the flutes, it was moved around the cylinder and finally towards the outlet. Friction between the paddy and steel parts of the huller causes the husk and bran to removed scrapped off.

3.4 Collection of Data

Necessary data were collected on quantity of husk burn, soaking, steaming time and temperatures of the paddy at various stages.

3.4.1 Measurement of husk feed rate

It is observed that average 150 bags of husk is fed into furnace during the period of 8 hours. Each bag of husk weighs about 16-17 (16 kg average) kg. Thus on an average 300 kg of husk is fed in one hour.

3.4.2 Measurement of steam

To measure the steam consumption in parboiling, the quantity of water which boiler consumes during definite time was measured. Simultaneously, the husk consumption during same time interval was also measured.

3.4.3 Measurement of electrical energy in paddy processing

An electrical energy meter (kilowatt-hour-meter) was used to measure the electrical energy consumption. Energy meter is an integrating instrument and takes into account both the power and the time, the product of which gives the energy. It dose not indicate the rate of energy to the load circuit (Gupta, 1979). The energy meter was connected in the electric circuit of individual machine. The machines were operated without load for 30 minutes and then observations of electrical energy consumption were taken. Thereafter all machines were operated with load for 30 minutes. The net energy consumption was calculated form the difference of on load and no load energy meter readings.

3.4.4 Determination of husk content

To determine husk content of paddy, 100 grams of paddy were taken. Their weight was noted down. Then the husk was removed by hand splitting and weight of brown rice and husk were taken separately. Four replications were taken.

$$Husk\ \ percentage = \frac{weight\ of\ \ husk}{weight\ of\ \ paddy} \times 100 \qquad (3.1)$$

3.4.5 Determination of head yield

To determine the head yield of the paddy, the weight of whole rice of 6/8 and more of actual kernel size at the outlet of the grader was measured and corresponding weight of polished rice was also measured. This ratio gives the head yield (Agrawal, 1984):

$$Head\ \ yield\ \ per\ cent = \frac{weight\ of\ \ head\ rice}{weight\ of\ \ polished\ rice} \times 100 \qquad (3.2)$$

3.4.6 Determination of broken percentage

To find out broken percentage, the weight of polished rice was measured and after grading the weight of rice kernels which are less than 6/8 of the actual size was measured. The broken percentage was calculated using the following formula (Agrawal, 1984):

$$Broken\ \ percentage = \frac{weight\ of\ \ broken\ rice}{weight\ of\ \ polished\ rice} \times 100 \qquad (3.3)$$

3.4.7 Determination of specific energy consumption

The specific energy consumption for milling of raw as well as parboiled paddy was calculated by taking the ratio of net energy consumption per unit time and the capacity handled during that period (Bakhara, 1991).

$$S.\,E.\,C. = \frac{N.\,E.\,C.}{C \times T} \tag{3.4}$$

Where,

S. F. C.	=	specific energy consumption, kWh/t
N. E. C.	=	net energy consumption, kWh
C	=	capacity handled, t/h
T	=	time, h

3.4.8 Human energy estimation

The human energy required in different activities to accomplished to the milling operation is calculated by taking observation of man hours and women hours separately. Following constants were used to convert them in term of MJ (Mittal *et al.* 1985).

1 man-hour	=	1.96 MJ	=	0.544 kWh
1 woman-hour	=	1.57 MJ	=	0.436 kWh

3.5 Energy consumption for parboiling

Parboiling is a hydrothermal treatment given to paddy to improve its milling, cooking and nutritional qualities and involves the three basic steps of soaking, steaming and drying. The energy consumption for parboiling can be determined by considering certain parameters given by the various investigators (Araullo *et al.* 1976). The method of estimation of quantity of heat required in all three operations for one tonne of paddy to be parboiled is discussed below.

3.5.1 Soaking operation

The quantity of water required to fill the pore space of paddy is calculated by using following expression

$$W_p = \frac{W_d \times P_p \times 1000}{B_d} \qquad (3.5)$$

Where,

W_p = weight of water required to fill the pore space of paddy, kg

W_d = weight of paddy to be soaked, kg

P_p = porosity of paddy, per cent

B_d = bulk density of paddy, kg/m^3

The quantity of water required for soaking is calculated by using following expression

$$W = W_d\left(\frac{m - m_0}{100}\right) + W_p \qquad (3.6)$$

Where,

W = weight of water required for soaking, kg

W_d = weight of paddy to be soaked, kg

m = final moisture content, % (w.b.)

m_0 = initial moisture content, % (w.b.)

W_p = weight of water required to fill the pore space of paddy, kg

About 10 per cent extra water is added in order to submerge the paddy completely. Hence, the total amount of thermal energy required to raise the temperature of the water from initial temperature to the soaking water temperature is calculated by following formula (Bhatane, 1984)

$$E_1 = W \times C_w \times \Delta\, t_1 \tag{3.7}$$

Where,

E_1 = heat required for soaking, kJ

W = total weight of water, kg

C_w = specific heat of water, kJ/kg ^{0}C

$\Delta\, t_1$ = temperature difference of initial water and heated water for soaking purpose, ^{0}C.

3.5.2 Steaming operation

To determine the energy required for steaming, the heat gained by paddy is calculated by using the following expression (Bhatane, 1984):

$$E_2 = (W_{dp} \times C_p \times \Delta\, t_2) + (W_s \times C_w \times \Delta\, t_2) \tag{3.8}$$

Where,

E_2 = energy gained by paddy in steaming, kJ

W_{dp} = weight of dry paddy, kg

C_p = specific heat of paddy, kJ/kg ^{0}C

W_s = weight of water in the soaked paddy, kg

$\Delta\, t_2$ = temperature difference between steamed and soaked paddy, ^{0}C

The heat losses during steaming are quite high, about 20 per cent extra heat is added so that the total heat required for soaking and steaming or the heat required for parboiling of paddy can be obtained.

3.5.3 Drying operation

After steaming, the moisture content of paddy rises from 35 to 50 per cent (w. b.). This moisture is reduced to the desired level of 14 to 16 per cent (w.b.). The heat energy required for reducing the moisture content is calculated by considering the standard operating conditions of hot air for drying with respect to its air flow rate, density, specific heat etc.

The LSU type dryer is most commonly used in commercial paddy processing plants. The temperature of ambient air is to be raised to 85^0C for drying of the paddy. The heat required to raise the temperature of air is determined by using the following expression (Bakhara, 1988)

$$E_3 = \left(A_r \times d \times C_a \times \Delta\, t_3 \times T_d\right) \tag{3.9}$$

Where,

E_3	=	heat required to raise the air temperature, kJ/ t of paddy
A_r	=	air flow rate, m^3/h-t
d	=	density of the air, kg/m^3
C_a	=	specific heat of air, kJ/kg ^{0}C
Δ t_3	=	temperature rise, ^{0}C
T_d	=	total drying time, h

It has been reported that the moisture content of paddy rises to 35-50 per cent (w.b.) after steaming (Chakraverty, 2000). This moisture is to be reduced to the desired level of 14-16 per cent (w.b.) moisture content. To determine the energy consumption in drying operation, the following formula is used,

$$E_{dr} = \left(\frac{W_{dr} \times C_f + E_{el} \times T + M_h}{Q_{dr}}\right) \tag{3.10}$$

Where,

E_{dr}	=	energy consumed, kWh/t of paddy

W_{dr} = quantity of fuel used for drying, kg

C_f = calorific value of fuel used, kWh/kg

E_{el} = electrical energy consumed, kWh/h

T = drying time, h

M_h = human energy, kWh

Q_{dr} = quantity of paddy dried, t

3.6 Effectiveness of the machines

The effectiveness of the machines is a measure of how effectively the machine was operating. It considers the quality aspect of the product obtained from the machine. The effectiveness for an individual rice mill machines has been calculated by using following expressions.

3.6.1 Paddy cleaner

The effectiveness of the paddy cleaner is determined by samples of clean feed for foreign matter when the paddy is fed to cleaning,

$$E_{fc} = \left(1 - \frac{F_p}{F_c}\right) \qquad (3.11)$$

Where,

E_{fc} = effectiveness of cleaning

F_p = amount of foreign matter in clean paddy, kg

F_c = amount of foreign matter in feed, kg

3.6.2 Effectiveness of destoner

The effectiveness of the destoner is determined by samples of clean feed for stones and other impurities when the paddy is fed to destoning,

$$E_{fd} = \left(1 - \frac{S_c}{S_f}\right) \tag{3.12}$$

Where,

E_{fd} = effectiveness of destoner

S_c = amount of stones and other impurities in clean paddy, kg

S_f = amount of stones and other impurities in feed, kg

3.6.3 Effectiveness of paddy sheller

To determined the effectiveness of the rubber roll paddy sheller following formula is used; (Chakraverty, 2000),

$$E_{fsh} = \left(1 - \frac{n_2}{n_1}\right) \tag{3.13}$$

Where,

E_{fsh} = effectiveness of rubber roll sheller

n_1 = amount of grain before hulling, kg

n_2 = amount of unhulled grain after hulling, kg

3.6.4 Effectiveness of paddy separator

Effectiveness of paddy separator is the ratio of the amount of the separated sample from the shelled rice and paddy outlets to the total amount of sample feed to the separator,

$$E_{fs} = \left(1 - \frac{P_p}{P_f}\right) \tag{3.14}$$

Where,

E_{fs} = effectiveness of paddy separator

P_p = weight of paddy in brown rice, kg

P_f = weight of paddy in feed, kg

3.6.5 Effectiveness of polisher

To determine the effectiveness of polisher, the actual per cent of polish is first determined by taking the ratio of bran removed and the brown rice fed to the polisher. Then the effectiveness of polisher is obtained by following expression,

$$E_{fp} = \left(1 - \frac{B_p}{B_{rf}}\right) \tag{3.15}$$

Where,

E_{fp} = effectiveness of polisher on the basis of head rice

B_p = weight of broken rice in product, kg

B_{rf} = weight of brown rice in feed, kg

3.6.6 Effectiveness of aspirator

The effectiveness of aspirator depends on the removal of bran sticking to the polished rice. The percentage bran in feed and in product of aspirator is to be determined and the effectiveness of aspirator is calculated using following expression,

$$E_{fa} = \left(1 - \frac{B_p}{B_f}\right) \tag{3.16}$$

Where,

E_{fa} = effectiveness of aspirator

B_p = weight of bran in product, per cent,

B_f = weight of bran in feed, per cent.

3.6.7 Effectiveness of rice grader

For determining the effectiveness of grader, the following formula is used,

$$E_{fg} = \left(1 - \frac{Br_p}{Br_f}\right) \tag{3.17}$$

Where,

E_{fg} = effectiveness of grader

Br_p = weight of brokens in product, kg

Br_p = weight of brokens in feed, kg

3.6.8 Effectiveness of whole rice mill

The effectiveness of complete rice mill depends upon the effectiveness of individual machine. Hence, the effectiveness of whole rice mill was determined with the following formula (Bhatane, 1984)

$$E_{fwrm} = \left(\frac{r}{R}\right) \times E_{fc} \times E_{fd} \times E_{fsh} \times E_{fs} \times E_{fp} \times E_{fa} \times E_{fg} \tag{3.18}$$

Where,

E_{fwrm} = effectiveness of whole rice mill

r = running capacity of rice mill, t/h

R = rated capacity of rice mill, t/h

E_{fc} = effectiveness of cleaner

E_{fd} = effectiveness of destoner

E_{fsh} = effectiveness of sheller

E_{fs} = effectiveness of separator

E_{fp} = effectiveness of polisher

Efa = effectiveness of aspirator

E_{fg} = effectiveness of grader

3.7 Electrical energy utilization index

An expression is developed to calculate the electrical energy utilization index for find the distinct feature of machines.

$$E.\,E.\,U.\,I. = \frac{N.\,E.\,C.}{T.\,E.\,C} \tag{3.19}$$

Where,

E. E. U. I. = electrical energy utilization index

N. E. C. = net energy consumption, kWh/h

T. E. C. = total energy consumption, kWh/h

3.8 Energy consumption in Mini rice mill and huller mill

Electrical and human energy consumption in both mini rice mill and huller mills was determined and calculated as discussed above.

3.9 Economic analysis

Economic analyses of rice mill were done on the basis of total processing cost and total value of processed rice. Find the net profit using following formula:

3.9.1 Profit

$$P = C_{p_m} - P_c - C_p \tag{3.20}$$

Where,

P	=	profit due to processing, Rs.
C_{pm}	=	cost of total processed material, Rs.
P_c	=	processing cost, Rs.
C_p	=	cost of raw paddy, Rs.

In this study the economic analysis was done by considering the present rates of following:

The cost of raw paddy	=	Rs. 5000 per tonne,
Electricity charge	=	Rs. 2.81 per kWh
Over head charge @ 25 % of total electricity bill	=	Rs. 0.70
Total electricity charge	=	Rs. 3.51 per kWh
Man labour	=	Rs. 6.25 per h,
Woman labour	=	Rs. 5.00 per h

3.9.2 Rate of return per rupee expenditure

Rate of return per rupee expenditure on processing of paddy in all rice mills is calculated using following expression,

$$R_{pe} = \frac{T.V_{pr}}{T_{pc}} \qquad (3.21)$$

Where,

R_{pe}	=	rate of return per rupee expenditure on processing, Rs.
$T.V_{pr}$	=	total value of processed rice, Rs.
T_{pc}	=	total processing cost, Rs.

3.10 Statistical analysis

The data on electrical energy consumption of various types of rice mills for production of one tonne milled rice were recorded during the course of study and subjected to statistical analysis as per method of “Analysis of variance” by one way classification (C.R.D.). The significance and non-significance of different types of rice mills were judged with the help of F (Variance ratio) table. The significance difference between the means was tested against the critical difference at 5 % level of significance.

CHAPTER - IV

RESULTS AND DISCUSSION

This chapter presents the observations and results obtained during the studies on audit of consumption of energies namely electrical, thermal and manual in parboiled rice mill, raw rice mill, mini rice mill and huller mill. The unit wise consumption of electrical, thermal and manual energy was determined at the rice mills. This study covered both type of rice i. e. raw and parboiled rice mill and all type of milling machinery, i. e. modern rice mill, mini rice mill and hullers.

4.1 Energy consumption in modern rice mill

The energy meter was connected in the electric circuit with individual motor of each machine to know the electrical energy consumption. The machines were operated without load for 30 minutes and with load for 30 minutes and the observations of electrical energy consumption were recorded. The net energy consumption was the difference of on load and no load energy meter readings.

4.1.1 Modern rice mill

4.1.1.1 Energy consumption in raw rice mill

The results obtained for the milling of raw paddy for 30 minutes duration are given in Appendix (A-1) and graphically presented in Fig. 4.1. It is obvious form the figure that, the highest electrical energy is required by the polisher at load (10.92 kWh), at no load (5.85 kWh) and consequently the net energy consumption (5.07 kWh) is also the highest among all the machines. Other high energy consumption at load was rubber roll sheller (3.55 kWh) and seven elevators (3.42 kWh) for production of one tonne milled raw rice. The minimum electrical energy consumption 0.50 kWh at load was by the husk blower and bran aspirator. The polisher consumed considerably large amount of 5.07 kWh net electrical energy. The friction between abrasive surface and grain is required for removal of bran. This required more energy as compared to the other machines. The figure also shows minimum 0.2 kWh net electrical energy consumption by aspirator and husk blower for production of one tonne milled raw rice.

The specific electrical energy consumption for each operation/machine was calculated by dividing the net electrical energy consumption by the quantity of material (paddy or different products obtained at various stages) processed and time of operation as given in equation 3.4. The electrical energy utilization index was calculated by using equation 3.20. The results of specific electrical energy consumption and electrical energy utilization index are given in Appendix (A-3) and graphically presented in Fig 4.2. The specific electrical energy consumption of polisher was found to be the highest as 5.07 kWh/t, followed by 1.92 kWh/t for rubber roll sheller, 1.63 kWh/t for cleaner and minimum specific electrical energy consumption was 0.22 kWh/t for elevators.

The electrical energy utilization index (E.E.U.I) is the ratio of net electrical energy to the electrical energy at load. This signifies the part of energy which is actually consumed for processing of grain by a particular machine. It shows the capacity of machine for actual energy utilization in product processing. Fig. 4.2 shows the highest value of E. E. U. I. as 0.86 by destoner and the lowest as 0.38 by aspirator. The possible reason for the highest electrical energy utilization index of destoner and the lowest electrical energy utilization index of aspirator are related with the quantity of grain being handled at a particular unit of time with respect to the energy consumed.

The Table 4.1 shows the unit wise measured parameters of raw rice mill. For processing of 2.8 tonnes paddy, requirement of manual energy was 11 men, 9 women and a supervisor (Mistri). The total manual energy used was 10.46 kWh.

Table 4.1 Measured parameters of energy input at raw rice mill

No.	Operation	Measured parameters	Magnitude
1	Milling	Quantity of paddy milled	2.80 t
		Electrical energy required	49.76 kWh
		Time required	1 h
		Labour required	9 man and 9 women
2	Weighing and bagging	Quantity of rice handled	2 t
		Labour required	3 men
		Time required	1 h
		Electrical energy required	0.5 kWh

4.1.1.2 Energy consumption in parboiled rice mill

In the parboiled rice mill, the electrical energy consumption without load and with load for 30 minutes each at 1.9 t/h running capacity was measured. These data are presented in Appendix (A-2) and graphically presented in Fig. 4.3. The parboiled rice mill was using three stage polishers comprising of vertical abrasive cone type, which consumed maximum amount of energy (6.94, 6.92 and 6.94 kWh for production of one tonne parboiled rice).

Fig. 4.3 also shows net electrical energy consumption for obtaining one tonne of parboiled rice. The consumption by the polisher-II was 3.62 kWh followed by 3.54 kWh and again followed by polisher-I, 3.49 kWh by polisher-III and 2.74 kWh by sheller. The huge amount of energy required for removal of bran may be the cause for maximum net electrical energy consumption. The grader consumed minimum net electrical energy 0.24 kWh. Hot air blower consumed the highest electrical energy at load (8.50 kWh for 30 minutes operation).

The specific electrical energy consumption and electrical energy utilization index by various machines in parboiled rice mill is given in Appendix (A-4) and graphically presented in Fig. 4.4. The highest specific energy consumption was by polisher-III (3.67 kWh/t) followed by polisher-II (3.62 kWh/t) and by polisher-I (3.37 kWh/t). The minimum specific energy consumption was 0.27 kWh/t by grader. Fig. 4.4 also shows the highest value of electrical energy utilization index of 0.85 by cleaner-II and lowest 0.26 by grader.

The measured parameters of energy input data at various operations for production of parboiled rice are presented in Table 4.2. It is clear, that the 3.5 kWh electrical energy is required for cleaning of 0.8 t raw paddy in 10 minutes with 2 labours. For soaking (3.5 h) and steaming (0.5 h) of 3.5 t cleaned paddy, 2 labours were required and 150 kg/h husk was used to produce thermal energy. The dryer capable of drying 12 t per 6 hours was engaged for drying. The hot air blower of dryer consumed 17.03 kWh electrical energy.

Table 4.2 Measured parameters of energy input at parboiled rice mill

No.	Operation	Measured Parameters	Magnitude
1	Cleaning	Electric energy required	3.5 kWh
		Quantity of cleaned paddy	0.8 t
		Time required	10 min.
		Labour required	2 men
2	Soaking and steaming	Quantity of paddy handled	3.5 t
		Husk feeding rate	150 kg/h
		Time required for heating of water from 25^0C to 85^0C	3.5 h
		Time of steaming	0.5 h
		Labour required	2 men

3	Drying	Capacity of L. S. U. dryer Time required Husk feeding rate Electrical energy required Labour required	12 t 6 h 150 kg/h 17.03 kWh 8 men and 4 women
4	Milling	Quantity of paddy milled Electrical energy required Time required Labour required	3 t 72.4 kWh 1 h 5 men and 10 women
5	Weighing and bagging	Quantity of rice handled Labour required Time required Electrical energy required	1.9 t 3 men 1 h 0.5 kWh

The parboiled rice mill selected in this study was a modern rice mill and therefore it did not require more manual energy. Parboiling is a hydrothermal treatment; the heat energy is required to complete this hydrothermal process. This heat energy was generated by burning of rice husk in an inclined grate furnace.

Necessary data were collected to calculate various types of energy consumed. The actual energy consumed in the various operations for processing of paddy is computed. Theoretical energy required for certain operations are also computed wherever possible. The results of energy consumption in different operations are given in Appendix A-5 and graphically presented in Fig. 4.5.

Fig 4.5 shows the various types of energy consumption in parboiled rice mill in different operations for production of one tonne milled parboiled rice. In the Fig. 4.5 (A) maximum 36.20 kWh electrical energy was consumed in milling followed by 8.52 kWh in drying and 7.26 kWh in other appliances, whereas the minimum was 0.50 kWh in weighing and bagging.

Fig. 4.5 (B) shows the thermal energy consumption in parboiled rice mill. The soaking operation consumed the highest thermal energy (525 kWh) followed by drying (262.50 kWh), whereas steaming operation consumed the lowest thermal energy (75 kWh). The operations which did not consume any amount of thermal energy were cleaning, milling, weighing, bagging and others.

It is clear from Fig. 4.5 (C) that the maximum manual energy consumption was 3.55 kWh in milling followed by 1.17 kWh in weighing and bagging and 1.09 kWh in soaking, whereas minimum manual energy consumption was 0.16 kWh in steaming.

From Fig. 4.6 it is seen that the cleaning operation consumed electrical energy of 1.16 kWh and manual energy of 0.181 kWh. The soaking operation followed by cleaning consumed electrical energy of 1.12 kWh, thermal energy of 525 kWh and manual energy of 1.09 kWh. In steaming operation requirements of thermal and manual energy were found to be 75 kWh and 0.16 kWh respectively. The steaming operation consumed electrical energy of 8.66 kWh, thermal energy of 262.50 kWh and manual energy of 0.51 kWh. The operation of milling consumed electrical energy of 36.02 kWh and manual energy of 3.55 kWh. The operation of weighing and bagging consumed 0.5 kWh of electrical energy and 1.17 kWh of manual energy. Besides this, the extra electrical energy consumption was found to be 7.26 kWh for lighting and other appliances which was equivalent to 15 % of total electrical energy required.

4.2. Energy consumption in mini rice mill

Mini rice mill has the components of modern rice mill like rubber rolls, rubber lined centrifugal sheller, husk aspirator, paddy separator and improved polisher. In this mill, shelling is done with rubber rolls and husk is separated by aspirator, whereas bran is removed by friction polisher in the present investigation. The electrical energy consumption of mini rice mill at load was 13.48 kWh; at no load was 8.40 kWh. Thus, net energy consumption was found to be 5.08 kWh for obtaining of one tonne milled rice. For mini rice mill, the specific energy consumption was 5.0 kWh/t and electrical energy utilization index was 0.38.

4.3 Electrical energy consumption in huller mills

The huller mills selected in the present investigation were engaged in production of raw rice. The total electrical energy consumption at load, net, specific electrical energy consumption and effectiveness for production of one tonne milled rice are discussed below:

4.3.1 Electrical energy consumption in huller-I

With data collected for production of one tonne rice, it was found that at load huller-I consumed 13.13 kWh of electrical energy, at no load the machine consumed 8.00 kWh and net electrical energy consumption was 5.13 kWh. The specific energy consumption and electrical energy utilization index were 5.13 kWh/t and 0.39 respectively.

4.3.2 Electrical energy consumption in huller-II

It was observed that the huller-II required 13.80 kWh of electrical energy at load, 8.40 kWh at no load and 5.40 kWh net energy for production one tonne milled rice. The specific energy consumption was 5.40 kWh/t, and Electrical Energy Utilization Index 0.39.

4.4 Total energy consumption in various rice mills

Fig. 4.7 shows that the total energy (electrical, thermal and manual) consumption for production of one tonne milled rice. It was found that parboiled rice mill consumed maximum energy (923.92 kWh) followed by raw rice mill (36.29 kWh) and huller mill (15.62 KWh), whereas the mini rice mill consumed minimum energy (14.42 kWh).

In the parboiled rice milling, the huge amount of thermal energy is required for soaking, steaming and drying of parboiled paddy. Therefore, the quantity of total energy consumed in parboiled rice milling seems to be very high (923.92 kWh), but because of the fact that the thermal energy is produced by burning of husk, which is byproduct of rice mill itself, no extra cost is required to be paid by the mill owner. The higher outturn of head rice and less broken percentage are the other advantageous feature of parboiled rice mill which offset the cost of extra energy consumed by it.

The higher amount of energy consumed in raw rice milling (36.29 kWh) can also be justified on the terms of higher head yield and lower broken percentage in comparison to particularly huller mill. The mini rice mill was found consuming less total energy (14.42 kWh) and simultaneously giving appreciable head outturn and less broken percentage.

4.5 Effectiveness of machines

The effectiveness of machine operation was calculated using expressions from chapter-III. The details of calculation are illustrated in the Appendix - (B).

4.5.1 Effectiveness of machines in raw rice mill

Table 4.3 shows that the effectiveness of cleaner was found to be the highest (0.90) followed by rubber roll sheller (0.88) which was at par with paddy separator. Minimum value of effectiveness was found with polisher and grader as 0.78. The effectiveness of whole raw rice mill calculated with the help of equation 3.18 was found to be 0.32.

Table 4.3 Effectiveness of various machines in raw rice mill

No.	Machines	Effectiveness
1	Cleaner	0.90
2	Destoner	0.87
3	Sheller	0.88
4	Separator	0.88
5	Polisher	0.78
6	Aspirator	0.87
7	Grader	0.78

4.5.2 Effectiveness of machines in parboiled rice mill

In case of parboiled rice mill (Table 4.4) the highest effectiveness was 0.92 with grader followed by the cleaner and sheller (0.88) whereas it was the lowest with polisher and bran aspirator (0.82). The effectiveness of whole parboiled rice mill calculated with the help of equation 3.18 was found to be 0.40.

Table 4.4 Effectiveness of various machines in parboiled rice mill

No.	Machine	Effectiveness
1	Cleaner	0.88
2	Sheller	0.88
3	Separator	0.87
4	Polisher	0.82
5	Aspirator	0.82
6	Grader	0.92

4.6 Economic consideration of paddy processing in various rice mills

4.6.1 Economic analysis

Economic assessment of paddy processing in various rice mills is given in Table 4.5 and graphically presented in Fig. 4.8. It is clear that the parboiled rice mill is most profitable as it gave Rs. 2215.72 profit per tonne of rice followed by raw rice mill (Rs. 1376.79 per tonne), Mini Rice Mill (Rs. 1193.21 per tonne) and huller (Rs. 1097.44 per tonne) respectively. Total value of processed rice, cost of raw paddy, processing cost and net profit is given in Table 4.5 and Fig. 4.8.

Table 4.5 Economic analysis of paddy processing in various types of rice mills

No.	Type of mill	Total value of processed rice	Cost of raw paddy	Processing cost of paddy	Profit
		(Rs./t)	(Rs./t)	(Rs./t)	(Rs./t)
1	Raw rice mill	6541.50	5000.00	164.71	1376.79
2	Parboiled rice mill	7735.00	5000.00	519.28	2215.72
3	Mini rice mill	6252.50	5000.00	59.29	1193.21
4	Huller mill	6217.00	5000.00	119.56	1097.44

4.6.2 Ex-post analysis

Rate of return per rupee expenditure is the value of profit which obtained by paddy processing through per unit of investment. Table 4.6 and Fig. 4.9 show the rate of return per rupee expenditure on paddy processing was highest (1.401) in parboiled rice mill followed by (1.267) in raw rice m ill, (1.236) in mini rice mill and (1.214) in huller mill.

Table 4.6 Ex-post analysis of paddy processing by various types of rice mills

No.	Type of mill	Total expenditure	Total value of processed rice	Rate of return per rupee expenditure on paddy processing
		(Rs.)	(Rs.)	
1	Raw rice mill	5164.71	6541.50	1.267
2	Parboiled rice mill	5519.28	7735.00	1.401
3	Mini rice mill	5059.29	6252.50	1.236
4	Huller mill	5119.56	6217.00	1.214

4.7 Comparison with studies done by others

The results found in present study are compared with Bakhara *et al*. (1991) and Borah *et al.* (1991).

4.7.1 Comparison of findings in present investigation with study done by Bakhara *et al.* (1991)

Comparative data regarding energy consumption in rice mills studied by Bakhara *et al*. (1991) in parboiled rice of 2 tonne per hour capacity in West Bengal and the present study is shown in Table 4.7. All the three types of energy namely electrical, thermal and manual required by the mills under present study was found to be higher than the previous study done by Bakhara *et al*. (1991). However some of the operations required little lower energy than the previous study. Drying operation required 8.66 kWh of electrical energy under present study which is lower than 11.75 kWh mentioned by Bakhara *et al*. (1991). The cleaning operation consumed 1.16 kWh of electrical energy in both studies. The thermal energy consumption in the mill studied by the Bakhara *et al*. (1991) was 481.03 kWh which is lower than the data of present study as 862.50 kWh.

The other operations in the present study also consumed considerably higher amount of energy for the same quantity of milled rice produced. The total energy consumed in the mill under present study (923.92 kWh) was quite higher than the earlier study i.e. 524.82 kWh.

The higher energy consumption may be due to older machines, inefficient operations and selection of oversized motor to run the machines.

4.7.2 Comparison of findings in present investigation with study done by Borah *et al.* (1991)

Table 4.8 shows the energy consumption at no load and at load for production of 2 tonne milled rice in one hour. In present study, the energy consumption at no load was 45 kWh in plant B followed by plant A (21.40 kWh). In the study by Borah *et al*. (1991) electrical energy consumption at no load was 38.6 kWh in plant C followed by 32.6 kWh in plant B and 28.03 kWh in plant A. In the present study electrical energy consumption at load was 97.46 kWh in plant B followed by 49.56 kWh in plant A whereas in the study by Borah *et al*. (1991) it was 65.92 kWh in plant C followed by 61.46 kWh in plant B and 50.50 kWh in plant A.

In present study each machine was operated by separate motor but in the study by Borah *et al*. (1991) all machines were driven by a single shaft.

4.8 Statistical analysis

Table 4.9 ANOVA table for electrical energy consumption in various types of rice mills

Source of Variation	S. S.	d. f.	M. S.	F-value	P-value
Type of rice mills	3309.788	3	1103.263	9496.218	1.63E-20
Error	1.39415	12	0.116179		

Total	3311.182	15			

Table 4.10 Mean of electrical energy consumption in various types of rice mills

Type of rice mills	Mean
Parboiled rice mill	48.69 [a]
Raw rice mill	24.79 [b]
Mini rice mill	13.46 [c]
Huller mill	13.46 [c]
C. D.	0.525

From the P value of the above analysis of variance (Table 4.9) it is evident the F-test for the different type of rice mills is highly significant at less than 5 % level of significance. This means that at least one type of rice mill is having significant impact on the electrical energy consumption for the production of the one tonne milled rice. Therefore, it becomes pertinent to look into the average effect of the electrical energy consumption for each type of rice mill under study.

Table 4.10 provides the averages electrical energy consumption, alongwith critical difference. On perusal of the averages, we find that the parboiled rice mill and raw rice mill, both consumed significantly different amount of electrical energy at 5 % level of significance compare to each other and also with respect to mini rice mill and huller mill during the production of one tonne milled rice. Parboiled rice mill consumed maximum electrical energy (48.69 kWh) followed by raw rice mill (24.79 kWh), mini rice mill (13.46 kWh) and huller mill (13.46 kWh). Mini rice mill and huller mill consumed at par levels of electrical energy for production of one tonne milled rice, their consumption are the minimum (13.46 kWh).

CHAPTER-V

SUMMARY, CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

5.1 Summary

In the present context of global energy crisis, every country has been exploring the possibilities of reducing the consumption of energy. Energy plays a key role in the socio-economic development of any country. Developing countries have a primary need to formulate strategies to achieve food self sufficiency which are energy efficient. India, with its typical socio-economic and not so sound energy situations, currently engaged in planned agricultural development, where the planners need information on the input requirements. Moreover the bulk of energy consumed in processing of agricultural products is often being substantial. Hence, it has become essential that effort should be made to conserve energy by its efficient utilization in agricultural production in general and processing of farm produce in particular.

The important utilities in a rice mill are water, air, steam, electricity and labour. In a rice mill some of the operations are done manually namely, feeding paddy to the bucket elevators and cleaning. So the man-hours should be included in this energy accounting study. Water is used for soaking and steam generation for parboiling of paddy. Electricity is used to run motors, pumps, blowers, conveyors, fans and light etc. The variations in the consumption rate of energy through the use of utilities during processing must directly accounted in the final cost of the finished product. The efficient utilization of energy is a great challenging task to the researchers.

The energy audit would give a positive orientation to the energy cost reduction, preventive maintenance and quality control programmes which are vital for production and utility activities. Such an audit programme will help to keep alive variations which occur in the energy costs, availability and reliability of supply of energy, decide an appropriate energy mix, identification of energy conservation technologies etc.

The study has been conducted in three types of rice mills viz. (a) Modern rice mills (raw rice mill and parboiled rice mill), (b) Mini rice mill and (c) Huller mill. The study was designed in such a way that each unit operation was studied closely and the energy input was determined experimentally. The electrical energy consumption was measured with an electrical energy meter. The energy meter was connected in the electric circuit of individual machine. The machines were operated without load for 30 minutes and the observations of electrical energy consumption were taken. Thereafter, all machines were operated with load for 30 minutes. The net energy consumption was calculated from the difference of on load and no load energy meter readings. From all the outlets of each machine, the sample were collected for one minute and analyzed in the laboratory for determining the capacity and effectiveness of machines.

The rated capacity of raw rice mill was 2 t/h and during study it has been found that the running capacity of rice mill is also 2 t/h. It has been also observed that each machine is operated with separate motor. The bucket elevators were used for feeding into the different machines, however some manual labour is required to move the paddy from activity area to another.

The results obtained indicate that the polisher consume a considerably large amount of net electrical energy 5.07 kWh. Minimum energy consumption was 0.5 kWh with aspirator. The specific energy consumption was high 5.07 kWh/t of polisher and minimum specific energy consumption was 0.39 kWh of separator. Manual energy consumption was 10.46 kWh/t, electrical energy consumption was 25.83 kWh/t and total energy consumption of rice mill was 36.29 kWh/t. The recovery of polished rice was 65 per cent.

Parboiled rice mill was a modern parboiled rice mill employing husked fired furnace, steam boiler and L. S. U. dryer. Pre-parboiling section was of 3 t/h capacity having a cleaner and a storage bin of 15 tonnes. The milling section gets the power from electricity whereas parboiling and drying of paddy is done by the heat energy generated by burning rice husk which is in fact free of cost.

Harvested paddy undergoes some sequential processing operations which convert it to the final primary product known as parboiled milled rice. The sequences of operations are soaking, steaming, drying, milling and lastly bagging of the final product milled rice. At each stage of the unit operations some level of energy input is required in the form of electrical energy, thermal energy and manual energy. The type and magnitude of the energy input is a function of the technology employed and the quantity of paddy being processed. To assess energy demands, quantitative data on operative conditions will be required for each unit operation. Based on the production technology under study, the type and magnitudes of the parameters required for the energy evaluation of each unit operation were recorded. For consistency, the energy components were calculated on the basis of one tonne of paddy. The recovery of mill was 68 per cent.

Maximum and minimum net electrical energy consumption was by polisher II (7.23 kWh) and Grader (0.48 kWh) for production of one tonne parboiled milled rice respectively. At load the electrical energy consumption of hot air blower was high (8.50 kWh) because the motor (25 hp) was used to operate the hot air blower. Aspirator was found consuming minimum energy 0.5 kWh at load. Maximum and minimum specific energy consumption was 3.67 kWh of polisher-III and 0.34 kWh of bucket elevator respectively. From the result the energy consumed in pre parboiling 1.34, soaking 527.21, steaming 75.16, drying 27158, milling 39.75 and weighing and bagging 1.67 kWh. The total energy consumption was 923.92 kWh for production of one tonne parboiled milled rice.

In case of mini rice mill the electrical energy consumption at load was 13.48 kWh, at no load 8.4 kWh, net electrical energy consumption was 5.08 kWh for obtaining of one tonne milled rice. The specific energy consumption was 5.0 kWh/t and electrical energy utilization index was 0.38.

Electrical energy consumption in huller-I at load was found 13.13 kWh, at no load the machine consumed 8.00 kWh and net electrical energy consumption was 5.13 kWh. The specific energy consumption and electrical energy utilization index were 5.13 kWh/t and 0.39 respectively.

It was observed that the huller-II required 13.80 kWh of electrical energy at load, 8.40 kWh at no load and 5.40 kWh net energy for production one tonne milled rice. The specific energy consumption was 5.40 kWh/t, and Electrical Energy Utilization Index 0.39.

5.2 Conclusions

From the above results the following conclusions may be drawn:

1. Parboiled rice mill consumed 38.95 per cent more energy for production of one tonne milled rice as compared to raw rice mill, 40.52 per cent more than huller mill and 161.64 per cent more than mini rice mill.
2. Raw rice mill consumed 1.13 per cent more energy in comparison to huller mill and 88.29 per cent more than mini rice mill.
3. Huller mill consumed 86.18 per cent more energy as compared to mini rice mill.
4. Milling of paddy in parboiled rice mill was found to be most profitable. It gave Rs. 2215.72 profit.

5. Raw rice mill, mini rice mill and huller mill gave the profit Rs. 1376.79, 1193.21 and 1097.44.
6. The rate of return per rupee expenditure was found more in parboiled rice mill over all other rice mills.
7. The highest recovery of head yield (68.00 %) was found in parboiled rice milling.
8. The lowest recovery of head yield (59.00 %) was found in huller.

5.3 Suggestions for future research work

The following points may be considered for future work for energy analysis of the different type rice mills:

1. A critical study of energy requirement and losses incurred in various types of rice mills.
2. A study should be conducted for compacting the rice husk in form of blocks or briquettes for better handling and heat utilization.
3. A study should be done to evaluate appropriate capacity of mechanical dryer, furnace and boiler with rice milling plant having parboiling unit so as to suggest ways to produce good quality rice along with improved recovery, save time and thermal energy.
4. Detailed study (micro study) on identifying the points where energy is being wasted, evolving techniques to measure such loss should be carried out to suggest possible way and technology by which this loss/waste could be minimized.

A STUDY ON ENERGY CONSUMPTION IN RICE MILLING USING ENERGY AUDIT PRINCIPLES

ABSTRACT

By

Suneel Kumar Goyal

Energy plays a key role in the socio-economic development of any country. Developing countries have a primary need to formulate strategies to achieve food self sufficiency which are energy efficient. Moreover, the bulk of energy consumed in processing of agricultural products is often being substantial. Hence, it has become essential that effort should be made to conserve energy by its efficient utilization in agricultural production in general and processing of farm produce in particular.

In view of the above, a study was undertaken to determine the energy consumption in post-harvest rice processing operations in selected rice mills viz. raw rice mill (2 t/h), parboiled rice mill (2 t/h), mini rice mill (0.5 t/h) and huller mills (0.6 t/h and 0.5 t/h) at Raipur (Chhattisgarh). The study was designed in such a way that each unit operation was studied closely and the energy input determined experimentally. The electrical energy consumption was measured with an electrical energy meter. The energy meter was connected in the electric circuit of individual machine. The machines were operated without load and with load for 30 minutes and observations of electrical energy consumption of individual machine were taken.

Among all the four types of rice mills, electrical energy consumption per tonne of rice milled was found to be the highest in parboiled rice mill (48.75 kWh) followed by raw rice mill (25.32 kWh), huller mill (20.21 kWh) and the lowest was found in mini rice mill (13.33 kWh). The highest total energy consumption for production of one tonne milled rice was found in parboiled rice mill (923.92 kWh) followed by raw rice mill (36.29 kWh) and huller mill (15.62 KWh), whereas the mini rice mill required minimum (14.42 kWh) energy.

On the basis of economic assessment of rice processing it has been found that the milling of paddy in parboiled rice mill is most profitable as it is given Rs. 2215.72 per tonne of paddy followed by milling in raw rice mill (Rs. 1376.79 per tonne), mini rice mill (Rs. 1193.21 per tonne) and huller (Rs. 1097.44 per tonne) respectively.

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APPENDIX: A-1

Electrical energy consumption for one tonne raw rice milling

No.	Machine	Rated	E. E. C. at no load	E. E. C. at load	N. E. E. C.
		kW	kWh for 30 minutes	kWh for 30 minutes	kWh for 30 minutes
1	Paddy cleaner	5.60	0.40	2.68	2.28
2	Destoner	2.24	0.15	1.09	0.94
3	Rubber roll sheller	7.46	0.90	3.55	2.65
4	Husk blower	1.12	0.30	0.50	0.20
5	Paddy separator	1.12	0.15	0.57	0.42
6	Polisher	22.38	5.85	10.92	5.07
7	Aspirator	1.12	0.30	0.50	0.20
8	Sieve with aspirator	2.24	0.25	1.05	0.80
9	Grader	1.12	0.30	0.55	0.25
10	Elevators (seven)	1.12	0.3×7 =2.1	3.42	1.32
	Total		**10.70**	**24.83**	**14.13**

APPENDIX: A-2

Electrical energy consumption for one tonne parboiled rice milling

No.	Machines	Rated	E. E. C. at no load	E. E. C. at load	N. E. E. C.
		kW	kWh for 30 minutes	kWh for 30 minutes	kWh for 30 minutes
1	Bucket elevator	3.73	1.20	1.72	0.52
2	Paddy cleaner	3.73	0.30	1.75	1.45
3	Hot air blower	18.65	8.50	8.50	0.00
4	Paddy cleaner	3.73	0.25	1.69	1.44
5	Rubber roll sheller	7.46	0.85	3.59	2.74
6	Husk blower	1.12	0.30	0.53	0.23
7	Paddy separator	3.73	0.35	1.69	1.34
8	Polisher-I	14.92	3.40	6.94	3.54
9	Polisher-II	14.92	3.30	6.92	3.62
10	Polisher-III	14.92	3.45	6.94	3.49
11	Aspirator (3 Nos.)	1.12	0.2×3=0.60	1.50	0.90
12	Grader (Sieve type)	1.12	0.25	0.52	0.27
13	Grader	2.24	0.70	0.94	0.24
14	Elevators (11 Nos.)	1.12	0.3×11=3.30	5.5	2.20
Total			**26.75**	**48.73**	**21.98**

E. E. C. – Electrical energy consumption (kWh), N. E. E. C. – Net electrical energy consumption (kWh)

APPENDIX: A-3

Specific electrical energy consumption and electrical energy utilization index for one tonne raw rice milling

No.	Machines	Capacity (t/h)	Specific Electrical Energy Consumption (kWh/t)	Electrical Energy Utilization Index
1	Paddy cleaner	2.80	1.63	0.85
2	Destoner	2.77	0.68	0.86
3	Rubber roll sheller	2.76	1.92	0.75
4	Paddy separator	2.15	0.39	0.73
5	Polisher	2.00	5.07	0.46
6	Aspirator	0.58	0.69	0.38
7	Sieve with aspirator	1.50	1.07	0.76
8	Grader	1.40	0.36	0.45
9	Elevators (7)	12.00	0.22	0.39
Total			**12.98**	

APPENDIX: A-4

Specific electric energy consumption and electrical energy utilization index for one tonne parboiled rice milling

No.	Machines	Capacity (t/h)	Specific Electric Energy Consumption (kWh/t)	Electrical Energy Utilization Index
1	Bucket elevator	3.5	0.29	0.29
2	Paddy cleaner I	3.0	0.97	0.83
3	Paddy cleaner II	2.95	0.98	0.85
4	Sheller	2.8	1.96	0.76
5	Separator	2.19	1.22	0.79
6	Polisher-I	2.10	3.37	0.51
7	Polisher-II	2.00	3.62	0.52
8	Polisher-III	1.90	3.67	0.50
9	Aspirator (3 Nos.)	1.20	1.50	0.60
10	Grader	1.80	0.27	0.26
11	Elevators (11 Nos.)	16	0.28	0.40
	Total		**18.13**	

APPENDIX: A-5

Energy consumption in various operations in parboiled rice mill

No.	Operation	Electrical energy (kWh/t)	Thermal energy (kWh/t)	Manual energy (kWh/t)	Total energy (kWh/t)
1	Cleaning	1.16	-	0.18	1.34
2	Soaking	1.12	525.00	1.09	527.21
3	Steaming	-	75.00	0.16	75.16
4	Drying	8.52	262.50	0.51	271.58
5	Milling	36.20	-	3.55	39.75
6	Weighing and bagging	0.50	-	1.17	1.67
7	Others	7.26	-	-	7.26
	Total	**54.76**	**862.50**	**6.66**	**923.92**

APPENDIX-B

Determination of capacity and effectiveness of machines

(A) Raw Rice mill

Sampling time 1 minute

(1) Paddy cleaner

No.	Replication	Weight of sample (kg)	Capacity (t/h)	Wt. of foreign matter in sample (kg)	Wt. of foreign matter in (kg)		Weight of feed paddy (kg)	Effectiveness
					Feed paddy	Clean paddy		
1	R_1	47.16	2.83	0.28	5.13	0.594	100	0.88
2	R_2	47.40	2.84	0.25	5.42	0.527	100	0.90
3	R_3	47.10	2.83	0.22	5.92	0.467	100	0.92
4	R_4	45.00	2.70	0.20	5.08	0.444	100	0.91
Average		46.67	2.80	0.24	5.39	0.508	100	0.90

(2) Destoner

No.	Replication	Weight of sample (kg)	Capacity (t/h)	Wt. of stones in sample (kg)	Wt. of stones in (kg)		Weight of feed paddy (kg)	Effectiveness
					Feed paddy	Clean paddy		
1	R_1	46.83	2.81	0.25	3.5	0.53	100	0.85
2	R_2	47.10	2.83	.018	3.0	0.38	100	0.87
3	R_3	47.00	2.82	0.20	3.2	0.43	100	0.87
4	R_4	43.30	2.60	0.15	3.3	0.33	100	0.90
Average		46.16	2.77	0.20	3.3	0.42	100	0.87

(3) Rubber Roll Sheller

No.	Replication	Weight of sample (kg)	Capacity (t/h)	Wt. of Shelled rice (kg)	Wt. of Paddy (kg)		Weight of feed (kg)	Effectiveness
					In 100 (kg)	In Sample		
1	R_1	45.1	2.70	87.14	12.86	5.8	100	0.87
2	R_2	48.4	2.90	87.20	12.80	6.2	100	0.87
3	R_3	45.3	2.71	87.86	12.14	5.5	100	0.88
4	R_4	45.5	2.72	88.79	11.21	5.1	100	0.89
Average		46.0	2.76	87.74	12.25	5.7	100	0.88

(4) Paddy separator (Indented tray type)

No.	Replication	Weight of sample (kg)	Capacity (t/h)	Wt. of paddy in sample (kg)	Wt. of Paddy (kg)		Weight of feed (kg)	Effectiveness
					In 100(kg)	In Sample		
1	R_1	35.18	2.11	0.50	12.86	1.42	100	0.89
2	R_2	37.65	2.26	0.48	12.80	1.27	100	0.90
3	R_3	35.01	2.10	0.55	12.14	1.57	100	0.87
4	R_4	35.10	2.12	0.53	11.21	1.51	100	0.86
Average		35.73	2.15	0.52	12.25	1.44	100	0.88

(5) Polisher

No.	Replication	Weight of sample (kg)	Capacity (t/h)	Wt. of head rice in sample (kg)	Wt. of broken rice (kg)		Weight of feed brown rice (kg)	Effectiveness
					In 100(kg)	In Sample		
1	R_1	30.0	1.80	77.5	22.5	6.60	100	0.78
2	R_2	34.2	2.05	76.00	23.0	7.82	100	0.78
3	R_3	35.0	2.10	76.00	23.0	8.00	100	0.78
4	R_4	34.1	2.05	77.00	22.0	7.48	100	0.78
Average		33.4	2.00	76.63	22.63	7.48	100	0.78

(6) Aspirator

No.	Replication	Weight of sample (kg)	Capacity (t/h)	Wt. of bran in sample (kg)	Wt. of bran (kg)		Weight of feed (kg)	Effectiveness
					In feed (kg)	In sample		
1	R_1	9.0	0.540	0.0564	4.26	0.627	100	0.85
2	R_2	8.1	0.486	0.0434	4.00	4.000	100	0.87
3	R_3	8.4	0.504	0.0468	4.10	0.557	100	0.87

4	R_4	8.1	0.486	0.0390	4.00	0.481	100	0.88
Average		8.4	0.500	0.0464	4.10	0.550	100	0.87

(7) Grader (Sieve type)

No.	Replication	Weight of sample (kg)	Capacity (t/h)	Wt. of head rice (kg)	Wt. of bran (kg)		Weight of broken in feed (kg)	Weight of feed, polished rice (kg)	Effectiveness
					In feed	In sample			
1	R_1	23.40	1.40	75.00	5.77	1.35	25.00	100	0.77
2	R_2	24.17	1.45	71.20	6.20	1.50	28.00	100	0.78
3	R_3	22.50	1.35	71.00	5.69	1.28	29.00	100	0.80
4	R_4	23.30	1.40	73.70	5.67	1.32	26.30	100	0.78
Average		23.34	1.40	72.72	5.83	1.36	27.28	100	0.78

(B) Parboiled Rice mill

Sampling time 1 minute

(1) Paddy cleaner

No.	Replication	Weight of sample (kg)	Capacity (t/h)	Wt. of foreign matter in sample	Wt. of foreign matter (kg)		Weight of feed paddy (kg)	Effectiveness
					Feed paddy	Clean paddy		

				(kg)				
1	R_1	50.00	3.0	0.35	5.82	0.70	100	0.87
2	R_2	51.67	3.1	0.42	5.98	0.81	100	0.86
3	R_3	48.34	2.9	0.30	5.40	0.62	100	0.88
4	R_4	49.80	3.0	0.35	5.65	0.70	100	0.88
Average		49.95	3.0	0.36	5.70	0.70	100	0.88

(2) Paddy Sheller

No.	Replication	Weight of sample (kg)	Capacity (t/h)	Wt. of Shelled rice (kg)	Wt. of Paddy (kg)		Weight of feed (kg)	Effectiveness
					In 100 kg	In sample		
1	R_1	47.5	2.85	86.95	13.05	6.2	100	0.87
2	R_2	48.4	2.90	87.60	12.40	6.0	100	0.88
3	R_3	45.0	2.70	88.60	11.40	5.1	100	0.89
4	R_4	45.8	2.75	88.43	11.57	5.3	100	0.88
Average		46.7	2.80	87.88	12.10	5.7	100	0.88

(3) Paddy separator (Compartment type)

No.	Replication	Weight of sample (kg)	Capacity (t/h)	Wt. of paddy in sample (kg)	Wt. of Paddy (kg)		Weight of feed (kg)	Effectiveness
					In 100(kg)	In Sample		
1	R_1	37.00	2.22	0.62	13.05	1.68	100	0.87
2	R_2	38.40	2.30	0.60	12.40	1.56	100	0.87
3	R_3	35.00	2.10	0.57	11.40	1.62	100	0.86
4	R_4	35.84	2.15	0.58	11.57	1.62	100	0.86
Average		36.56	2.19	0.59	12.10	1.62	100	0.87

(4) Polisher

No.	Replication	Weight of sample (kg)	Capacity (t/h)	Wt. of head rice in sample (kg)	Wt. of broken rice (kg)		Weight of feed brown rice (kg)	Effectiveness
					In 100(kg)	In Sample		
1	R_1	35.00	2.10	81.50	18.50	6.30	100	0.82
2	R_2	32.50	1.95	81.50	15.50	5.85	100	0.82
3	R_3	35.85	2.15	81.00	19.00	6.81	100	0.81
4	R_4	30.85	1.85	80.50	19.50	5.86	100	0.81
Average		33.55	2.01	81.13	18.88	6.20	100	0.82

(5) Aspirator

No.	Replication	Weight of sample (kg)	Capacity (t/h)	Wt. of bran in sample (kg)	Wt. of bran (kg)		Weight of feed (kg)	Effectiveness
					In feed (kg)	In sample		
1	R_1	8.10	0.486	0.0472	0.583	4.0	100	0.85
2	R_2	5.70	0.342	0.0385	0.675	3.2	100	0.79
3	R_3	6.50	0.390	0.0420	0.646	3.6	100	0.82
4	R_4	6.36	0.382	0.0400	0.629	3.8	100	0.83
Average		6.67	0.400	0.0419	0.633	3.7	100	0.83

(6) Grader

No.	Replication	Weight of sample (kg)	Capacity (t/h)	Wt. of head rice (kg)	Wt. of bran (kg)		Weight of broken in feed (kg)	Weight of feed, polished rice (kg)	Effectiveness
					In feed	In sample			
1	R_1	29.17	1.75	76.4	0.600	2.06	23.60	100	0.91
2	R_2	30.84	1.85	75.8	0.585	1.96	24.20	100	0.92
3	R_3	31.34	1.88	77.5	0.625	2.00	22.50	100	0.91
4	R_4	28.67	1.72	76.6	0.540	1.89	23.40	100	0.92
Average		30.00	1.80	76.84	0.588	1.98	23.16	100	0.92

Appendix: C

Energy consumption in parboiled rice mill

(1) Energy consumption in pre-parboiling

(a) Electrical energy = $\left(\dfrac{6.93 \times 10}{60}\right) = 1.155\ kWh$

(b) Manual energy

$$\frac{2 \times 10}{60} = 0.333 \text{ Man-hr}$$

$$0.333 \times 1.96 = 0.653 \text{ MJ}$$

$$= 0.181 \text{ kWh}$$

Total energy consumption = 1.155 + 0.181 = 1.336 kWh

Per tonne energy consumed = $\dfrac{1.336}{0.8} = 1.67$ kWh

1. Energy consumed in parboiling of paddy

Quantity of paddy handled	=	3.5 t
Husk feeding rate	=	150 kg/h
Duration of water heating (25^0 - 85^0C)	=	3.5 h
Duration of soaking	=	3.5 h
Duration of steaming	=	0.5 h
Steam generation rate	=	145 kg/h
Capacity of water tank	=	8 m^3

(a) Energy consumed in soaking

= soaking time × wt. of husk × calorific value of husk

= 3.5×150×3000

= 1575000 kcal

= 1837.5 kWh

Thermal energy consumed in soaking = $\frac{1837.5}{3.5}$ = **525 kWh/t**

(b) Energy consumed for steaming

= steaming time × wt. of husk × calorific value of husk

= 0.5×150×3000

= 225000 kcal

= 262.5 kWh

Thermal energy consumed in steaming = $\frac{262.5}{3.5}$ = **75 kWh/t**

Total energy consumed = 1837.5 + 262.5 = 2100 kWh

Electrical energy consumption by 3 hp motor (hot water circulation) for soaking operation of 0.5 h = 3× 0.746×0.5

=1.119 kWh

Manual energy consumed (2 labours) = (3.5 + 0.5) × 2

= 8 man-hr

= 4.63 kWh

Manual energy consumed in soaking operation = 3.5× 2

= 7 man-hr

= 3.81 kWh

= **1.089 kWh/t**

Manual energy consumed in steaming operation = 0.5×2

= 1 man-hr

= 0.544 kWh

= **0.155 kWh/t**

Total specific energy consumption

$$= \frac{2100 + 1.119 + 4.36}{3.5} = \frac{2105.48}{3.5} = \mathbf{601.57\ kWh/t}$$

2. Theoretical heat requirement for parboiling:

(a) Initial moisture content of paddy	=	16 % (w. b.)
(b) Final moisture content of paddy	=	50 % (w. b.)
(c) Bulk density	=	584 kg/m^3
(d) Porosity of paddy	=	50 % (assume)
(e) Initial temperature of paddy	=	25^{0}C
(f) Temperature of paddy just after soaking	=	65^{0}C
(g) Temperature of soaking water	=	85^{0}C
(i) Temperature of paddy and water mixture	=	70^{0}C
(j) Temperature of paddy just after steaming	=	100^{0}C
(k) Specific heat of paddy	=	0.45 kcal/kg-^{0}C
(l) Sensible heat of water	=	25^{0}C

(i) Soaking operation

Wt. of water required to fill the pore space of paddy

$$W_p = \frac{W_d \times \eta \times 1000}{B_d}$$

$$= \frac{3500 \times 0.5 \times 1000}{584}$$

=2996.58 kg = 2.997 m^3 or liter

$$W = W_d \left(\frac{m - m_0}{100} \right) + W_p$$

$$= 3500 \left(\frac{50 - 16}{100} \right) + 2997$$

= 4187 kg

Heat required rising the temperature of water from 25^0C – 85^0C

$$E_1 = m \times s \times \Delta t_1$$

= 4187× (85 - 25) ×4.2

= 1055124 kJ

= 293.09 kWh

= 83.74 kWh/t

(ii) Steaming operation

Heat consumed by paddy in steaming operation

$$E_2 = \left(W_p \times C_p \times \Delta t_2\right) + \left(W_d \times C_w \times \Delta t_2\right)$$

= [2310×0.45× (100-65)] + [1190×1× (100-65)]

=35574+41650

= 77224 kcal

= 90.09 kWh

= 25.74 kWh/t

(iii) Energy consumption in drying

(a) Capacity of L. S. U. dryer	=	2 t
(b) Duration of drying	=	6 h
(c) Husk feeding rate	=	150 kg/h
(d) Electrical energy consumed	=	17.03 kWh
(e) Human labour	=	12 nos.
(f) Initial moisture content of paddy	=	50 % (w. b.)
(g) Final moisture content of paddy	=	16 % (w. b.)
(i) Air flow rate	=	3600 m^3/h
(j) Density of air	=	0.865 kg/m^3 (assume)
(k) Ambient air temperature	=	25^0C (assume)
(l) Specific heat of air	=	0.24 kJ/kg (assume)
(m) Heated air temperature	=	85^0C

Actual heat utilized by paddy during drying in 6 h

$$E_d = A_r \times d \times C_a \times \Delta t_3 \times T_d$$

= (60×60) ×0.865×0.24× (85-25) ×6

= 269049.6 kcal

= 313.89 kWh

= **26.16 kWh/t**

Actual heat produced in drying from husk

= wt. of husk × time× calorific value of husk

= 150×6×3000

= 2700000 kcal

= 3150 kWh

= **262.5 kWh/t**

Energy consumed in drying = $\left(\dfrac{W_{dr} \times C_f + E_{el} \times T \times M_h}{Q_{dr}}\right)$

$$= \frac{150 \times 3.5 + 17.03 \times 6 + 6.53}{12}$$

= **52.08 kWh/t**

Electrical energy consumed in drying = 17.03×6

= 102.18 kWh

= **8.52 kWh/t**

Manual energy consumed in drying

Man labour = 8 nos.

= 8×1.96 = 15.68 MJ

= 4.36 kWh

= **0.363 kWh/t**

Woman labour = 4 nos.

= 4×1.57 = 6.28 MJ

= 1.74 kWh

= **0.145 kWh/t**

Total energy consumed in drying $= \dfrac{3150 + 102.18 + 4.36 + 1.75}{12}$

= **271.52 kWh/t**

3. Energy consumed in milling

Electrical energy consumed = 72.5 kWh

= 36.3 kWh/t

Manual energy consumed

Man labour = 5 nos.

= 5×1.97 = 9.8 MJ

= 2.722 kWh

= 1.361 kWh/t

Woman labour (Reja) = 10 nos.

= 10×1.57 = 15.7 MJ

= 4.361 kWh

= 2.185 kWh/t

Total energy consumed in milling $= \frac{72.4 + 2.722 + 4.361}{2}$

= **39.7 kWh/t**

4. Weighing and bagging

Manual energy

Manual labour = 3 nos.

= 3×1.96 = 5.88 MJ

= 1.63 kWh

= 1.17 kWh/t

Electrical energy = 0.5 kWh/t

Total energy consumed in Weighing and bagging = 1.17+0.5

= **1.67 kWh/t**

Other appliances as lights, fans etc. generally use about 15 % of total electricity consumed (De, 2002).

Electricity used in mill = 48.75 kWh/t

Electricity consumed by other appliances = $\frac{48.75 \times 15}{100}$ = **7.31 kWh/t**

Total energy consumed in whole parboiled rice mill of paddy processing

= 1.67+601.57+271.52+39.75+1.67+7.3

= **923.92 kWh/t**

Appendix: D

Economic analysis of rice mills

1. **Modern rice mills**

(i) Raw rice mill

Recovery = 65 %

Return after paddy processed

No.	Products/ byproducts	Per cent	Quantity (t)	Rate (Rs/t)	Amount (Rs)
1	Head rice	67	0.436	11000	4796.00
2	Broken rice	24	0.156	7500	1170.00
3	Small rice broken	9	0.059	5000	115.50
4	Bran	5	0.033	3500	165.00
5	Husk	22	0.220	750	295.00
	Total				6541.40

* Impurities = 8 %

Expenditure:

1. Electricity charge @ Rs. 3.51per kWh, 3.51×25.32 = Rs. 88.87
2. Extra electricity charge @ Rs. 3.51 per kWh, 3.51×3.80 = Rs. 13.34
3. Labour charge

   (a) Man @ Rs. 6.25/h 6×6.25 = Rs. 37.50

   (b) Woman @ Rs. 5.00/h 5×5 = Rs. 25.00

   Total processing cost = Rs. 164.71

Cost of raw paddy = Rs. 5000.00

Total expenditure = Rs. 5164.71

Profit due to processing = 6 541.50 – 5164.71

= Rs. 1376.79

(ii) Parboiled rice mill

Recovery = 68 %

Return after paddy processed

No.	Products/ byproducts	Per cent	Quantity (t)	Rate (Rs/t)	Amount (Rs)

1	Head rice	77	0.524	12000	6288.00
2	Broken rice	17	0.116	8000	928.00
3	Small rice broken	6	0.041	5000	205.00
4	Bran	6	0.041	4000	164.00
5	Husk	20	0.20	750	150.00
	Total				7735.00

* Impurities = 6 %

Expenditure:

1. Electricity charge @ Rs. 3.51per kWh, 3.51× 48.75 = Rs. 171.11

2. Extra electricity charge @ Rs. 3.51 per kWh, 3.51×7.31 = Rs. 25.67

3. Labour charge

(a) Man @ Rs. 6.25/h 10×6.25 = Rs. 62.50

(b) Woman @ Rs. 5.00/h 7×5 = Rs. 35.00

4. Husk @ Rs. 750/t, 0.3×750 = Rs. 225.00

Total processing cost = Rs. 519.28

Cost of raw paddy = Rs. 5000.00

Total expenditure = Rs. 5519.28

Profit due to processing = 7735.00 – 5519.28

= Rs. 2215.72

2. Mini rice mill

Recovery = 68 %

Return after paddy processed

No.	Products/ byproducts	Per cent	Quantity (t)	Rate (Rs/t)	Amount (Rs)

1	Head rice	74	0.503	10000	5030.00
2	Broken rice	20	0.136	7000	952.00
4	Bran	6	0.041	2500	102.50
5	Husk	24	0.240	700	168.00
	Total				6252.50

* Impurities = 2 %

Expenditure:

1. Electricity charge @ Rs. 3.51per kWh,   3.51×13.33   =   Rs. 46.79
2. Labour charge

   Man @ Rs. 6.25/h   2×6.25   =   Rs. 12.50

   Total processing cost   =   Rs. 59.29

Cost of raw paddy   =   Rs. 5000.00

Total expenditure   =   Rs. 5059.29

Profit due to processing   = 6 252.50 – 5059.29

= Rs. 1193.21

4. Huller mill

Recovery = 59 %

Return after paddy processed

No.	Products/ byproducts	Per cent	Quantity (t)	Rate (Rs/t)	Amount (Rs)
1	Head rice	70	0.413	10000	4130.00
2	Broken rice	30	0.177	6000	1062.00
4	Kodha (husk + bran+ small brokens)	41	0.410	2500	1025.00
	Total				6217.00

Expenditure: (In two passes)

1. Electricity charge @ Rs. 3.51per kWh, $3.51 \times 13.47 \times 2$ = Rs. 94 .56 2.

Labour charge

Man @ Rs. 6.25/h $2 \times 6.25 \times 2$ = Rs. 25.00

Total processing cost = Rs. 119.56

Cost of raw paddy = Rs. 5000.00

Total expenditure = Rs. 5119.56

Profit due to processing = 6 217.00 – 5119.56

= Rs. 1097.44

APPENDIX: A-6

Electrical energy consumption in raw rice mill

(Time of operation – 30 minutes)

No.	Machine	Rated kW	E. E. C. at no load (kWh)	E. E. C. at load R_1 (kWh)	N. E. E. C. (kWh)	E. E. C. at load R_2 (kWh)	N. E. E. C. (kWh)	E. E. C. at load R_3 (kWh)	N. E. E. C. (kWh)	E. E. C. at load R_4 (kWh)	N. E. E. C. (kWh)	Average E. E. C. at load (kWh)	Average N. E. E. C. (kWh)
1	Cleaner	5.6	0.40	2.55	2.15	2.65	2.25	2.75	2.35	2.75	2.35	2.68	2.28
2	Destoner	2.24	0.15	1.10	0.95	1.20	1.05	1.00	0.85	1.05	0.90	1.10	0.94
3	Sheller	7.46	0.90	3.65	2.75	3.65	2.75	3.60	2.70	2.30	2.40	2.55	2.65
4	Husk blower	1.12	0.30	0.50	0.20	0.55	0.25	0.50	0.20	0.45	0.15	0.50	0.20
5	Separator	1.12	0.15	0.60	0.45	0.50	0.35	0.55	0.40	0.60	0.45	0.57	0.42
6	Polisher	22.38	5.85	10.90	5.05	11.00	5.15	10.80	4.95	10.95	5.10	10.92	5.07
7	Aspirator	1.12	0.30	0.45	0.15	0.50	0.20	0.45	0.15	0.55	0.25	0.50	0.20
8	Sieve with aspirator	2.24	0.25	1.00	0.75	1.05	0.80	1.15	0.90	1.00	0.75	1.05	0.80
9	Grader	1.12	0.30	0.60	0.30	0.50	0.20	0.55	0.25	0.55	0.25	0.55	0.25
10	Elevators (7)	1.12	2.10	3.50	1.40	3.15	1.05	3.85	1.75	3.15	1.05	3.42	1.32
	Total		**10.70**	**24.85**	**14.15**	**24.75**	**28.05**	**25.20**	**14.50**	**24.35**	**13.65**	**24.83**	**14.13**

E. E. C. – Electrical energy consumption (kWh), N. E. E. C. – Net electrical energy consumption (kWh), R - Replications

APPENDIX: A-7

Electrical energy consumption in parboiled rice mill

(Time of operation – 30 minutes)

No.	Machine	Rated kW	E. E. C. at no load	E. E. C. at load R_1	N. E. E. C.	E. E. C. at load R_2	N. E. E. C.	E. E. C. at load R_3	N. E. E. C.	E. E. C. at load R_4	N. E. E. C.	Average E. E. C. at load	Average N. E. E. C.
			(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	Bucket type elevator	3.73	1.20	1.75	0.55	1.65	0.45	1.75	0.50	1.70	0.50	1.72	0.52
2	Cleaner	3.73	0.30	1.70	1.40	1.75	1.45	1.75	1.45	1.80	1.50	1.75	1.45
3	Hot air blower	18.65	8.50	8.50	0.00	8.50	0.00	8.50	0.00	8.50	0.00	8.50	0.00
4	Cleaner	3.73	0.25	1.75	1.50	1.60	1.35	1.70	1.49	1.70	1.45	1.69	1.44
5	Sheller	7.46	0.85	3.65	2.80	3.55	2.70	3.50	2.65	3.65	2.80	3.59	2.74
6	Husk blower	1.12	0.30	0.55	0.25	0.50	0.20	0.50	0.20	0.55	2.50	0.53	0.23
7	Separator	3.73	0.35	1.75	1.40	1.60	1.25	1.65	1.30	1.75	1.40	1.69	1.34
8	Polisher I	14.92	3.40	7.05	3.65	6.80	3.40	6.90	3.50	7.00	3.60	6.94	3.54
9	Polisher II	14.92	3.30	6.80	3.50	6.90	3.60	7.00	3.70	6.95	3.65	6.92	3.62
10	Polisher III	14.92	3.45	7.05	3.60	6.90	3.45	6.85	3.40	6.95	3.50	6.94	3.49
11	Aspirator (3)	1.12	0.20×3 =0.60	0.45×3 =1.35	0.25×3 =0.75	0.50×3 =1.50	0.30×3 =0.90	0.5×3 =1.50	0.30×3 =0.90	0.55×3 =1.65	0.35×3 =1.05	1.50	0.90
12	Grader (sieve type)	1.12	0.25	0.50	0.25	0.50	0.25	0.50	0.30	0.50	0.25	0.52	0.27
13	Grader	2.24	0.70	0.95	0.25	1.00	0.30	0.55	0.20	0.90	0.20	0.94	0.24
14	Elevators (11)	1.12	0.30×11 =3.30	0.45×11 =4.95	0.15×11 =1.65	0.5×11 =5.50	0.2×11 =2.20	0.55×11 =6.05	0.25×11 =2.75	0.5×11 =5.50	0.2×11 =2.20	5.50	2.20
	Total		**26.75**	**48.30**	**21.55**	**48.25**	**21.50**	**49.10**	**22.35**	**49.10**	**22.40**	**48.7**	**21.98**

E. E. C**. –** Electrical energy consumption (kWh), N. E. E. C. – Net electrical energy consumption (kWh), R - Replications

APPENDIX: A-8

Electrical energy consumption in huller mills

(Time of operation – 30 minutes)

No.	Machine	Rated kW	E. E. C. at no load	E. E. C. at load R_1	N. E. E. C.	E. E. C. at load R_2	N. E. E. C.	E. E. C. at load R_3	N. E. E. C.	E. E. C. at load R_4	N. E. E. C.	Average E. E. C. at load	Average N. E. E. C.
			(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	Huller-I	11.19	2.4	4.10	1.7	3.9	1.5	3.75	1.35	4.0	0.6	3.94	1.54
2	Huller-II	7.46	2.1	3.35	1.25	3.5	1.4	3.45	1.35	3.5	1.4	3.45	1.35

Electrical energy consumption in mini rice mills

No.	Machine	Rated kW	E. E. C. at no load	E. E. C. at load R_1	N. E. E. C.	E. E. C. at load R_2	N. E. E. C.	E. E. C. at load R_3	N. E. E. C.	E. E. C. at load R_4	N. E. E. C.	Average E. E. C. at load	Average N. E. E. C.
			(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	Mini rice mills	7.46	2.10	3.33	1.23	3.46	1.36	3.33	1.23	3.33	1.23	3.37	1.27

E. E. C. – Electrical energy consumption (kWh), N. E. E. C. – Net electrical energy consumption (kWh), R - Replications

Table-4.7 Comparison of findings of present investigation and study done by Bakhara *et al.* (1991) on operation wise energy consumption in parboiled rice mill

No.	Operations	Electrical energy (kWh/t)		Thermal energy (kWh/t)		Manual energy (kWh/t)		Total energy (kWh/t)	
		Bakhara *et al.* (1991)	**Present study**	**Bakhara *et al.* (1991)**	**Present study**	**Bakhara *et al.* (1991)**	**Present study**	**Bakhara *et al.* (1991)**	**Present study**
1	Cleaning	1.16	1.16	-	-	0.012	0.18	1.17	1.34
2	Parboiling	0.31	1.19	167.00	600.00	0.025	1.25	167.33	602.37
3	Drying	11.75	8.66	314.03	262.50	0.075	0.51	325.86	271.67
4	Milling	29.84	36.20	-	-	0.150	3.55	30.00	39.75
5	Weighing & bagging	-	0.50	-	-	0.130	1.17	0.13	1.67
6	Others	-	7.26	-	-	-	-	-	7.26
	Total	**43.06**	**54.76**	**481.03**	**862.50**	**0.392**	**6.66**	**524.82**	**923.92**

Table - 4.8 Comparison of findings of present investigation and study done by Borah *et al.* (1991) on operation wise energy

consumption in raw and parboiled rice mill

No.	Machines	Electrical energy consumption (kWh) in study done by Borah *et al.* (1991) for production of 2t/h rice						Electrical energy consumption (kWh) in present study for production of 2t/h rice			
		Plant 'A' (Raw)		Plant 'B' (Parboi.)		Plant 'C' (Parboi.)		Plant 'A' (Raw)		Plant 'B' (Parboi.)	
		No load	At load	No load	At load	No load	At load	No load	At load	No load	At load
1	Bucket elevator	-	-	-	-	-	-	-	-	2.40	3.43
2	Pre-cleaner	0.18	2.75	0.28	2.82	0.26	2.29	0.80	5.35	1.10	6.88
3	Hot air blower	-	-	-	-	-	-	-	-	8.50	8.50
4	Destoner	-	-	-	-	-	-	0.30	2.18	-	-
5	Sheller	0.29	1.54	0.28	1.40	0.52	1.80	1.80	7.10	1.70	7.18
6	Husk aspirator	2.00	3.75	2.35	4.10	2.26	3.96	-	-	-	-
7	Husk blower	-	-	-	-	-	-	0.60	1.0	0.60	1.05
8	Paddy separator	1.47	1.65	1.12	1.53	1.33	1.59	0.30	1.13	0.70	3.38
9	Polishers*	3.50	13.96	6.81	29.80	11.84	33.53	11.70	21.83	20.30	41.59
10	Aspirators**	-	-	-	-	-	-	0.60	1.00	1.20	3.00
11	Jet pearler	2.94	8.95	2.03	2.83	2.26	3.51	-	-	-	-
12	Sieve with aspirator		-	-	-	-	-	0.50	2.10	0.50	1.03
13	Grader	1.45	2.15	0.75	-	0.53	-	0.60	1.10	1.40	1.88
14	Elevators***	0.42	-	-	-	-	-	4.20	6.83	6.60	11.00
15	Shaft	15.78	15.78	18.98	18.98	19.60	19.60	-	-	-	-
Total		**28.03**	**50.50**	**32.60**	**61.46**	**38.60**	**65.92**	**21.40**	**49.56**	**45.00**	**97.46**

In study done by Borah *et al.* (1991), * 2 Nos. in plant A, 3 Nos. in plant B and 4 nos. in plant C
In present study (1) * 1 No. in plat A and 3 Nos. in plant B, ** 3 Nos. in plant B. (2) *** 7 Nos. in plant A and 11 Nos. in plant B.