J Food Sci Technol (November 2014) 51(11):2907–2916
DOI 10.1007/s13197-012-0747-3

REVIEW

Energy use pattern in rice milling industries—a critical appraisal

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Revised: 15 April 2012 / Accepted: 17 May 2012 / Published online: 7 June 2012

Abstract Rice milling industry is one of the most energy consuming industries. Like capital, labour and material, energy is one of the production factors which used to produce final product. In economical term, energy is demand-derived goods and can be regarded as intermediate good whose demand depends on the demand of final product. This paper deals with various types of energy pattern used in rice milling industries viz., thermal energy, mechanical energy, electrical energy and human energy. 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, cleaning, sun drying, feeding paddy to the bucket elevators, weighing and packaging, etc. So the man-hours are also included in energy accounting. Water is used for soaking and steam generation. Electricity is the main energy source for these rice mills and is imported form the state electricity board grids. Electricity is used to run motors, pumps, blowers, conveyors, fans, lights, etc. The variations in the consumption rate of energy through the use of utilities during processing must also accounted for final cost of the finished product. The paddy milling consumes significant quantity of fuels and electricity. The major energy consuming equipments in the rice milling units are; boilers and steam distribution, blowers, pumps, conveyers, elevators, motors, transmission systems, weighing, etc. Though, wide variety of technologies has been evolved for efficient use of energy for various equipments of rice mills, so far, only a few have improved their energy efficiency levels. Most of the rice mills use old and locally available technologies and are also completely dependent on locally available technical personnel.

Keywords Paddy · Post-harvest operations · Rice · Energy requirement · Energy production system · Energy consumption

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Introduction

Rice is an important food crop in India and second most important crop in the world. It is the staple food for the world's most densely populated region and for hundreds of millions in Asia, Africa and Latin America. In India, rice processing is the oldest and the largest agro processing industry. At present it has a turnover of more than Rs. 36,500 crores per annum. India processes about 85 million tones of paddy per year and provides staple foodgrain and other valuable products required by the population. Recently, more than 50 % of the overall rice production is processed by modern mills, 40 % by conventional mills, and the remaining 10 % by hand pounding (Shweta et al. 2011).

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 (Bakhara et al. 1991). 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 (Baqui et al. 2007). 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 (Borah and Prasad 1993). 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 is the staple food for 65 % of the population in India. It is the largest consumed calorie source among the food grains. With a per capita availability of 73.8 kg it meets 31 % of the total calorie requirement of the population. India is the second largest producer of rice in the world next to China. The all India area, production, and yield of rice in the year 2009-10 was 45.32 million hectares, 91.12 million tonnes and 2,089 kg/ha, respectively. In India paddy occupies the first place both in area and production (FAO 2010). Country has been producing a significant quantity of staple food grains for the last few decades. The rice production has also increase to meet the demand of the increased population of the country. This bulk quantity of rough rice is produced locally; both in households and at commercial levels and thousands of people are engaged in the rice processing sector. Energy requirements are a great concern fro processing of this bulk amount of rice (Shweta et al. 2011).

In this paper the energy requirement of for rice processing at commercial level is discussed. There are two types of mills engaged in rice processing i.e. conventional and modern rice mills. *Conventional rice mills*: Conventional rice mills are the units, in which the paddy processing is carried out by using steel hullers, an age old technology which is inefficient. Different activities like cleaning, drying, grading, polishing etc. are carried out manually. *Modern rice mills*: Modern rice mills are the units, in which the paddy processing is carried out by using rubber roll shellers, a modern technology which is more efficient. Majority of the activities are carried out using machineries like driers, aspirators, graders, polishers etc. Different stages of paddy processing in commercial rice mills are followed viz., parboiling process, drying of parboiled paddy and finally milling operation to get finished product.

Rice milling industry is the largest agro-based industry in India. In 2009, India had approximately 1,74,296 rice milling units. The number of hullers was 95,808, shellers 6,724 huller-cum-shellers 10,540 and modern/modernized rice mill 36,088, respectively (MoFPI 2010). Information related energy used pattern in rice mills is vital for developing work plan to acquire better control over processing 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, cleaning, sun drying, weighing and bagging. 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, lights, etc. (Shweta et al. 2011). The variations in the consumption rate of energy through the use of utilities during processing must also accounted for final cost of the finished product (Gautam et al. 1988). The efficient utilization of energy is a great challenging task to the researchers.

Rice industry is one of the most energy consuming industries (Gupta and George 2009). It uses rice husk as a fuel. 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 (Baqui et al. 2007). 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.

The term milling, in connection with the traditional method of processing or huller mills means removal of husk, bran and a part of endosperm in a single operation. This results in a mixture containing husk, bran and brown rice. In a huller mill, a metallic roller is used as a milling unit cleaned by a fixed or vibratory screen and/or fan. The huller mills are low capacity units handling 300–500 kg/h of paddy and in these, it is difficult to regulate the degree of polish and rice is generally over-polished. Broken percentage is 20–30 %. Also husk gets powdered alongwith the bran and thus rendering it uneconomical for extraction of bran oil (Aravllo et al. 1976).

In modern method of processing, the term milling encompasses cleaning, drying, dehusking, aspirating of husk, separating paddy and brown rice, polishing to remove bran and grading rice and broken. A modern rice mill consists of a paddy pre-cleaning system which sieves and aspirators, efficient paddy separators, improved rice whiteners, graders and auxiliary equipment such as elevators, conveyors, automatic weighing machine. Parboiling is a pre-milling most-heat treatment given to raw paddy in order to improve its milling quality, nutritive value, cooking quality and storability. Equipments for parboiling and drying have been installed in some modern rice mills. If parboiling operation is used then, there is an overall increase in total rice recovery of about 6 % over huller mills and 10–20 % reduced percentage of broken (Houston 1972). If different sets of machines are used then all the by-products viz.; husk, bran and broken are obtained in a useable form and this rice milling system may be energy intensive.

Energy requirements for post harvest operations of paddy

Energy requirement for milling of rice depends on the quality and type of grains, process, equipment and other parameters. These include grain quality, uniformity of grain size, grain hardness, quality of final product, type/capacity/age/combination of equipment used, fuel or power source, efficiency of drives and power transmission (Roy et al. 2008). Such a variety of factors affecting the energy requirements in rice milling industries.

Parboiling and drying

Parboiling is a hydrothermal pre-milling treatment is done in tree steps, viz., soaking, steaming and drying. The main factors involved in controlling the quality of parboiling rice are soaking time and temperature; steaming pressure time and stages, tempering time and drying time, temperature stages, these factors vary from mill to mill. Although, the equipments and steps followed in most of the mills are same, yet their energy management is different (Sehgal et al. 1982).

Bhattacharya (1985) estimated the energy requirement of various parboiling methods. The energy requirement of RPEC method was 9.54×10^5 J/kg of paddy, CFTRI method 16.4×10^5 J/kg of paddy and pressure parboiling 3.75×10^5 J/kg of paddy, respectively. 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 as: in *soaking* process the hot water requirement for soaking one tonne of paddy was estimated to be 1,200 kg. The heat required raising the temperature of water from 25 °C–85 °C was calculated as 72,000 kcal (83.72 kWh). The *steaming* operation, if carried out immediately after the soaking, needed about 21,000 kcal (24.42 kWh) per tonne of paddy. *Drying* operation required hot air at 80 °C 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 (159.30 kWh) per tonne of paddy. Hence, the energy requirement for complete parboiling operation came to 2,30,000 kcal (267.47 kWh) per tonne of paddy produced. According to Sehgal and Bhatnagar (1987) the energy input for processing of one tonne of paddy ranged from 350 to 920 kWh. Generally, non-uniform energy input trends were observed in different parboiling and drying processes (Basu 1966). The parboiling and drying operations consumed more than 90 % of total energy required in a rice milling system (FAO, 1969 and Islam et al. 2004). 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 (Baqui et al. 2010). 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 4.7×10^9 and 1.86×10^8 kWh/year, respectively. The total energy requirement for the rice industry was 4.86×10^9 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 (Gupta 1966 and Anonymous 2006). It is estimated that 50 % of paddy processed in India is parboiled paddy by using various methods of parboiling (Basu 1966). Drying is 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 Table 1. In a study conducted by 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 is worked out to be 66.94, 108.61, 108.61, 118 and 75.27 kWh/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 229.72 kWh/t of paddy.

Dash et al. (1994) conduct a study on milling capacity and energy utilization of rice mills in the state of Orissa and found that parboiled and milling sections of rice mills of the state consumed 1.682×10^{10} and 6.695×10^{10} MJ/year, respectively. Thus, total energy requirement for the industry was 1.749×10^{10} MJ/year. The manual energy input was also calculated. De (2002) reported that parboiling and drying

Table 1 Energy demand of rice processing operations (Kapur et al. 1994)

Operation	System/method	Energy demand, MJ/t	
		Raw	Parboiled
Milling[a]	Huller	144.0	164
	Sheller	108.0	123
	Modern rice mill	79.2	90
Parboiling[b]	Single steaming	–	241
	Double steaming	–	391
	Open drum	–	391
	Hot soaking and steaming	–	425
	Pressure parboiling	–	271
Drying[b]		–	827

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

[b] 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

operations required thermal energy. The useful thermal energy intensity for parboiling had been estimated to be ranged between 66.94 kWh/t and 118 kWh/t of paddy for different methods of parboiling (Bakari et al. 2010). The traditional single steaming method requires minimum energy, while hot soaking and steaming method require the maximum energy as quoted by Kapur et al. (1997b). The thermal energy intensity of drying had been estimated to be 230 kWh/t of paddy. The total electrical energy consumption in cleaning, drying, milling, grading and packaging, office and boiler in white rice mill was approximately 190 MJ/t paddy and 238 MJ/t paddy in a parboiled rice mill (Ekasilp et al. 1995).

Energy requirement for milling

Anonymous (1966) reported 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 % lower as compared to Binny type mill and 8–10 % 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 one tonne of rice was 25 kWh or 6.9 l 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) found the power requirements of different types of rice mills i.e. Dandekar, Binny, Kisan and Satake mills. The milling capacities of these mills were 2.5, 4.0, 5.0 and 9.0 t/h, respectively and power requirements were 10, 15, 15 and 18 hp, respectively. It was also 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 process one tonne of paddy per hour. In the rice mill, shaft power is provided for operating the equipment and process heat is provided by steam generated in boiler. The shaft power requirement for each individual component of the milling section of a 2 t/h capacity 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 of 2 t/h capacity namely, Vijay Laxmi rice mill and Shiba Durga rice mill of West Bengal and reported the total energy consumption was 524.48 kWh and 67.22 kWh/t of rice produced in the integrated and semi- mechanized mill, respectively.

Borah and Prasad (1993) observed 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 is 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. Sarda (1966), Mukharjee (1984) and De (2002) proposed 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.

Goyal et al. (2008) reported that the energy consumption in post harvest rice processing operations in parboiled rice mill, raw rice mill, mini rice mill and huller mill were 923.92, 36.29, 14.42 and 15.65 KWh/t, respectively. Operation wise energy consumption were required as in pre-parboiling cleaning 1.34, soaking 527.21, steaming 75.16, drying 271.58, milling 39.75, weighing and bagging 1.67 KWh/t.

Paddy separator

Gariboldi (1974) observed 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 to 1.492 kW/t of husked rice.

Polisher

Faulkner et al. (1969) reported that the major portion of the total energy consumed in milling of paddy is 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) stated that power requirement of an individual polisher is 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 (Sarda 1966). 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, quality of final product, type/capacity/age/combination of equipment used, fuel/power source, efficiency of driver and power transmission (Roy et al. 2008). 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 (Kapur 2002). A summary of results of some such studies is given in Table 2. 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.

The values of mechanical energy intensity for rice processing operations (Table 2) (Kapur et al. 1997a). Energy in its different forms as biomass, human, fossil and electricity are used in each unit operation. Mechanized processing industry normally required direct fuel energy, steam and electricity. About 48 % of the total energy is used in the form of as direct fuel, 13 % is used in the form of as electricity, 29 % as processed steam and 10 % is in the form of hot water (Adolfson 1982). About two-thirds of electricity is consumed in generating mechanical power to operate conveyer, pumps, compressors and other machinery. Other appliances as lighting, etc. normally consumed about 15 % of electricity (De 2002).

Goyal et al. (2008) carried out a study to evaluate energy consumption in the parboiled rice mill; it was a modern rice mill. Hence, there was no need of more manual energy.

Nayak (1996) compared single huller and modern rice mill in West Bengal and he found that the modern rice milling system in addition to being self-sufficient in energy, employs additional 4.0179 labour per tonne of paddy processed, yield 3.5 lakh tones of additional rice worth 10.5 million rupees and produces 4.2 lakh tonees of pure rice bran which can partially yield 84,000 tonnes of bran oil in West Bengal. Additional products of modern rice mill which are of considerable economic value are cement and silicon from paddy husk, animal feed and chemicals like sodium silicate, furfural, etc. All these products can be economically manufactured from by-products of milling industry providing additional income, employment and overall prosperity to the Nation economy.

Energy production system in rice mills

Basically in the rice mills two types of energy production systems are commercially available,

(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 (Quaak et al. 1999). It involves: (a). oxidation of the carbon into carbon dioxide and carbon mono oxide, reduction of carbon dioxide into carbon monoxide, (b) release of H_2 from chemical bond and (c) formation of small quantities of methane gas (CH_4).

Andre et al. (1980) found that the efficiency of the gasification process was generally about 70–80 %. The thermodynamic efficiency of thermal engine was about 37 %. Engine is coupled to an alternator allowing electricity generation with an efficiency of 93 %. Each kWh (3.6 MJ) is obtained from 0.55 lb (25 g) of diesel fuel and 2,200 kcal (2.56 kWh) under gaseous form.

(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 (Quaak et al. 1999). 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. Kuppuswami (1976) reported that rice milling industry generated more than that is consumed. It is found that approximately 200 kg of husk is obtained from milling of one tonne of paddy. It produced 660 kg of steam, which generated 100 kWh of electricity through steam turbine. But

Table 2 Reported values of mechanical energy intensity for rice processing operations

Mechanical energy intensity, kWh/t[a]					
Milling		Parboiling	Drying	Remark	Reference
Raw	Parboiled	9.4	–	2 t/h modern mill	Pathak et al. (1982)
25.6	–				
–	–	3.37	9.30	1, 1.5, 2 and 3 t/h parboiling plants using pressure parboiling method	
		8.77	30.46		
		22.38	24.61		
		9.30	24.61		
		7.46	24.80		
		13.92	25.36		
		5.04	25.36		
		3.85	13.92		
46	50	–	–	1-2 t/h modern mill	
–	29.84	–	–	2 t/h modern mill	Bakhara et al. (1991-92)
18	20	–	–	1.5 t/h modern mills except the last which is an integrated complex	
25	22				
	55				
20	–	–	–	Modern mill	Bal (1992)
30				Sheller	
40				Huller	
24.75	28.46	7.83	12.51	120 & 4 t/h modern mills	

[a]t refers tonne of paddy initially at moisture content of 16 %

milling of one tonne of paddy required only 65 kWh of electricity, thus rendering 35 kWh as surplus energy. Dasgupta et al. (2003) found that the various physical factors which affect the burning of rice husk and efficiency of furnace are variety of rice husk, particle size of husk, moisture content of husk, size grading and rate of air flow through the bed and height of fuel bed.

The average calorific value of paddy husk is 3,000 kcal/kg (3.5 kWh/kg). Hence, a rice mill having capacity of one tonne per hour producing 200 kg of husk per hour is capable of generating 6,00,000 kcal (700 kWh) of heat energy per hour. Thus, if an overall energy conversion efficiency of 41 % is assumed from the system, a surplus energy to the extent of 5, 00,000 kcal (583.33 kWh) could be available with the mill where parboiling operations are not carried out (Arora 1982). Pathak (1999) studied that 4.5 kg pressure steam is 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 common a 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/t of paddy.

One tonne of paddy produces 200 kg of husk, of which at least 180 kg could be recovered to be used as fuel. The heat value of husk was about 5 kWh/kg. 180 kg husk at an over all efficiency of 70 % in co-generation plant can supply 437.5 kWh energy. In a ratio 1: 9 between shaft power and process steam about 44 kWh mechanical energy that is much more than what is needed for milling, and sufficient heat energy would be available to produce parboiled rice (Dasgupta 2001).

An energy analysis was conducted by Ahiduzzaman and Islam (2009) on the steam power plant of a large white mill. The boiler fired by paddy husk raised steam for a steam engine coupled to a generator. Additional electricity was imported to meet the total demand and of the mill. Potential for power generation is assessed on two alternative systems namely the boiler and turbine system and the gasifier and internal combustion engine system. Both cases of husk match and power match are considered. For the case of power match, both alternative power generation systems are economically feasible.

Paddy husk fired furnaces

(1) Box-type furnace

Ilyas 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°, 45° and 50° and consists of cast iron bars arranged in a stair-case fashion.

(2) Cyclone type husk fired furnace

According to Ahiduzzaman and Islam (2009) the principle of operation of cyclone furnace is 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 and it 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 2,100 cm^3 of heated air-flue gas mixture can be maintained at 90 °C 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 % 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 is obtained 1,000 °C at husk feeding rate of 30 kg/h and an air flow rate of 2.80 m^3/min.

(3) Fluidized bed husk fired furnace

With view to improve the combustion efficiency, fluidized bed furnace is considered as the best suited. The furnace is 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 °C. At the husk consumption rate of 4 kg/min, heat out put is approximately 8.72 kWh/min. A constant temperature obtainable at the outlet of the furnace is 100 °C. The internal temperature of the furnace reaches upto 1,200 °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 (Ravindran 1982). Nowdays, concern with environmental is uses are increasing considerably in every agricultural sector. To preferably avoid, or at least reduce the environmental impacts, food production should involve assessing the environmental impact of the entire food chain. One of the well known methodologies used for the evaluation of the environment is a life cycle assessment (LCA) (Kasmaprapruet et al. 2009).

In a study conducted by Bhatia (1974) resulted that the efficiency of boilers ranges form 50–85 %. Straight electrical power generation brings the over all efficiency down to about 20 %. Husk consumption is calculated at 350 kg/h with an estimated at 2.56 kWh/kg recovery from the husk. Surface area is 46 m^2 and pressure is 7 kg/cm^2. This is a natural draft unit with a 18.28 m high stack.

Energy conversion and source for various energies

Rice husk is a by-product of rice and has a good value as a biomass fuel. This biomass amounts to 20 % of total rough rice (paddy) produced. Rice husk is mainly used as fuel for parboiling and drying of paddy before milling. In a study conducted in West Bengal, India, it was reported that 1,659 MJ of biomass energy was consumed for rice parboiling (Roy et al. 2006). In a study by the IDRC (International Development Research Center, Canada) it was reported that theoretically the net energy demand for hot soaking, steaming and drying were 360 MJ, 105.5 MJ and 574 MJ, respectively, to process one tonne of paddy. It was also mentioned that about 200 kg of rice husk (2,800 MJ) was needed to process one tonne of paddy if the efficiency of a husk fired boiler is 45 % (Araullo et al. 1985).

In fact, it is a normal practice in Bangladesh that the rice is first parboiled and dried and then it is dehusked. However, it was reported that if the rice is dehusked before parboiling then the energy consumption of parboiling operation could be cut down by 40 % (Ka et al. 1999). The drying process is mainly done under direct sunlight radiation on a floor. There are some mechanical processes for paddy drying wherein the rice husk is used as a source of thermal energy for air heating and electricity is used for running blower-motors. The specific energy consumption of drying is largely dependent on the moisture content and hot air temperature.

LSU (Louisiana State University) type dryers are used for mechanical drying of rice in Bangladesh. LSU type dryers are a mixing type of dryer. They consist of a vertical compartment and the rice grain falls down from the top of the dryer and is re-circulated until it is dried. As the rice descends in the dryer it is mixed so that individual grains are not exposed to only the hottest air, but rather a combination of both hotter and cooler air. Because of this, the LSU type dryers generally use higher temperatures and lower air velocities than non-mixing dryers (Araullo et al. 1985). It was reported from a comparative study of rotary dryer and 3-stage counter flow dryer that use of 3-stage counter flow dryer resulted in a 34 % savings in fuel energy (Bakker-Arkema et al. 1984). After drying the milling process is completely done using electrical energy.

Theoretically it is assumed that about 200 kg of husk can be obtained from each tonne of paddy, however, in practice, it was found that on average 187 kg of husk could be obtained from each tonne of paddy (Ahiduzzaman 2007). The parboiling and drying operation of rice processing consumes a huge amount of energy from renewable sources. Specific energy consumption of rice processing is reported in several studies. However, this study also analyzed the energy demand nationally for rice processing in Bangladesh. It is high time, since as an energy-starved country, Bangladesh needs proper assessment of energy consumption for rice processing from a national perspective. The environmental issue is a great concern for the country like Bangladesh, especially for the adverse effects of sea level rise due to global warming.

Essential, all mechanical energy is produced as a result of thermal energy or from the direct conversion of electrical energy (Sarda 1966). The conversion of thermal energy into mechanical energy is normally accomplished in some sort of a heat-engine operating on a thermodynamic heat-engine or power cycle with limited conversion efficiency (RESC 1983). The conversion of electrical energy into mechanical energy is usually accomplished as the result of the interacting magnetic fields found in electric motors (Mukharjee 1984).

According to Baqui et al. (2010) for providing mechanical energy to the equipment performing processing operations, a prime-mover is required. The prime-movers could be diesel engines, spark ignition engines, dual-fuel engines, electric motors, etc. On the other basis of fuels used, internal combustion engines can be grouped into petrol (very high speed adopted for motor vehicles, upto 100 hp, normally used for standby duties), distribute fuel oil (medium and light speed 700–2,000 rpm, upto 4,000 hp, normally used for standby or shaft power), light residential fuel oil (medium speed, 600–1,000 rpm, upto 5,000 hp, generally used for continuous production of shaft power) and heavy residual fuel oil (slow speed, upto 400–600 rpm, upto 30,000 hp, continuous duty).

Manual energy

Labour (manual energy) plays a crucial role in Indian rice processing industries as some of the operations are done manually and hence can not be avoided in any energy accounting process (Bakhara et al. 1991). The human energy required in different activities to accomplished for the milling operation is calculated by taking observation of man hours and women hours separately. Many researchers have convert and utilized the manual energy in Mega Joule (MJ). Following constants are used to convert them in term of MJ (Mittal et al. 1985).2

$$1\ \text{man} - \text{hour} = 1.96\text{MJ} = 0.544\text{kWh}$$
$$1\ \text{woman} - \text{hour} = 1.57\text{MJ} = 0.436\text{kWh}$$

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 2002). Pathak (1999) suggested that the contribution of processing waste and by products to captive power generation in rice processing industries would become more meaning full if simultaneous efforts are made to conserve energy. Use of energy efficient processes and equipment, co-generation, recovery and recycling of thermal energy, proper insulation, etc. are some of the steps that could reduce gross consumption and allow an industry to move closer to energy self-sufficiency using its own renewable resources like process waste.

Reduction in parboiling time

Pillaiyar (1998) reported that soaking paddy for 1 h at 70 °C, draining water and tempering for 4 h restricted the grain moisture and on steaming the moisture was 28 %. The paddy parboiled by short soaking tempering (SST) dried faster and saved 25 % drying time. In the sand parboiling technique, soaked paddy is mixed with hot sand at 150–180 °C. In a traverse time of 40–60 s through the commercial mechanical sand roster, the soaked paddy is gelatinized and dried to a moisture content of 16–18 % 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 % in drying time.

Energy saving opportunities in rice mills

1. Paddy cleaner blower operates throughout the year and hence its system efficiency should be analyzed.
2. The hot water after soaking may be wasted as a drain that represents enthalpy loss.

3. The dryer blowers should be studies and efficiency of the system established, depending upon the site conditions and best remedial action needs to be evaluated.
4. The condensate from the dryers could well be flashing away which represents heat loss that is recoverable.
5. The system efficiency of the de-husker and pre-cleaner blowers should be studies, depending upon the site conditions, best remedial action needs to be evaluated.
6. The efficiency of the power blower should be studies and depending upon the site conditions, best remedial action needs to be evaluated. Also there may be a huge pressure drop across the silencer and system modified may be required to avoid the same.
7. The polishers are having big rated motors. A motor load survey should be carried out. Also associated with these polishers are their blowers system efficiency can be analyzed.

Conclusion

The efficient utilization of energy is a great challenging task to the researchers. Rice industry is one of the most energy consuming industries. If rice husk used as a fuel, the reduction in the use of rice husk would enable the rice industry to spare rice husk. 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. Such type of review will help in determining the energy use pattern as well as total energy consumption by the rice milling system of the country and provide a idea for better planning of the conservation and application of energy substitute technologies.

Acknowledgements Authors are heartily thankful to Dr. S. Patel, Head of Department, Agricultural Process and Food Engineering, Faculty of Agricultural Engineering, IGAU, Raipur (C. G.), Er. Suresh Chandra and Prof. Samsher (Head of Department), Agricultural Engineering and Food Technology, S. V. B. Patel Uni. of Agric. & Tech., Meerut (U. P.) for their continuous advice, guidance and encouragement for preparing this manuscript.

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