GTZ PROJECT: CN 83006037

REPORT ON

ESTIMATION OF ENERGY EFFICIENCY OF THE EXISTING RICE PARBOILING SYSTEMS IN BANGLADESH

FOR

SUSTAINABLE ENERGY FOR DEVELOPEMT (SED)
GERMAN TECHNICAL COOPERATION (GTZ), BANGLADESH

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15 March to 31 July 2007

Preface

Traditional biomass fuels are the major energy resource in Bangladesh. Rice husk is the most important rural energy resource of the country. About 8 million tonne of rice husk is produced each year and is mainly used for parboiling of paddy. Parboiling of paddy is predominantly done at small and medium scale mills with primitive parboiling systems operating at very low combustion efficiency. Fuel feed mechanisms are hand throwing causing hazardous flash back to the fireman during fuel feeding. There is a huge potential of efficiency improvement in the system (boiler/steam vessel and furnace). The GTZ under the project "Promotion of the Use of Renewable Energies" (PURE) has initiated developing an energy efficient rice parboiling technology. Before introducing an efficient system, it is important to know the efficiencies of existing systems. Therefore, GTZ has engaged a team of experts to study the present situation under project entitled *Estimation of Energy Efficiency of the Existing Rice Parboiling Systems in Bangladesh*. The TOR of this study was:

i) Identify the categories of rice parboiling systems in Bangladesh,
ii) select a sample number of rice parboiling systems from each category and
iii) study the efficiencies of selected rice parboiling systems.

The study has been carried out by the study team comprising of Dr. Engr. Mohammad Abdul Baqui, Former Director General, Bangladesh Rice Research Institute (BRRI), Gazipur as the Team Leader, Engr. Md. Ahiduzzaman, Senior Scientific Officer, BRRI, Gazipur, Dr. Engr. Md. Khalequzzaman, Senior Energy Specialist, Sustainable Energy for Development (SED), GTZ, Bangladesh, and Engr. M. Mustafizur Rahman, Energy Auditor, Energy Audit Cell, Ministry of Power, Energy and Mineral Resources, Dhaka as the Team Members.

Mr. Erich Otto Gomm, Project Coordinator, GTZ and Mr. Dilder Ahmed Taufiq, Chief of Operation, SED, GTZ are gratefully acknowledged for their kind assistance provided in completion of the assignment. At last but not the least, the study team expresses their sincere thanks to all of the staff of Sustainable Energy for Development (SED) project of GTZ for their help.

EXECUTIVE SUMMARY

The main objective of this study is to survey the existing rice parboiling process and equipment and their efficiency for burning husk to produce energy mainly inside the rice parboiling system. In order to fulfill the objectives the study team visited 50 number of small and medium size rice mils of capacity ranging from 2.4 ton to 22.5 ton of paddy per batch. The study team estimated the thermal efficiency of the selected rice parboiling systems by measuring the quantity of the heat utilized by the steam needed for parboiling as output divided by the quantity of heat provided by husk burning into the system as input. For the above tests the study team collected the following data in person with adequate test equipment using standard methods of calculating thermal efficiency were used.

- Quantity of husk consumed to complete a parboiling process
- Quantity of paddy processed
- Time required completing the parboiling process
- Relevant data needed for calculating the energy efficiency and
- The information that that causes, hazardous situation while parboiling process is under operation

Based on the findings of the field study the rice mills can be categorized by their capacity as:

- large: above 10 ton/batch, this category posses 30% of the population
- medium: between 5 - 10 ton/batch, this category posses 50% of the population
- small: less than 5 ton/batch, this category posses 20% of the population

However, according to the configuration of steam generating unit (boiler/steam vessel) these rice mills can be categorized into six groups such as:

a. local made cylindrical vessel,
b. local made semi-cylindrical with flat bottom,
c. parallel connected of oil drum,
d. modified Lancashire boiler,
e. locomotive boiler (from old ship or steam engine boiler) and
f. vertical boiler (old ship boiler).

The overall thermal efficiency of all steam generating units is ranged from 13% to 50%. About 60% of the systems are being operated between 20 to 30% efficiency, about 30% of them are being operated between 30 to 40% efficiency. The highest efficiency as 50% has been found in the imported standard Locomotive boiler. The flue gas after leaving the furnace has been analyzed by a digital flue gas analyzer. The carbon monoxide content in the flue gas from all of the furnaces has been found more than 10000 ppm which indicates incomplete burning of the husk biomass and causing lower efficiency. The study team observed the good and bad practices which are responsible for imparting influence in the overall efficiency of the furnaces. The study team also recorded the insufficient safety instrumentation in some of the rice mills under study, i.e. inadequate chimney height, inadequate fuel feeding grate, absence of controlling device for proper air-fuel mixture etc. Based on the results of the study it has been found that rice husk appears as a very attractive raw material particularly in rice parboiling energy system. However, in order to obtain full benefit it would be necessary to develop a new heat conversion system (furnace, boilers and steam vessel) for efficient conversions of rice husk into saleable heat energy. Therefore, a basic need exists for developing more efficient methods to extract maximum heat from rice husk.

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1.0 Introduction

Biomass is by far the dominant energy source in Bangladesh, accounting for 67% of the countries total energy consumption ((RWEDP 2000). Among the Asian countries India has the highest total use of biomass mainly as wood whereas, Bangladesh has the high proportional use of non-wood biomass. This biomass is derived from rice husk (23.3%), cow-dung (20.4%), rice straw (11.6%) and lesser amounts of jute stick, bagasse, fire wood, twigs, leaves and other wastes materials (BBS, 2004). The production growth rate of rice husk energy is about 2.57% (Ahiduzzaman, 2006). Rice husk is obtained as the by product from the milling process of paddy. Therefore, availability of rice husk more or less depends on the production of paddy in a particular year in Bangladesh. It is reported that in 2006 Bangladesh produced about 41 million tons of paddy that would produce about 8 million tons of rice husk (BRRI, 2006). It is also reported that that about 90% of husk is produced in the rice mills scattered in the country and 86.57% of the husk is consumed in the mills themselves in parboiling paddy (Tariq, 1999). Rice husk as the largest single source amongst biomass fuels, dedicated efforts are clearly warranted to promote its optimal use.

Parboiling of paddy is a hydrothermal process that may be defined as gelatinization of starch within the rice grain. During the parboiling process the starch and protein expand and fill the internal air space which creates strong cohesion between them. Both fissures and cracks present in the endosperm are sealed and tough enough to withstand milling stresses which increases the total yield of edible rice and minimizes the broken rice quantity.

Parboiling process of rice is predominantly at small mills with primitive parboiling system and poor combustion creating heavy smoke with non-CO_2 emissions. There is a very limited number of efficient combustion system exists in Dinajpur and Naogaon districts (Dasgupta et al. 2003). The majority small rice mills produce a mix of bran and husk as a by product due to the use of 'Engleberg' huller. This mix of rice husk and bran has a good price as cattle, poultry and fish feed. There is other process of rice milling in which rice husk and bran are produced separately. The surplus of this type of rice husk is used for making densified rice husk fuel (briquette) which is very much popular as cooking fuel in small restaurant and poor urban household for whom an increased supply of cheaper fuel would be important (Ahiduzzaman 2006).

It is estimated that there were about 100000 (including large, medium and small) rice mills in the country (Baqui, 1997). Among them about 40000 rice mills has parboiling units (Ali 2004) with a capacity of 7.5 to 16 tons of paddy per batch (3 days). The average rice husk production is 2400 kg/batch (800kg/day). Presently on an average 86.57% of rice husk is used for parboiling. The parboiling system is traditional in nature and very inefficient in terms of energy utilization. A study indicated that the variability of husk consumption in the traditional parboiling systems is very high that varies from 60 kg to 200 kg per ton of paddy parboiling. Thus the study clearly indicates that there are already efficient steam generators operating at the rural level.

The purpose of this assignment is to determine energy efficiencies of traditional parboiling systems through determining the rice husk combustion efficiency in rice parboiling units with a particular focus on small and medium scale rural rice mills in Bangladesh

2.0 Methodology
2.1 Site selection

Rice mills were selected from different sites of Bangladesh where a cluster of rice mill population are developed. The rice mills were selected such a way that the rice processing zones of Dhaka, Rajshahi, Sylhet, Chittagong and Khulna division were covered. Figure 1 shows the rice mill zones of Bangladesh visited by the study team. Fifty number of different rice parboiling units were studied from the above clusters and their salient features were listed in Annex 1 and Annex 2. The distribution of rice mill under study is shown in Table 1.

Figure 1. Map of Bangladesh indicating the district with main rice processing zones

During the visit the study team did not observed any rice mills in Barisal down town areas. The local people informed the study team that presently rice grains from Barisal region are being transported to Munshiganj area by trawler and get milled there. After milling the traders bring the clean rice back to Barisal region. There might have a few some rice mills in the remote areas of Barisal but due to time constraints the study team did not visit the remote areas of Barisal region.

Table 1. Zone wise distribution of number of parboiling system under study

Name of Zone	*Number*
Dhaka division	*16*
Rajshahi division	*15*
Khulna division	*11*
Chittagaon division	*5*
Sylhet division	*3*
Total	*50*

2.2 Test procedure of boiler/steam vessel

The boiler/steam vessel has been filled with water to a predetermined level by a water pump. The water level was checked with a dipstick made from bamboo or wood or by siphon tube arrangement. After measuring the water level the flexible pipe was removed and the valve on the filling spigot closed. Sufficient amount of rice husk was put near by the furnace and the quantity of husk was weighed with a spring balance. Before staring fire, the operators generally check the valves on the pipes for steam outlets are open. After this check, firing is started under the boiler/steam vessel. The operators observe the outlet pipes for signs of steam. When steam was seen to emerge from the outlet pipes, the workers put wet paddy from soaking tanks into the steaming bins. Steam was allowed to pass through the paddy in one steaming bin. Initially steam condenses in the paddy bed. After a short period of time, steam is seen to emerge from top of the paddy bed. At this stage, steam was diverted to the second steaming bin and the steamed paddy removed from the first bin. The cyclic batch process was continued until the entire soaked paddy has been parboiled. The parboiling activity is generally carried out during the night. After all the paddy has been parboiled, the remaining husk fuel near the furnace has been weighed again and subtracted from the total quantity to determine the actual amount of husk consumed for parboiling. The difference between the initial weight and final weight of the husk is the amount of husk required for parboiling. The efficiencies of the steam vessel/boilers were determined from the volume of water evaporated and the quantity of fuel used. Following data were also noted during the test:

- size, shape and thickness of boiler/steam vessel
- quantity of paddy processed
- quantity of water evaporated
- time required to complete the parboiling process
- type of husk used

- presence of chimney or not
- presence pf safety devices or not
- presence of carbon monoxide and oxygen in the flue gas
- temperature of feed water and flue gas
- quantity of water required in the vessel after parboiling process
- other hazardous condition of operation

2.3 Determination of inside volume of boiler/steam vessel

The length, diameter and wall thickness of steam vessel were measured. The presence of steam generator safety measures like safety valve, pressure gauge, temperature meter, chimney etc were observed and were recorded. The volume of cylindrical steam generator was calculated using the equation (1).

$$V = 1000 \times \frac{\pi D^2}{4} \times L \text{ ---------(1)}$$

Where,

V = Volume of steam generator, litre
D = Diameter of steam generator, m
L = Length of steam generator, m

The semi-cylindrical was in irregular shape. Therefore, the cross-sectional area was divided into a number of trapezoids i.e., the boundaries between the extremities of the ordinates were assumed to be straight lines. The following equation (2) of trapezoidal rule was used to calculate the cross-sectional area.

$A = d/2 (O_0 + 2O_1 + 2O_2 + ...+ 2O_{n-1} + O_n)$.................. (2)

where,

A = X-sectional area of steam generator, m^2
d = common distance between ordinates, m
O = ordinates at each point f division, m

The cross-section was multiplied by the length of steam generator to calculate the volume of steam generator (equation 3).

$V = 1000 \times A \times L$ --------- (3)

Where,

V = Volume of steam generator, litre
A = X-sectional area of steam generator, m^2
L = Length of steam generator, m

2.4 Determination of Initial, final and evaporated water (steam) volume for different boiler/vessel

2.4.1 Cylindrical vessel (Horizontal)

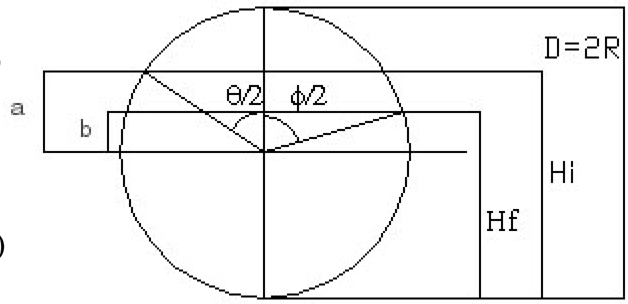
Most of the steam generator has no water level glass. To determine the initial and final water level inside the vessel, siphon tube was used (Photo 1). The study team observed that there were 3 different cases of water level inside vessel viz. i) case-1: both the initial and final level more than half full; ii) case-2: initial level more than half full and final level less than half full; iii) case-3: initial and final level less than half full. The x-section of wetted area was calculated and it was multiplied by the length of the vessel to calculate the water volume.

Photo 1. Measuring the water level by using siphon tube

CASE-1: both the initial and final level more than half full:

Initial Volume,

$$V_i = \left[\pi R^2 - \frac{R^2}{2}(\theta - \sin\theta) \right] x\, L \quad \text{------------------ (4)}$$



Final volume,

$$V_f = \left[\pi R^2 - \frac{R^2}{2}(\phi - \sin\phi) \right] x\; L \quad \text{----------------- (5)}$$

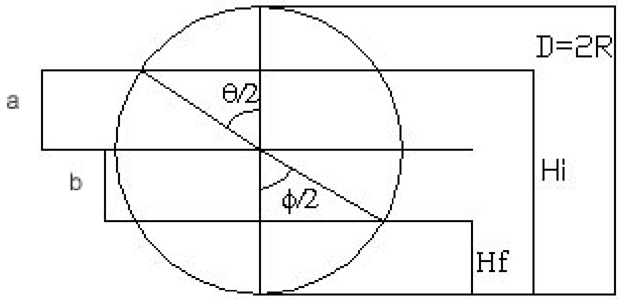
Where,

V_i= Initial water volume, m^3
V_f = Final water volume, m^3
R = Radius of steam generator, m
$\theta = 2 \cos^{-1}(a/R)$ ------------ (6)
$a = H_i - R$
H_i = Initial water level, m
$\varphi = 2 \cos^{-1} (b/R)$ ------------ (7)
$b = H_f - R$
H_f = Final water level, m
L = Length of steam generator

CASE-2: initial level more than half full and final level less than half full:

Initial Volume,

$$V_i = \left[\pi R^2 - \frac{R^2}{2}(\theta - \sin\theta) \right] x\, L \quad \text{---------- (8)}$$



Final volume,

$$V_f = \left[\frac{R^2}{2}(\phi - \sin\phi) \right] x\ L \quad \text{-------------- (9)}$$

Where,

V_i= Initial water volume, m^3

V_f = Final water volume, m^3

R = Radius of steam generator, m

$\theta = 2 \cos^{-1}(a/R)$ ------------ (10)

a = H_i - R

H_i = Initial water level, m

$\varphi = 2 \cos^{-1} (b/R)$ ------------ (11)

b = R - H_f

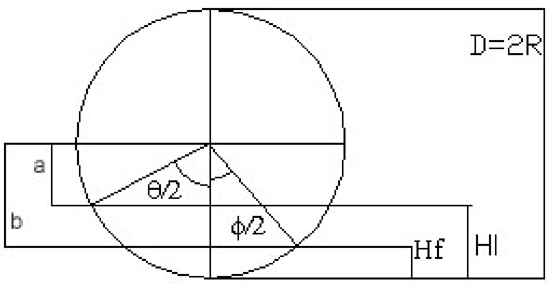
H_f = Final water level, m

L = Length of steam generator

CASE-3: initial and final level less than half full:

Initial Volume,

$$V_i = \left[\frac{R^2}{2}(\theta - \sin\theta) \right] x\, L \quad \text{------------------- (12)}$$



Final volume,

$$V_f = \left[\frac{R^2}{2}(\phi - \sin\phi) \right] x\ L \quad \text{--------------- (13)}$$

Where,

V_i= Initial water volume, m^3

V_f = Final water volume, m^3

R = Radius of steam generator, m

$\theta = 2 \cos^{-1}(a/R)$ ----------------- (14)

a = H_i - R

H_i = Initial water level, m

$\varphi = 2 \cos^{-1} (b/R)$ ----------------- (15)

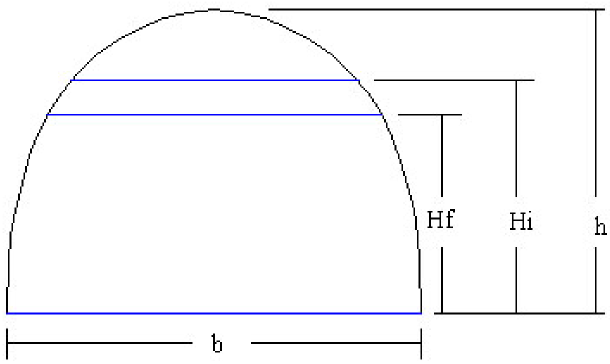
b = R - H_f

H_f = Final water level, m

L = Length of steam generator

2.4.2 Semi-cylindrical steam generator

The initial and final water level inside steam generator was determined by siphon tube. Since the cross sectional view of this type of steam generator is irregular; therefore, the cross-sectional area was divided into a number of trapezoids i.e., the boundaries between the extremities of the ordinates were assumed to be straight lines. The equation 2 of trapezoidal rule was used to calculate the cross-sectional area. The cross-section was multiplied by the length of steam generator to calculate the volume of steam generator.



The cross-sectional view of semi-cylindrical steam generator

Initial volume of water

V_i = Initial wetted X-sectional area × Length of steam generator -------------------(16)

Final volume of water

V_i = Final wetted X-sectional area × Length of steam generator ------------------(17)

Weight of feed water, kg

W_{feed} =*Volume of feed water* (m^3) × *specific weight of water* (kg/m^3) × Sp. gravity--------(18)

Weight of final water, kg

W_{final} =*Volume of final water* (m^3) × *specific weight of water* (kg/m^3) × Sp. gravity-------(19)

Weight of evaporated water (kg), $W_{steam} = W_{feed} - W_{final}$ -------------- (20)

2.4.3 Calculation of efficiency of steam generator

Sensible heat in feed water, kJ/kg

$$h_{feed} = W_{feed} \times C_{pw} \times t_{feed} \quad \text{-- (21)}$$

where,

h_{feed} = heat content in feed water, kJ/kg
W_{feed} = weight of feed water, kg
C_{pw} = 4.1868 kJ/kg-K
t_{feed} = temperature of water, °C

Heat addition to steam, kJ/kg

$$q_1 = h_f + xh_{fg} - h_{feed} \quad (22)$$

where,

q_1 = heat addition to steam, kJ/kg
h_f = sensible heat in hot water, kJ/kg
x = 0.95, quality of steam
h_{fg} = latent heat of vaporization, kJ/kg
h_{feed} = sensible heat in feed water, kJ/kg

Heat addition to remaining hot water in the steam vessel, kJ/kg

$$h_{rw} = h_f - h_{feed} \quad (23)$$

Total heat addition into vessel/boiler, kJ

$$E_{out} = q_1 \times W_{steam} + h_{rw} \times (W_{feed} - W_{steam}) \quad (24)$$

Total energy supplied, kJ

$$E_{in} = W_{husk} \times C_{husk} \quad (25)$$

where, E_{in} = Energy input, kJ
W_{husk} = weight of husk, kg
C_{husk}= calorific value of rice husk, kJ/kg

Thermal Efficiency of steam vessel,

$$\eta_{effi.} = E_{out} / E_{in} \times 100\ \% \quad (26)$$

3.0 Findings of the Field Study

3.1 Rice parboiling system

The parboiling system consists mainly of two parts one is the steam generation unit (steam vessel and furnace) and other part is steaming bin for parboiling paddy. Steaming bin is connected with the steam generator with a steam pipe (Figure 2 & Photo 2). The study team found that the steam is produced at a very low pressure in traditional rice parboiling systems in Bangladesh. However, some rice miller uses high pressure and high temperature steam for producing special quality of parboiled rice.

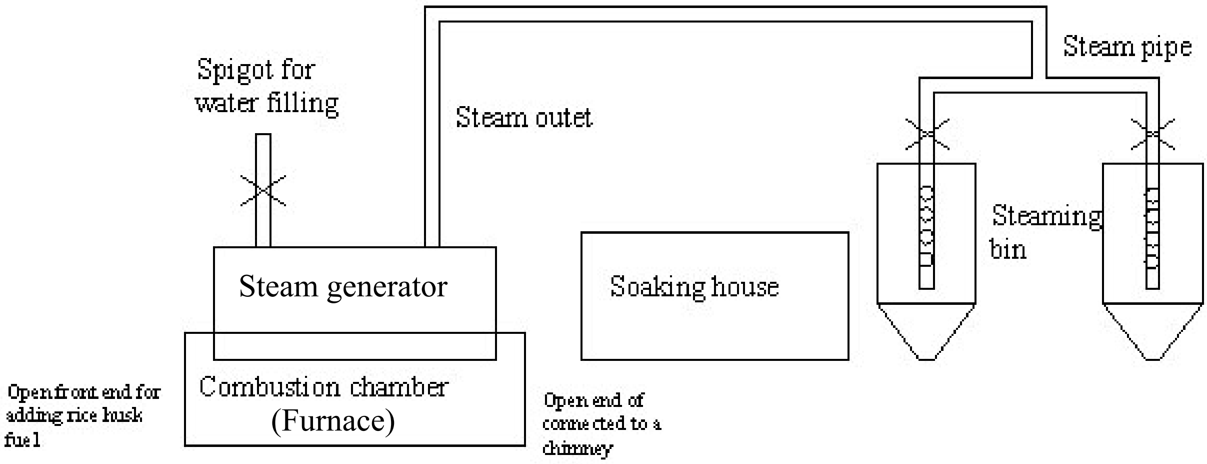


Figure 2. Schematic diagram of a conventional rice parboiling system

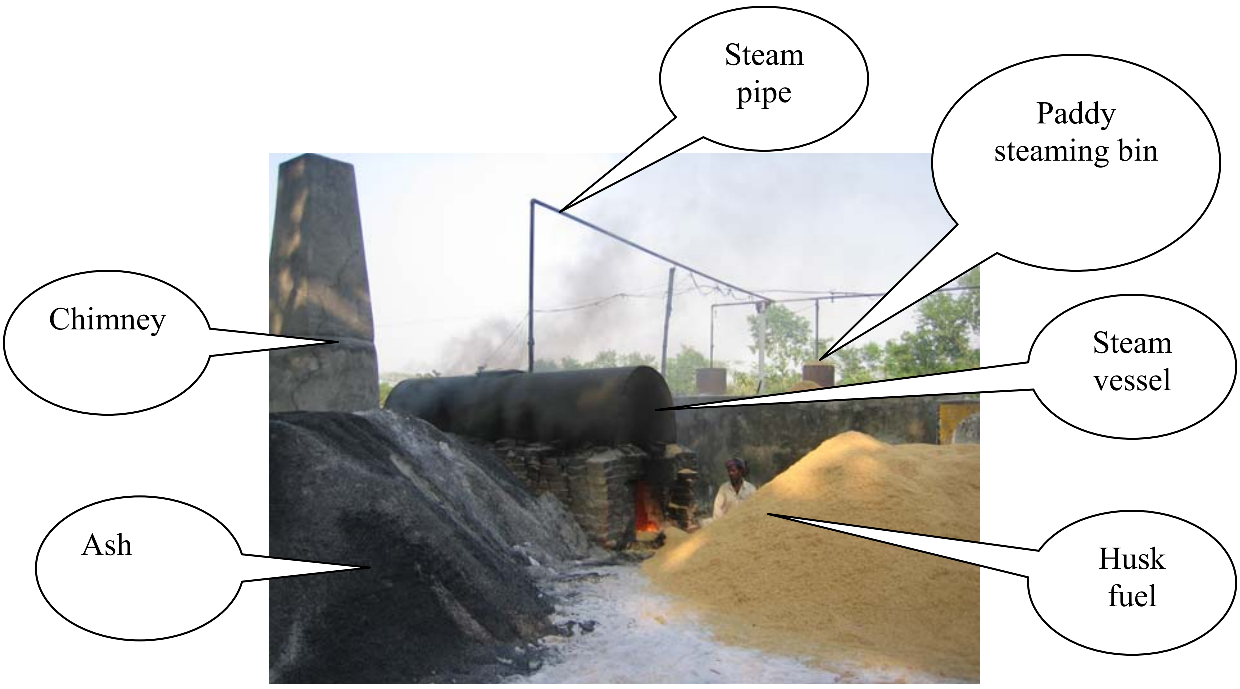


Photo 2. A conventional rice parboiling system

3.2 Types of rice parboiling steam generator

The steam generators used in small mills are fabricated by the local engineering workshops from low-grade structural steel sheet. In some areas, old oil drum is connected together to make a steam generator for steam production. Some old boilers from ship and steam engine boilers are also used in rice parboiling system. The designs of steam generators differ greatly and are dependent on the preference of the local technicians. The following basic configurations were observed during the field study by the study team:

g. Local made cylindrical vessel
h. Local made semi-cylindrical with flat bottom
i. Parallel connected of oil drum
j. Modified Lancashire boiler
k. Locomotive boiler (from old ship or steam engine boiler)
l. Vertical boiler (old ship boiler)

The above configurations are shown in Photo 3 to Photo 9.

a. Local made cylindrical vessel

This type of steam vessel is mostly (76%) used in country wide. All of this type of vessel is local made with structural steel. Local engineering workmanship can easily fabricate the vessel. The size and dimensions of this type of vessel varies according to rice mill capacity and cost of fabrication. The metal thickness is selected according to availability and cost of steel. Most of the thickness of the steel sheet is ranged from 2.0 mm to 3 mm. Some special vessels were also found having higher thickness such as, 9.5 mm, 10.0 mm, 12.0 mm and 19.0 mm. This type of system is operated under a very low pressure. However, some systems made with thick metal sheet have been operated under high pressure sometimes the pressure raised to 50 psi.

Photo 3. Local made cylindrical steam generator

b. Local made semi-cylindrical vessel

This type of steam generator is generally used in some particular regions viz. Gazipur and Mymensingh. This type of vessel is easy to fabricate and easy to install. The bottom part of the vessel is flat. The flat part is exposed to fire. This type of system is operated under very low pressure.

Photo 4. Local made semi-cylindrical steam generator

c. Local made oil drum vessel

This type of steam generator is constructed by connecting a couple of used oil drums together. This type steam generator is the cheapest one. This type of vessel is mainly used in small rice mills. However, its life is very short sometimes only 6 months. This type of system is found to be used in some region of the country viz. Kustia, Chuadanga, Jessore etc. This type of system is operated under atmospheric pressure.

Photo 5. Local made oil drum steam generator

d. Modified Lancashire steam generator

This type of steam generator is the modified version from the original Lancashire boiler. The outer shell of the boiler is made of thick metal sheet (12 mm). The outer shell is made of large compressor vessel and it is generally collected from old ship. This type of steam generator is operated under high pressure and some times the pressure raised upto 100 psi.

Photo 6. Local made Lancashire type steam generator

e. Locomotive boiler

This type of boiler is collected generally from old rejected steam engine or from old ship. This type of boiler is well designed considering all safety aspects. This type of boiler has continuous water feeding system. It is very compact and the firing box (combustion chamber) is attached with the boiler and there is water jacket surround the fire box.

Photo 7. Old boiler from steam engine (Locomotive)

f. Vertical tubular boiler

This type of boiler is collected from old ship. The shape of the boiler is just like a vertical cylinder. The upper part contains water tank and lower part contains the fire box where the fuel is burnt. The middle to bottom part of the boiler contains water jacket surround the flue path and some water pipe is inserted across the boiler to increase the heat absorption capacity. There two type of vertical boiler were found according to the position of chimney viz. i) chimney position if along with the center of the cylinder (Photo 8) and ii) chimney position is sideway of middle part of the boiler (Photo 9).

Photo 8. Vertical tubular boiler collected from ship

Photo 9. Vertical tubular boiler collected from ship

3.3 Accessories of steam generators

3.3.1 Water level gauge

Water level gauge is a device that is used to indicate the level of the water in the steam vessel; therefore is also called water level indicator. Traditional steam vessels were found having no water level gauge. However, only some package boilers were found having water level gauge (Photo 10)

Photo 10. Showing water level gauge and pressure gauge of locomotive boiler

3.3.2 Safety valves

Safety valve is used to prevent the steam pressure in the steam vessel exceeding the desired rated pressure. Most of the steam vessels were installed without any safety valves. Out of fifty installations visited, a few boilers/steam vessel had pressure gauges, quality pressure relief valves. The study team observed that the operators generally do not close the steam outlet port to avoid pressure development in the steam vessel.

However, there are different types of safety valves identified during the field visit. All of these safety valves are local made. Local artisans have made these types of safety valves as their own ideas (Photo 11); such as (a) thin metal sheet safety device, (b) rubber hose pipe, (c) inside spring loaded spindle, (d) lever with dead load safety devices, (e) spring loaded cap and (f) dead load type. Proper safety valves are installed on the certified boilers.

Safety is totally reliant on the skill and observations of the boiler fireman. Accidents with these boilers are a common occurrence, in some cases with fatal consequences for workers on the site. The main reason for the accidents is when the operators forget to check that at least one valve on the steam outlet pipes is open. The materials of construction used in these systems also compromise safety.

During the visit when the team visited a site where a boiler explosion had recently caused two fatal casualties. The devastation was wide spread. At present, no alternative standardized safe system is available in Bangladesh. This may also be a contributing factor in the reluctance of the local bodies to implement the Boiler Act with vigor.

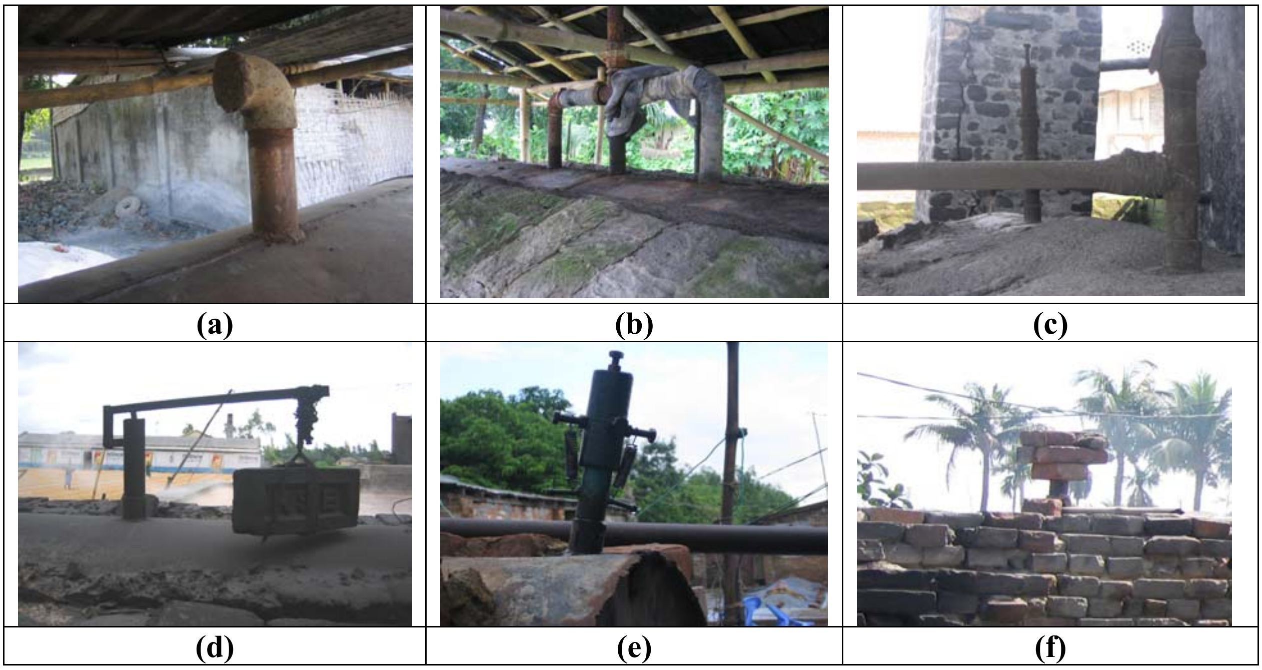


Photo 11. Different types of safety devices (a) Thin metal sheet (b) Rubber hose pipe (c) Inside spring loaded spindle (d) Lever with dead load (e) Spring loaded cap (f) Dead load

3.3.3 Chimney

The chimney should be an integral part of a combustion system. The study team observed that most of the traditional furnaces have no chimney. The advantage of chimney is that it creates a natural draught of air flow through the fuel and thus an adequate air fuel mixture is expected is the chimney height is properly adjusted.

Photo 12. Showing the practices of chimney use in different rice parboiling systems (a) no chimney installed (b) inadequate chimney height and improper installation of chimney to the furnace

3.3.4 Pressure gauge

Function of the pressure gauge is to indicate the steam pressure of the steam vessel in bar or psi or kg/cm^2. It is not found in any traditional steam vessel. Only the certified boilers were found having proper pressure gauges (Photo 10). However, for traditional parboiling system very low pressure (7 – 10 psi) is required which is not at all dangerous. But the pressure gauge is essential to know the operating pressure during parboiling period, because sometimes blockage may occur in the steam delivery pipe and preventive action can be taken immediately if a pressure gauge is installed.

3.3.4 Good and bad practices in rice parboiling systems

3.3.4.1 Fuel feeding system

Most of the traditional combustion systems have large opening for husk fuel feeding which allows a large volume of air enter into the combustion chamber and causes inadequate air-fuel mixture results in a reduced efficiency. Most of the operators feed the fuel by hand, some operators use fuel throwing spoon. In Dinajpur and Shantahar areas some operators were found using a recently developed blower feeding system (Photo 13). The advantage of this blower is that it can maintain a uniform rate of fuel feeding and results in higher efficiency.

		
(a)	**(b)**	**(c)**

Photo 13. Showing different types of fuel feeding systems (a) Hand feeding (b) Spoon feeding (c) Blower feeding

3.3.4.2 High moisture content in husk

Husk fuel generally contains 7 to 10% moisture. In some rice mills husk were found stored in open sky and absorbs moisture from atmosphere especially in rainy days and reduced efficiency expected due to excess moisture in husk.

3.3.4.3 Ash disposal

Husk fuel contains a higher quantity of ash (20%) than that of wood biomass fuel. Therefore, a frequent ash removal is required. Due to the improperly designed traditional furnaces need frequent ash disposal and a large amount of heat get lost. It was observed that the ash continues firing after removal from the furnace (Photo 14) and the black ash clearly indicates that a significant amount of heat energy is disposed.

(a)	(b)

Photo 14. Heat loss through ash disposal (a) ash disposal during burning of husk (b) incomplete burnt ash disposal

3.3.4.4 Large fuel feeding port

Because of manual fuel feeding systems most traditional systems were found having unnecessary large feeding port (Photo 15). Through this large opening a large quantity of air is mixed with the fuel, cooling down the flame temperature results in reduced efficiency. Heat radiation and flash of flame occurs frequently which causes heat loss as well as heat shock to the operators.

Photo 15. Showing large opening for fuel feeding causes high excess air-fuel ratio

3.3.4.5 Furnace grate

Most of the combustion systems do not have any grate. However only few furnaces in Hilli, Dinajpur were found to have local made inclined grate. The grate is made from angle iron and bricks arranged in such a way that air can flow easily between the gaps of the brick layers. The systems are continuously hand feeding system with a small opening of fuel port at the top of the grate. This is a good practice because an adequate air-fuel mixture is possible and a higher efficiency is expected.

3.4 Overall performances of the rice parboiling system under study

Six different types of steam generation unit were identified in rice parboiling systems. Majority of the steam generation units are local made. Sufficient water is fed into the steam vessel for producing required steam. The size of the steam vessel varies according to the rice mill capacity because the whole amount of water is fed at a time in the vessel. The steam production capacity and steam usages varies rice mill to rice mill. The thermal efficiency of the steam vessel also varies among the rice mills. A summary of the findings is shown in Annex 3. Detailed calculations of the performances are presented in Annex 4. to Annex 6. Descriptions of the performances are presented in the following sections below.

3.4.1 Capacity of the rice mill

The capacity of the rice mills varies from 2.4 ton to 22.5 ton per batch operation. A 3-day period is required to complete all activities in a batch operation of milling process. About 50% (out of 50) rice mills was in between 5 ton and 10 ton capacity per batch operation. About 30% of rice milling capacity was above 10 ton capacity and rest the 20% of rice mill was less than 5 ton capacity (Figure 3).

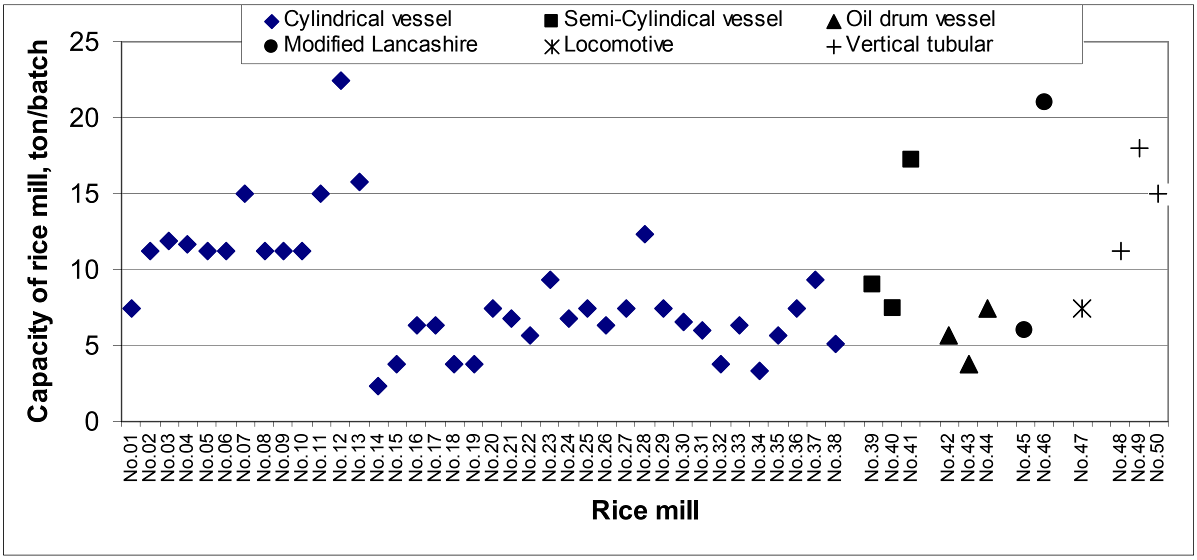


Figure 3. Capacity of the rice mill under study

3.4.2 Size of the steam vessel

The volume of the steam vessel ranged from 1567 litre to 5278 litre. The most of the steam vessel's (60% out of 50 numbers) capacity ranged from 2000 to 3000 litre (Figure 4). The volume of steam vessel depends on the size of a batch i.e. the quantity of paddy is parboiled at a time. Often the amount of parboiled paddy in a batch is the less than the amount of its designed batch capacity, however; the steam vessel is filled up with higher amount of water than the required amount of steam. The operator can not see the amount of water filled up in the vessel because there is no water level gauge. Therefore, lot of unused hot water remains in the vessel after completion of parboiling operation.

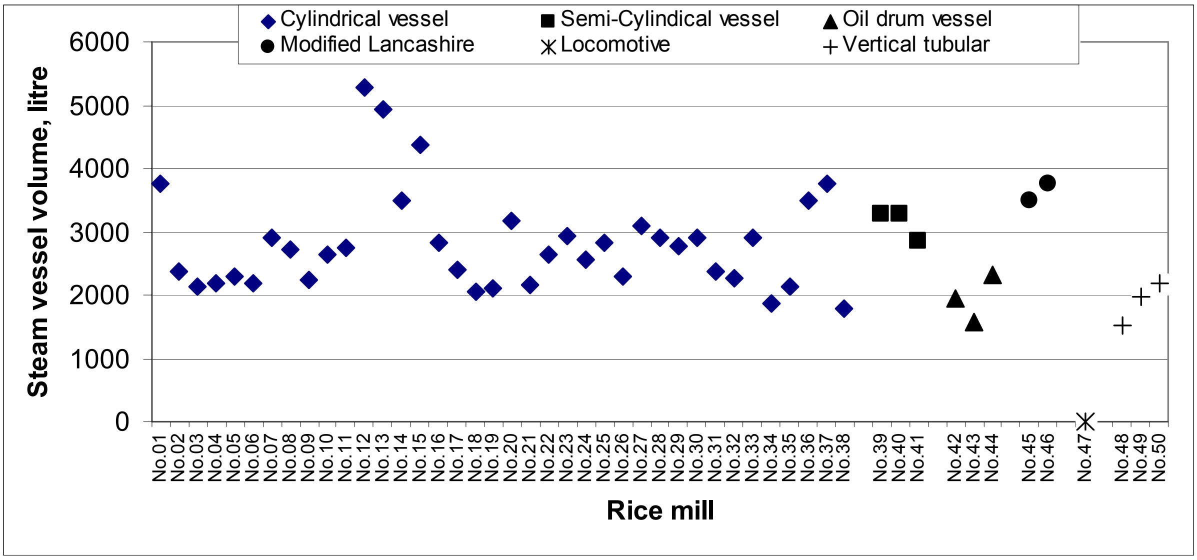


Figure 4. Volume of steam generation vessel of the rice mill

3.4.3 Capacity of the steam generator

The capacity of the steam generator ranged from 153 kg/hr to 863 kg/hr. However it was found that the most of the (60% out of 50 numbers) steam generator's capacity ranged from 300 to 500 kg steam per hour (Figure 5). The operator regulates the steam production rate by controlling the amount of fuel feeding. The results showed that the small and medium scale rice mill need low capacity steam generation unit under low pressure (7 to 10 psi) whereas the industrial boiler capacity ranges from 1.5 ton/hr to 3.0 ton/hr under high pressure (up to 150 psi). It is clearly revealed from the results that low pressure and low capacity steam generation unit is needed for small and medium scale rice mill. Therefore, a separate specification and standard for small and medium scale rice parboiling system can be incorporated in the existing national boiler act.

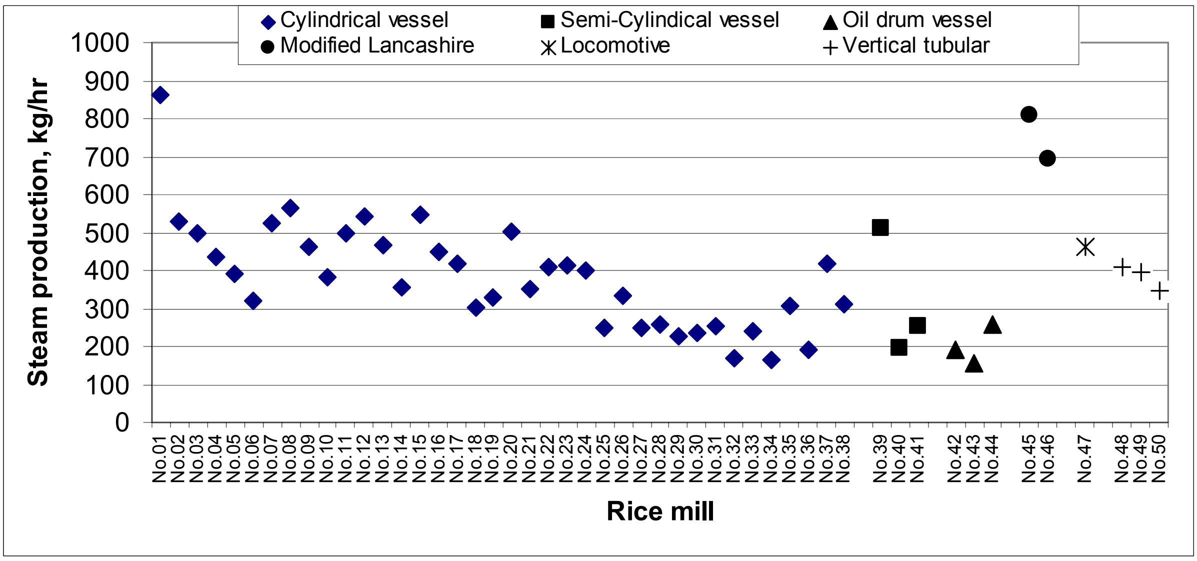


Figure 5. Steam production capacity of steam vessel of the rice mill

3.4.4 Steam used for parboiling of paddy

The steam usages for rice parboiling are depended on the type of rice processing or quality of rice. There are several types of parboiling process viz. half parboiled, full parboiled, double parboiled and high pressure steam parboiled for puffed rice. The steam consumption ranged from 65 to 193 kg steam per ton of paddy for parboiling. About 76% of total rice mill under study consumed from 100 to 150 kg steam per ton paddy parboiling (Figure 6). The wide range of steam consumption reveals that there is no standard for steam consumption for parboiling of paddy. However, it was found that the use rate of steam (kg of steam per ton) decreased with the increased quality of rice parboiling capacity. A study should be conducted to find out a standard for steam consumption rate and quality of steam (pressure and temperature of steam) for parboiling the different grade of rice in the country context.

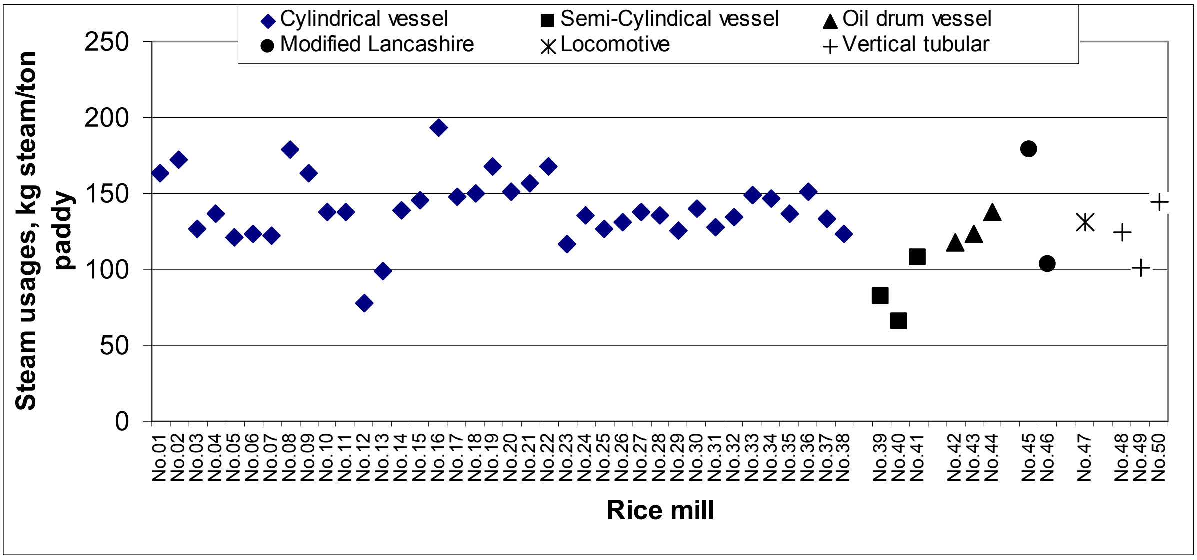


Figure 6. Steam use pattern in rice mill for parboiling of paddy

3.4.5 Thermal efficiencies of the rice parboiling systems

The gases from the fuel combustion cannot be cooled to air temperature in the steam generator, and therefore all the heat which is realized by the combustion of the fuel cannot be transferred to the water in the boiler/vessel. The efficiency of the boiler/steam vessel is therefore always less than 100%. The efficiency of the rice parboiling systems under study ranged from as low as 13% to as high as 50%. About 60% of the systems were found to be operated between 20% to 30% efficiency and about 30% of the systems were found to be operated between 30 to 40% efficiency. The highest efficiency was found for the Locomotive fire tube steam generator (50%). The efficiencies of the rice parboiling system are presented in Figure 7. The large variations in thermal efficiency of the parboiling system indicate that the steam vessel and combustion furnace are not properly designed. The air-fuel ratio could not be maintained due to the intermittent hand feeding of rice husk fuel. There is great scope of improvement in the system. FAO (1978) mentioned that in India and Sri Lanka, most of the installation using husk for fuel for steam generation are operating at less than 50% of efficiency level, either because of inefficient design and construction or because of the deterioration of the capability of a good design and well manufactured plan.

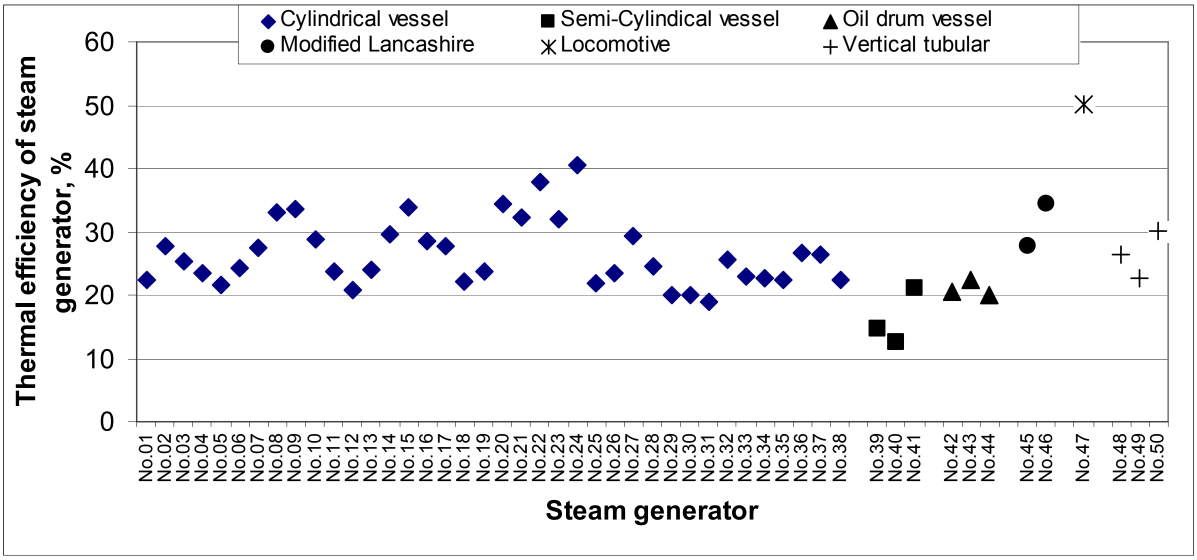


Figure 7. Efficiencies of steam generator of rice parboiling system

The steam-fuel ratio of a steam generation system is an indicator of the performance of the system. Higher steam-fuel ratio indicates the higher performance of the system. The steam-husk ratio of the parboiling system under study ranged from 0.58 to 2.24. About 90% of the system's steam-husk ratio was found between 1 and 2 (Figure 8). This wide range of ratio of steam-husk could be minimized by incorporating an efficient system.

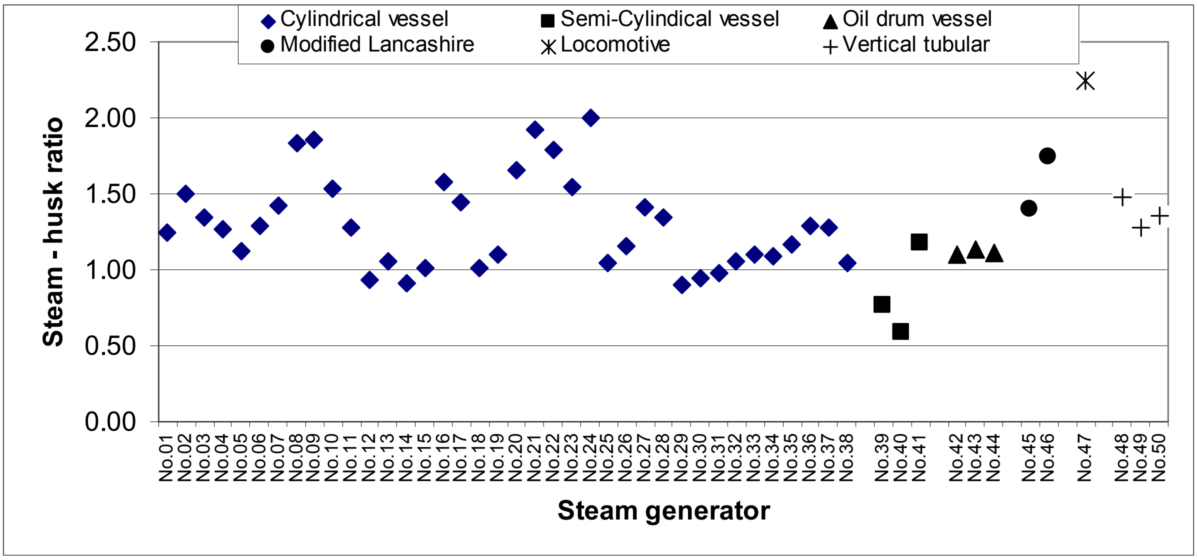


Figure 8. Steam – Husk ratio of different steam generator of rice mill

The steam-husk ratio and efficiencies of the rice parboiling systems are directly correlated (r^2 =0.92) and the efficiencies increased with the increase of steam-husk ratio (Figure 9). If the steam husk ratio is known then the efficiency of a steam generation system can be estimated easily by using the regression equation of steam-husk ratio and efficiency.

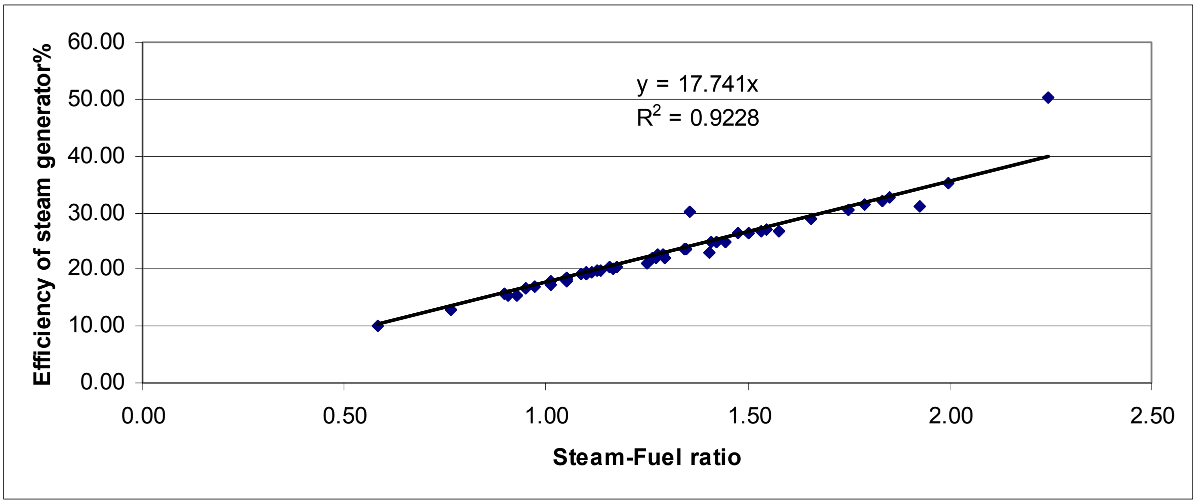


Figure 9. Relationship between steam-fuel ratio and efficiency of steam generator

3.5 Flue gas analysis

Flue gas generally contains carbon dioxide, carbon monoxide, water vapor, nitrogen and oxygen. Measured quantity of these components indicates whether the air-fuel ratio in the combustion chamber is adequate or not. The flue gas was analyzed by using a digital flue gas analyzer (Photo 16). The results presented in Table 2 shows that the flue gas contains over 10,000 ppm of carbon monoxide indicating incomplete burning of rice husk. Low oxygen content (1.5%) indicates the presence of insufficient oxygen in the combustion chamber. High temperature of flue gas also indicates that a lot of heat get lost through the flue gas.

Table 2. Flue gas analysis result of selected traditional parboiling systems

Parameter measured	**Concentration**
Ambient temperature	30 – 33°C
Flue gas temperature	650 – 740°C
Carbon monoxide (CO)	over 10,000 ppm
Oxygen O_2	1.5 to 4.5%

Note: Average values of selected traditional parboiling systems are presented

Photo 16. Showing measuring carbon monoxide and oxygen content of the flue gas by a digital flue gas analyzer

3.6 Losses of energy

3.6.1 Heat retained in remaining water in the vessel

In this study it was found that the volume of the steam vessel is larger than that of the required volume of water to produce steam. Due to the use of larger size of steam vessel a large amount of hot water is left over in the vessel after parboiling operation is completed. On an average about 4% of heat absorbed by the traditional steam vessel is left in the vessel and this value goes up to 16%. This loss of energy could be prevented by selecting a proper size of vessel for a definite quantity of batch of paddy for parboiling or by filling right amount of water for a certain amount of paddy to be parboiled.

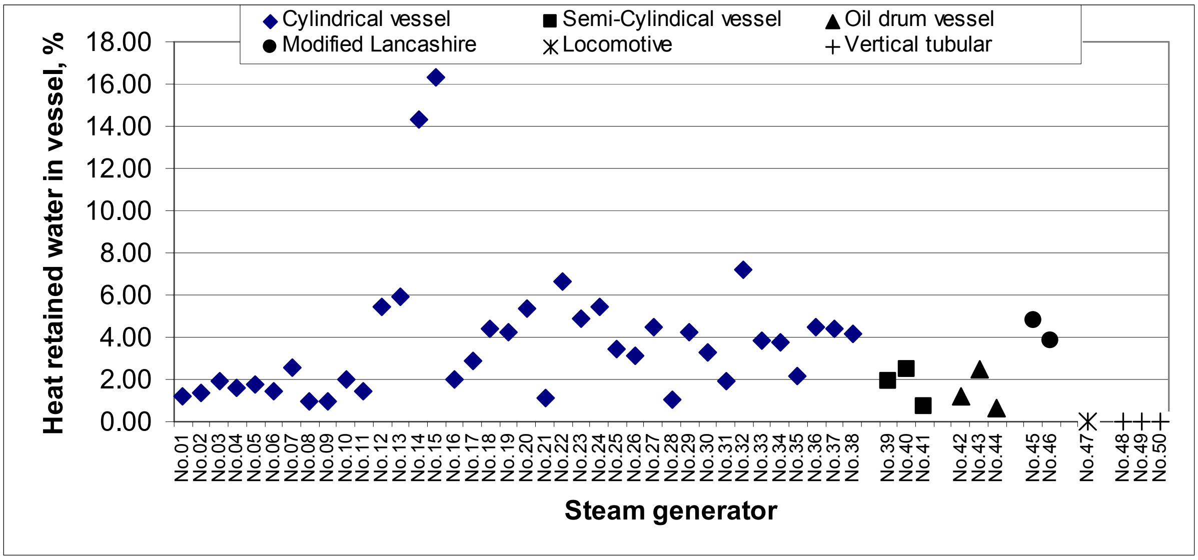


Figure 10. Percentage of unused heat in the retained water in the steam vessel

3.6.2 Heat radiation loss through uninsulated long steam delivery pipe

All of the steam vessels under study were found uninsulated steam pipe. Sometimes the length of steam pipe was found greater than 100 feet. These bared long steam pipes degrades the quality of steam (reduced enthalpy and temperature of steam) by radiation heat loss through the bared surface of steam pipe. A study indicated that at least 6% efficiency is increased of the system if proper insulation is provided. Therefore, there is a scope to reduce the heat loss providing proper insulation on steam pipe. A promotional program of insulation of steam generation system could be undertaken to reduce the energy loss and save the rice husk as well.

3.6.3 Heat retained in furnace wall

All of the parboiling system follows a 3-day batch operation for drying and milling of paddy. The operation of steam generation is continued only for 4 to 7 hours. Between the batches the steam vessel and the furnace wall material becomes cold. After 3-days the furnace is fired again for another batch. It takes about an hour to generate steam and by this time furnace wall material absorbs a lot of heat. Due to the alternate heating and cooling of furnace wall material, a lot of thermal energy is lost. To minimize the loss of heat, the use of furnace wall material should be as less as possible. For example, water leg or water jacket could be used instead of furnace wall.

3.6.4 High excess air

Adequate air-fuel mixture is necessary for complete combustion for any kind of fuel. The excess air cools down the flame temperature that reduces the penetration rate of heat to the water in the steam vessel/boiler. The study team found that there are many unnecessary large ports in the traditional system which causes excess air flow and causes cooling down of the flame temperature.

3.6.5 High flue gas temperature

The chief loss of heat is almost invariably the heat carried away in the waste. The path of flue gas inside the furnace is very short and the maximum length of flue is the length of steam vessel. A traditional practice is that the fuel is thrown into furnace at a distance about 2 feet from the fuel port which cut down the flue path also. High temperature (650-750 °C) of flue gas indicates that it carries out lot of heat from the combustion chamber.

3.6.6 High radiation through uninsulated vessel and different openings of furnace

High heat radiation is expected from the system due to the bared surface of vessel and different opening of furnace

4. Conclusion and recommendation

Based on the findings from the field study it was found that the energy efficiency of the existing steam generating units varies greatly from 13% to 50%. Different types of rice parboiling combustion systems are being used country wide. Different designs of the steam generators are also being used by the rice millers. However, the steam generators can be categorized mainly of 6 types as mentioned in the section 3.1. Most of the systems are local made. The range of variation in shape, size and designs indicates that the village artisans do not follow any standard design or any fabrication procedure. They are unskilled and have no technical know how on manufacturing of modern and efficient steam generation system. They always use their own idea and experience without considering the efficiency. Therefore, there is a great potential to improve the skill of village artisans to make a relatively efficient steam generator as well as to minimize the rice husk energy consumption in parboiling paddy.

The variability in efficiency and in configuration among the steam vessel is also proves the absence of any standard specifications and manufacturing process. Local *mistrires* use locally available materials and tools in making the steam generation unit at their own wish and ideas. They always consider minimizing the cost neglecting the safety aspects, heat loss and environmental pollution and other hazards in operating the system as a whole.

From the findings of field study it is expected that the energy efficiency of the existing units may be raised upto 60% by modifying both the design of the stem generation as well as the furnace and the specific husk consumption may be reduced to 50%.

Based on the expected output for example we can calculate that a rice mill currently consumed 1000 kg of husk per day in steam generation can save upto 500 kg of husk per day. Considering 10 days of operation in a month and 8 month operation per year, the total saving would be about 40 tons per year that would result and additional profit of husk of TK60000.00 per year per mill (cost of husk @Tk1.50 per kg) i.e, US$833.00 per year per mill. If the capital investment of improve steam generation unit and the improve furnace would cost about Tk120000.00 (65,000 for steam generator + 55,000 for furnace). The pay back period would be 2 years of operation.

The field survey findings demonstrated that the working conditions of rice mill are hazardous and unsafe when the furnace is in operation flame comes out from the side port and fuel feeding inlet. Presence of carbon monoxide (CO) is detected at an unacceptable level (upto 10000 ppm). There were also high levels of radiation heat from the steam vessel and the large fuel inlet port. Incomplete combustion of husk in the conventional furnace created an unhygienic working condition for the operation.

Lack of instrumentation particularly absence of safety valve, pressure gauge and water level indicator endangers the life of workers. Discussion with workers, owners and operators indicated that they all were fully aware of dangers, but there are quite ignorance about it because the labourers are easily replaceable in Bangladesh. Sometimes death and injury of poor workers have severe consequences for their livelihood strategies if such accident is occurred.

Steam consumption per ton of paddy parboiling varies widely (65 to 193 kg steam per ton of paddy) for different user. Therefore, a study should be undertaken to optimize the steam consumption rate for rice parboiling to minimize the waste of steam as well as to save energy.

Heat loss of existing steam generation systems should be minimized by incorporating proper insulation and the furnace should be redesigned to enhance heat penetration to water and reduce heat loss.

Hence to ensure sustainable supply and use of rice husk biomass energy, there is a need to design a safer and more efficient system. The local manufacturing capability should be taken into account in the design process. Therefore, a proper adaptive research on the development and extension of energy efficient rice parboiling system is a demand led programme of gtz. The programme would help to create awareness among the users of rice husk energy, improve lively hood of workers, and ensures environmental sustainability and reducing emission for protecting the global environment and meet of goal of MDG.

References:

Ahiduzzaman, M (2006): Production and Use of Densified Biofuel in Mymensingh District (Bangladesh) under Technical and Socio-economical Aspects. M.Sc. Thesis submitted to the Department of Sustainable Energy Systems and Management, University of Flensburg, Germany.

Ali M (2004): A report on the boiler explosions in the rice mills of Bangladesh. Directorate General of Food, GoB. Abdul Ghani Road, Dhaka.

Baqui, M A, M E, Harun, D Jones and R Stringfellow (1997): Export potential of traditional rice varieties from Bangladesh. A report on field work conducted jointly by Bangladesh Rice Research Institute and Natural Resources Institute (NRI), UK.

BBS (2004): Statistical Year Book of Bangladesh. Bangladesh Bureau of Statistics. Planning Division, Ministry of Planning, published in December 2005.

Dasgupta, N., Baqui, M. A., Dhingra S., Raman, P., Ahiduzzaman, M. And Kishore, V.V. N. (2003): Benefits of Improved Rice Husk Combustion, Bangladesh. NRI report no. 2764.

FAO (1978): rice-husk conversion to energy. FAO Agricultural Service Bulletin 31.

RWEDP. (2000): Basics of Wood Energy Planning – A Manual- DRAFT. Regional Wood Energy Development Programme in ASIA GCP/RAS/154/NET. Food and Agricultural Organization of the United Nations. Bangkok, January 2000. Report No. 64. p.2.

Tariq, A S (1999): A project concept note, submitted to the Crop-postharvest programme, NRI, DFID, UK.

Annex 1: List of rice mill visited to determine the energy efficiency of rice parboiling system

SL No.	Name of rice mill	Address	Type of steam generator unit
1	M/S Momtaz Rice Mill	Md. Momtaz Uddin Bormi Bazar Sripur, Gazipur	Cylindrical vessel
2	M/S Amzad Rice Mill	Md. Amzad Hossain Chechua Bazar Muktagacha Mymensingh	Cylindrical vessel
3	M/S Khandaker Rice and Flour Mill	Md. Abu Taher Mia Chechua Bazar Muktagacha Mymensingh	Cylindrical vessel
4	M/S Syedpara Rice and Flour Mill	Md. Samsul Haque Chechua Bazar Muktagacha Mymensingh	Cylindrical vessel
5	M/S Islam Rice Mill	Haji Md. Abdul Kuddus Chechua Bazar Muktagacha Mymensingh	Cylindrical vessel
6	M/S Madina Rice Mill	Md. Motaleb Hossain Chechua Bazar Muktagacha Mymensingh	Cylindrical vessel
7	M/S Agomoni Auto Rice and Flour Mill	Md. Manwar Ferdus Chechua Bazar Muktagacha Mymensingh	Cylindrical vessel
8	M/S Milon Rice and Flour Mill	Md. Abul Quasem Chechua Bazar Muktagacha Mymensingh	Cylindrical vessel
9	M/S Anwar Rice and Flour Mill	Md. Nazrul Islam Chechua Bazar Muktagacha Mymensingh	Cylindrical vessel
10	M/S Hisbul Bahar Rice Mill	Md. Korban Sarker Chechua Bazar Muktagacha Mymensingh	Cylindrical vessel
11	M/S Sarker Rice and Flour Mill	Abdul Mannan Sarker Chechua Bazar Muktagacha Mymensingh	Cylindrical vessel

Annex 1. Contd...

SL No.	Name of rice mill	Address	Type of steam generator unit
12	M/S Khan Rice Mill	Ziaul Karim Khan Sonarampur, Ashuganj B. Baria	Cylindrical vessel
13	M/S Macca Rice Mill	Mohammad Suruj Mia Sonarampur, Ashuganj B. Baria	Cylindrical vessel
14	M/S Bhai Bhai Rice Mill-1	Md. Abu Taher Paruara, Burichang Comilla	Cylindrical vessel
15	M/S Bhai Bhai Rice Mill-2	Md. Abu Taher Paruara, Burichang Comilla	Cylindrical vessel
16	M/S Fuad Rice Mill	Fahmida Begum Pulhat, Dinajpur	Cylindrical vessel
17	M/S Fyzur Rahman Rice Mill	Mr. Fyzur Rahman Pulhat, Dinajpur	Cylindrical vessel
18	M/S Ahmed and Son's Industries	Md. Mokarram Hossain Pulhat, Dinajpur	Cylindrical vessel
19	M/S Jamal Industries	Md. Belal Hossain Pulaht, Majhipara Dinajpur	Cylindrical vessel
20	M/S Kauser Industries Limited	Md. Abdul Razzak Pulhat Dinajpur	Cylindrical vessel
21	M/S Abul Hossain Husking Mill	Abul Hossain Shah North Faridpur Pulhat, Dinajpur	Cylindrical vessel
22	M/S Shah Newaz Husking Mill	Shah Newaz North Faridpur Pulhat, Dinajpur	Cylindrical vessel
23	M/S Hossain Rice Mill	Md. Zakir Hossain Pulhat, Dinajpur	Cylindrical vessel
24	M/S Sobhanallah Husking Mill	Mr. Sanwar Hossain Pulhat, Dinajpur	Cylindrical vessel
25	M/S Momana Husking Mill	Maksud Ali Pulhat, Dinajpur	Cylindrical vessel
26	M/S Tanvir Husking Mill	Akbar Ali Pulhat, Dinajpur	Cylindrical vessel
27	M/S Hushmi Rice Mill	Mutafa Belal Pulhat, Dinajpur	Cylindrical vessel
28	M/S Satter Rice Mill, Bogra	Sherua Bat Tala Sherpur, Bogra	Cylindrical vessel
29	M/S Aktaruzzaman Rice Mill	Md. Abu Selim Shingjhuli Chougacha, Jessore	Cylindrical Vessel
30	M/S Alamgir Rice Mill	S.M. Alamgir Mukul Purapara Chougacha, Jessore	Cylindrical Vessel

Annex 1. Contd...

SL No.	Name of rice mill	Address	Type of steam generator unit
31	M/s Amin Ahmed Rice Mill	Md. Amin Ahamed Gadkhali, Jhikargacha Jessore	Cylindrical Vessel
32	M/s Bhai Bhai Rice Mill	Md. Elahi Box North Burui Bagan P.O. Jadobpur Sharsha, Jessore	Cylindrical Vessel
33	M/S Moniruzzaman Rice Mill	Md. Jahan Ali Dofadar North Burui Bagan P.O. Jadobpur Sharsha, Jessore	Cylindrical Vessel
34	M/S Bhai Bhai Rice Mill	Mojaharul Haque Padmavila Bazar P.O. Ghuni, Jessore	Cylindrical Vessel
35	M/S Jaman Rice Mill	Md. SaifurRahman Padmavila Bazar P.O. Ghuni Jessore	Cylindrical Vessel
36	M/S Fajila Rice Mill	Md. Delwar Hossain Sheikh Labonchora, Khulna	Cylindrical Vessel
37	M/S Islamia Rice Mill	Md. Kaji Shobhan Labonchora, Khulna	Cylindrical Vessel
38	M/S Arpi Rice Mill	Md. Ahad Munshi Shadur Bridge Rajoir, Madaripur	Cylindrical Vessel
39	M/S Baba Rice Mill[1]	Kaliakoir Gazipur	Semi-cylindrical vessel
40	M/S Mohanagar Rice Mill[1]	Kaliakoir Gazipur	Semi-cylindrical vessel
41	M/S Mitali Auto Rice Mill[1]	Md. Ibrahim Fakir Maona Chourasta Sripur, Gazipur	Semi-cylindrical vessel
42	M/S Nisha Rice Mill	Md. Nazrul Islam Birkeda, Kahalu Bogra	Cylindrical vessel (Oil drum)
43	M/S Karnofuli Rice Mill	Khalilur Rahman Khaja Nagar Poradah, Kustia	Cylindrical Vessel (Oil drum)
44	M/S Hasina Rice Mill	Md. Hashmat Ali Gadkhali, Jhikargacha Jessore	Cylindrical Vessel (Oil drum)
45	M/S Ashrafi Rice Mill[2]	Engr. Ashrafi Farhad Hossain Bormi, Gazipur	Modified Lancashire boiler
46	M/S Rubel and Brothers Boiler Rice Mill[2]	Abdur Rahman Rob Paruara, Burichang Comilla	Modified Lancashire boiler

[1] Semi-cylinder with flat bottom

Annex 1. Contd...

SL No.	Name of rice mill	Address	Type of steam generator unit
47	M/S Amanat Rice Mill[3]	Abu Bakar Chairman Pulhat, Dinajpur	Locomotive boiler (Fire tube)
48	M/S Rafiq Rice Mill	Abul Hashem Mia Umednagar Baniachang Road Habiganj	Vertical tubular boiler
49	M/S Intaz Rice Mill	Haji Ishaque Miah Lengapara Shaestaganj Habiganj	Vertical tubular boiler
50	M/S Sheik Rice Mill	Umednagar Baniachang Road Habiganj	Vertical tubular boiler

[2] Local made
[3] Purchased from Chittagong Port

Annex 2. Specification of steam generators under study

Name of rice mill	Boiler/steam vessel shape	Insulated or not (Yes/No)	Chimney (Yes/No)	Safety valve (Yes/No)	Pressure meter (Yes/No)	Water level gauge (Yes/No)	Vessel thickness mm	Boiler/vessel dimension, mm		Vessel volume, litre
								Length	Diameter/ Width	3763
1. M/S Momtaz Rice Mill, Bormi	Cylindrical	No	Yes	Yes	No	No		3658	1310	
2. M/S Amzad Rice Mill, Muktagacha	Cylindrical	No	No	No	No	No		2643	1143	2142
3. M/S Khandaker Rice and Flour Mill, Muktagacha	Cylindrical	No	No	No	No	No		2387	1143	2189
4. M/S Syedpara Rice and Flour Mill, Muktagacha	Cylindrical	No	No	No	No	No		2438	1143	2280
5. M/S Islam Rice Mill, Muktagacha	Cylindrical	No	No	No	No	No		2540	1143	2189
6. M/S Madina Rice Mill, Muktagacha	Cylindrical	No	No	No	No	No		2438	1143	2914
7. M/S Agomoni Auto Rice and Flour Mill, Muktagacha	Cylindrical	No	No	No	No	No		3175	1168	2727
8. M/S Milon Rice and Flour Mill, Muktagacha	Cylindrical	No	No	No	No	No		2972	1168	2238
9. M/S Anwar Rice and Flour Mill, Muktagacha	Cylindrical	No	No	No	No	No		2438	1168	2645
10. M/S Hisbul Bahar Rice Mill, Muktagacha	Cylindrical	No	No	No	No	No		2946	1143	2736
11. M/S Sarker Rice and Flour Mill, Muktagacha	Cylindrical	No	No	No	No	No		3048	1143	5278
12. M/S Khan Rice Mill, Ashuganj	Cylindrical	No	Yes	Yes	Yes	No	19.0	4724	1422	4925
13. M/S Mocca Rice Mill, Ashuganj	Cylindrical	No	Yes	Yes	Yes	No	9.5	4572	1372	3502
14. M/S Bhai Bhai Rice Mill-1, Comilla	Cylindrical	No	Yes	Yes	No	No		4877	914.4	4378
15. M/S Bhai Bhai Rice Mill-2 Comilla	Cylindrical	No	Yes	Yes	Yes	No		3658	1524	3750
16. M/S Fuad Rice Mill, Pulhat	Cylindrical	No	Yes	No	No	No	2.54	4801	750	2402

Annex 2. Contd...

Name of rice mill	**Boiler/steam vessel shape**	**Insulated or not (Yes/No)**	**Chimney (Yes/No)**	**Safety valve (Yes/No)**	**Pressure meter (Yes/No)**	**Water level gauge (Yes/No)**	**Vessel thickness** mm	**Boiler/vessel dimension, mm**		**Vessel volume, litre**
								Length	Diameter/ Width	3763
17. M/S Fyzur Rahman Rice Mill, Pulhat	Cylindrical	No	Yes	No	No	No	2.11	4013	762	2052
18. M/S Ahmed and Son's Industries, Pulhat	Cylindrical	No	Yes	No	No	No		3429	762	2113
19. M/S Jamal Industries, Pulhat	Cylindrical	No	Yes	No	No	No		3531	762	
20. M/S Kauser Industries Limited, Pulhat	Cylindrical	No	Yes	No	No	No		4801	838.2	2159
21. M/S Abul Hossain Husking Mill, Pulhat	Cylindrical	No	Yes	No	No	No		3607	762	2627
22. M/S Shah Newaz Husking Mill, Pulhat	Cylindrical	No	Yes	No	No	No		3658	914.4	2929
23. M/S Hossain Rice Mill, Pulhat	Cylindrical	No	Yes	No	No	No		4318	863.6	2554
24. M/S Sobhanallah Husking Mill, Pulhat	Cylindrical	No	Yes	Yes	No	No		4267	762	2825
25. M/S Momana Husking Mill, Pulhat	Cylindrical	No	Yes	Yes	No	No		4166	863.6	2295
26. M/S Tanvir Husking Mill, Pulhat	Cylindrical	No	Yes	No	No	No		3835	762	3101
27. M/S Hushmi Rice Mill, Pulhat	Cylindrical	No	Yes	Yes	No	No		5182	762	2919
28. M/S Satter Rice Mill, Bogra	Cylindrical	No	Yes	Yes	No	No		4877	762	1940
29. M/S Aktaruzzaman Rice Mill, Jessore	Cylindrical	No	Yes	Yes	No	No	1..8	3480	1016	2906
30. M/S Alamgir Rice Mill, Jessore	Cylindrical	No	No	Yes	No	No		4648	796	1567
31. M/S M/s Amin Ahmed Rice Mill, Jessore	Cylindrical	No	Yes	Yes	No	No		3962	762	2320
32. M/S M/s Bhai Bhai Rice Mill, Jadobpur, Jessore	Cylindrical	No	Yes	Yes	No	No		3353	863.6	2919
33. M/S Moniruzzaman Rice Mill, Jessore	Cylindrical	No	Yes	Yes	No	No		3658	1016	1861
34. M/S Bhai Bhai Rice Mill, PdmaVila, Jessore	Cylindrical	No	Yes	Yes	No	No		2743	863.6	2140
35. M/S Jaman Rice Mill, Jessore	Cylindrical	No	Yes	Yes	No	No		3353	812.8	3502

Annex 2. Contd...

Name of rice mill	**Boiler/steam vessel shape**	**Insulated or not (Yes/No)**	**Chimney (Yes/No)**	**Safety valve (Yes/No)**	**Pressure meter (Yes/No)**	**Water level gauge (Yes/No)**	**Vessel thickness** mm	**Boiler/vessel dimension, mm**		**Vessel volume, litre**
								Length	Diameter/ Width	3763
36. M/S Fajila Rice Mill; Khulna	Cylindrical	No	Yes	Yes	No	No		4877	914.4	3755
37. M/S Islamia Rice Mill, Khulna	Cylindrical	No	Yes	Yes	No	No		4826	990.6	1800
38. M/S Arpi Rice Mill, madaripur	Cylindrical	No	No	Yes	No	No	2.11	2438	939.8	3763
39. M/S Baba Rice Mill, Kaliakoir	Semi- Cylindrical	No	Yes	No	No	No		3658	1219	
40. M/S Mohanagar Rice Mill, Kaliakoir	Semi- Cylindrical	No	Yes	No	No	No		3658	1219	3502
41. M/S Mitali Auto Rice Mill, Mawna	Semi- Cylindrical	No	Yes	No	No	No		3200	1219	2372
42. M/S Nisha Rice Mill, Kahalu	Oil drum	No	Yes	Yes	No	No		4420	558.8	
43. M/S Karnofuli Rice Mill, Kustia	Oil drum	No	No	No	No	No		3500	570	2371
44. M/S Hasina Rice Mill, Jessore	Oil drum	No	No	No	No	No		5182	570	2274
45. M/S Ashrafi Rice Mill, Bormi	Modified Lancashire	No	Yes	Yes	Yes	Yes		3658	1219	
46. M/S Rubel and Brothers Boiler Rice Mill, Comilla	Modified Lancashire	No	Yes	Yes	Yes	Yes	10.0	3759	1270	2828
47. M/S Amanat Rice Mill, Pulhat	Locomotive	No	Yes	Yes	Yes	Yes				3160
48. M/S Rafiq Rice Mill, Habiganj	Vertical	No	Yes	Yes	Yes	Yes		3226	1499	
49. M/S Intaz Rice Mill, Habiganj	Vertical	No	Yes	Yes	Yes	Yes	19.0	3658	1499	
50. M/S Sheik Rice Mill, Habiganj	Vertical	No	Yes	Yes	Yes	Yes	12.5	3000	1769	2777

Annex 3. Summary of Category wise performance of rice parboiling systems under study

Sl. No.	Name of category of steam (vessel/boiler)	No. of unit studied	Volume of steam vessel (litre)	Rice mill capacity, (ton/batch)	Steam production rate (kg/hr)	Steam usage (kg steam/ton paddy)	Thermal efficiency (%)
1	Cylindrical vessel	38	1800 - 5278	2.36 – 22.50	165 – 864	78 - 194	19 - 41
2	Semi-cylindrical vessel	3	2863 - 3272	7.50 – 17.25	195 - 510	65 - 108	13 - 21
3	Oil drum	3	1567 - 2320	3.75 – 7.50	154 – 259	118 - 138	20 - 22
4	Modified Lancashire boiler	2	4032 another one is continuous water feeding type	6.00 – 21.00	693 – 807	103 - 179	28 - 34
5	Locomotive boiler (Fire tube)	1	Continuous water feeding type	7.50	461	131	50
6	Vertical tubular boiler	3	1523 - 2185	11.25 – 18.00	345 - 409	101 - 144	23 - 30

Annex 4. Initial and final water volume of steam generation units visited

Name of rice mill	Vessel Length (mm)	Radius /width R(mm)	Initial water level, H_i (mm)	a = ABS (R-H_i)	$\theta = 2*\cos^{-1}(a/R)$	Initial wetted area (m^2)	Initial volume (m^3)	Final water level, H_f (mm)	b = ABS (R-H_f)	$\varphi = 2*\cos^{-1}(b/R)$	Final wetted area (m^2)	Final volume, (m^3)
1. M/S Momtaz Rice Mill, Bormi	3658	1310	540	115	2.788618	0.524038	1.9167	260	395	1.846946	0.189808	0.694
2. M/S Amzad Rice Mill, Muktagacha	2643	1143	1143	571.5	0	1.026083	2.7115	381	190.5	2.461919	0.299402	0.791
3. M/S Khandaker Rice and Flour Mill, Muktagacha	2387	1143	1118	546.1	0.598516	1.020351	2.4352	470	101.5	2.784493	0.39764	0.949
4. M/S Syedpara Rice and Flour Mill, Muktagacha	2438	1143	1143	571.5	0	1.026083	2.5020	457	114.3	2.738877	0.383273	0.935
5. M/S Islam Rice Mill, Muktagacha	2540	1143	914	342.9	1.85459	0.879991	2.2352	431.8	139.7	2.647699	0.354969	0.902
6. M/S Madina Rice Mill, Muktagacha	2438	1143	864	292.1	2.068639	0.831744	2.0281	355.6	215.9	2.366803	0.27227	0.664
7. M/S Agomoni Auto Rice and Flour Mill, Muktagacha	3175	1168	1041	457.2	1.343902	1.009134	3.2040	508	76.2	2.879978	0.447318	1.420
8. M/S Milon Rice and Flour Mill, Muktagacha	2972	1168	838	254	2.241999	0.823235	2.4465	228.6	355.6	1.832762	0.147928	0.440
9. M/S Anwar Rice and Flour Mill, Muktagacha	2438	1168	940	355.6	1.832762	0.924265	2.2537	254	330.2	1.940199	0.171951	0.419
10. M/S Hisbul Bahar Rice Mill, Muktagacha	2946	1143	864	292.1	2.068639	0.831744	2.4507	393.7	177.8	2.508869	0.313144	0.923
11. M/S Sarker Rice and Flour Mill, Muktagacha	3048	1143	1143	571.5	0	1.026083	3.1275	431.8	139.7	2.647699	0.354969	1.082
12. M/S Khan Rice Mill, Ashuganj	4724	1422	1133	421.64	1.872388	1.35699	6.4110	873.8	162.56	2.680373	1.023713	4.836
13. M/S Mocca Rice Mill, Ashuganj	4572	1372	1002	315.722	2.184768	1.156	5.2852	755.7	69.85	2.937535	0.83442	3.815
14. M/S Bhai Bhai Rice Mill-1, Comilla	4877	914.4	889	431.8	0.669792	0.651575	3.1776	787.4	330.2	1.527573	0.601456	2.933
15. M/S Bhai Bhai Rice Mill-2 Comilla	3658	1524	900	138	2.777378	1.12123	4.1010	820	58	2.989214	1.00038	3.659
16. M/S Fuad Rice Mill, Pulhat	4801	750	750	375	0	0.441786	2.1208	330	45	2.901013	0.187224	0.899
17. M/S Fyzur Rahman Rice Mill, Pulhat	4013	762	762	381	0	0.456037	1.8302	381	0	3.141593	0.228018	0.915
18. M/S Ahmed and Son's	3429	762	760	379	0.205016	0.455933	1.5634	480	99	2.615874	0.302599	1.038

Annex 4. Contd...

Name of rice mill	Vessel Length (mm)	Radius /width R(mm)	Initial water level, H_i (mm)	a = ABS (R-H_i)	θ = 2*$\cos^{-1}$(a/R)	Initial wetted area (m^2)	Initial volume (m^3)	Final water level, H_f (mm)	b = ABS (R-H_f)	φ = 2*$\cos^{-1}$(b/R)	Final wetted area (m^2)	Final volume, (m^3)
Industries, Pulhat												
19. M/S Jamal Industries, Pulhat	3531	762	760	379	0.205016	0.455933	1.6097	460	79	2.723864	0.287782	1.016
20. M/S Kauser Industries Limited, Pulhat	4801	838.2	830	410.9	0.396281	0.550901	2.6447	480	60.9	2.849937	0.326768	1.569
21. M/S Abul Hossain Husking Mill, Pulhat	3607	762	760	379	0.205016	0.455933	1.6445	300	81	2.713126	0.166765	0.601
22. M/S Shah Newaz Husking Mill, Pulhat	3658	914	910	452.8	0.277694	0.656321	2.4006	550	92.8	2.732803	0.412616	1.509
23. M/S Hossain Rice Mill, Pulhat	4318	863.6	860	428.2	0.258438	0.585487	2.5281	490	58.2	2.8712	0.342986	1.481
24. M/S Sobhanallah Husking Mill, Pulhat	4267	762	760	379	0.205016	0.455933	1.9456	410	29	2.989214	0.250095	1.067
25. M/S Momana Husking Mill, Pulhat	4166	863.6	737	304.8	1.574257	0.532218	2.2170	457.2	25.4	3.023878	0.3148	1.311
26. M/S Tanvir Husking Mill, Pulhat	3835	762	762	381	0	0.456037	1.7491	406.4	25.4	3.00816	0.247359	0.949
27. M/S Hushmi Rice Mill, Pulhat	5182	762	762	381	0	0.456037	2.3630	431.8	50.8	2.874129	0.266613	1.381
28. M/S Satter Rice Mill, Bogra	4877	762	760	379	0.205016	0.455933	2.2235	228.6	152.4	2.318559	0.115065	0.561
29. M/S Aktaruzzaman Rice Mill, Jessore	3480	1016	964	456	0.912832	0.795043	2.7666	645.8	137.8	2.592189	0.543634	1.892
30. M/S Alamgir Rice Mill, Jessore	4648	796	730	332	1.168337	0.47798	2.2217	450	52	2.879537	0.290094	1.348
31. M/S M/s Amin Ahmed Rice Mill, Jessore	3962	762	559	177.8	2.170556	0.35841	1.4202	304.8	76.2	2.738877	0.170343	0.675
32. M/S M/s Bhai Bhai Rice Mill, Jadobpur, Jessore	3353	863.6	864	431.8	0	0.585754	1.9639	622.3	190.5	2.227774	0.451888	1.515
33. M/S Moniruzzaman Rice Mill, Jessore	3658	1016	762	254	2.094395	0.652233	2.3856	508	0	3.141593	0.405366	1.483
34. M/S Bhai Bhai Rice Mill, PdmaVila, Jessore	2743	863.6	610	177.8	2.292813	0.441968	1.2124	406.4	25.4	3.023878	0.270954	0.743
35. M/S Jaman Rice Mill, Jessore	3353	812.8	610	203.2	2.094395	0.417429	1.3996	325.1	81.28	2.738877	0.193813	0.650
36. M/S Fajila Rice Mill; Khulna	4877	914.4	864	406.4	0.951764	0.64234	3.1326	558.8	101.6	2.693406	0.420479	2.051
37. M/S Islamia Rice Mill, Khulna	4826	990.6	813	317.5	1.749925	0.676753	3.2660	533.4	38.1	2.987594	0.423056	2.042
38. M/S Arpi Rice Mill, madaripur	2438	939.8	940	469.9	0	0.693683	1.6915	584.2	114.3	2.650176	0.453192	1.105

Annex 4. Contd...

Name of rice mill	Vessel Length (mm)	Radius /width R(mm)	Initial water level, H_i (mm)	a = ABS (R-H_i)	θ = 2*$\cos^{-1}$(a/R)	Initial wetted area (m^2)	Initial volume (m^3)	Final water level, H_f (mm)	b = ABS (R-H_f)	φ = 2*$\cos^{-1}$(b/R)	Final wetted area (m^2)	Final volume, (m^3)
39. M/S Baba Rice Mill, Kaliakoir	3658	1219					1.9255	275			0.329555	1.205
40. M/S Mohanagar Rice Mill, Kaliakoir	3658	1219					1.4719	230			0.277425	1.015
41. M/S Mitali Auto Rice Mill, Mawna	3200	1219					2.3962	140			0.168945	0.541
42. M/S Nisha Rice Mill, Kahalu	4420	558.8	457	177.8	1.762043	0.214791	0.9493	177.8	101.6	2.397256	0.067126	0.297
43. M/S Karnofuli Rice Mill, Kustia	3500	570	550	265	0.753721	0.252359	0.8833	280	5	3.106503	0.124738	0.437
44. M/S Hasina Rice Mill, Jessore	5182	570	559	273.8	0.562554	0.25399	1.3161	152.4	132.6	2.173729	0.054829	0.284
45. M/S Ashrafi Rice Mill, Bormi	3658	1219	927	317.4	2.046323	0.952426	3.2464	673	63.5	2.932881	0.661006	2.180
46. M/S Rubel and Brothers Boiler Rice Mill, Comilla	3759	1270	1067			3.387	3.6133	431.8	203.2		3.387	1.463
47. M/S Amanat Rice Mill, Pulhat			1905	-	-	1.263	2.4060	1168	-	-	1.263	1.476
48. M/S Rafiq Rice Mill, Habiganj	3226	1499	2972	2222.5		1.763848	1.5233	70.1	679.196		1.763849	0.124
49. M/S Intaz Rice Mill, Habiganj	3658	1499	3353	2603.5		1.763848	1.9713	80.52	668.782		1.763849	0.142
50. M/S Sheik Rice Mill, Habiganj	3000	1769	3000	2115.5		2.457794	2.1850	7.112	877.388		2.457794	0.0175

Annex 5. Steam production and steam use pattern for rice parboiling

Name of rice mill	Initial volume of water (m^3)	Feed water temp. (°C)	Specific gravity of water	**Initial weight of water, kg**	Final volume of water (m^3)	Specific gravity of water at 100°C	**Final weight of water, kg**	**Steam produced, (kg)**	Time required to produce steam, hr	**Steam capacity, kg/hr**	Paddy parboiled (ton)	**Steam use (kg/ton paddy)**
1. M/S Momtaz Rice Mill, Bormi	1.9167	52	0.98715	**1892**	0.694	0.9584	**665**	**1227**	1.42	**864**	7.5	**164**
2. M/S Amzad Rice Mill, Muktagacha	2.7115	32	0.99505	**2698**	0.791	0.9584	**758**	**1940**	3.67	**529**	11.25	**172**
3. M/S Khandaker Rice and Flour Mill, Muktagacha	2.4352	33	0.99472	**2422**	0.949	0.9584	**910**	**1513**	3.05	**496**	11.925	**127**
4. M/S Syedpara Rice and Flour Mill, Muktagacha	2.5020	36.4	0.99371	**2486**	0.935	0.9584	**896**	**1591**	3.67	**433**	11.625	**137**
5. M/S Islam Rice Mill, Muktagacha	2.2352	28	0.99626	**2227**	0.902	0.9584	**864**	**1363**	3.5	**389**	11.25	**121**
6. M/S Madina Rice Mill, Muktagacha	2.0281	28.6	0.9962	**2020**	0.664	0.9584	**636**	**1384**	4.33	**320**	11.25	**123**
7. M/S Agomoni Auto Rice and Flour Mill, Muktagacha	3.2040	31	0.99536	**3189**	1.420	0.9584	**1361**	**1828**	3.5	**522**	15	**122**
8. M/S Milon Rice and Flour Mill, Muktagacha	2.4465	30	0.99567	**2436**	0.440	0.9584	**421**	**2015**	3.58	**563**	11.25	**179**
9. M/S Anwar Rice and Flour Mill, Muktagacha	2.2537	29	0.99596	**2245**	0.419	0.9584	**402**	**1843**	4	**461**	11.25	**164**
10. M/S Hisbul Bahar Rice Mill, Muktagacha	2.4507	35	0.99405	**2436**	0.923	0.9584	**884**	**1552**	4.08	**380**	11.25	**138**
11. M/S Sarker Rice and Flour Mill, Muktagacha	3.1275	35.4	0.99403	**3109**	1.082	0.9584	**1037**	**2072**	4.17	**497**	15	**138**
12. M/S Khan Rice Mill, Ashuganj	6.4110	75.1	0.99488	**6378**	4.836	0.9584	**4635**	**1743**	3.22	**541**	22.5	**77**
13. M/S Mocca Rice Mill, Ashuganj	5.2852	53.9	0.98524	**5207**	3.815	0.9584	**3656**	**1551**	3.33	**466**	15.75	**98**
14. M/S Bhai Bhai Rice Mill-1, Comilla	3.1776	50	0.98807	**3140**	2.933	0.9584	**2811**	**329**	0.92	**357**	2.3625	**139**
15. M/S Bhai Bhai Rice Mill-2 Comilla	4.1010	50	0.98807	**4052**	3.659	0.9584	**3507**	**545**	1	**545**	3.75	**145**
16. M/S Fuad Rice Mill, Pulhat	2.1208	51.1	0.98761	**2095**	0.899	0.9584	**861**	**1233**	2.75	**448**	6.375	**193**
17. M/S Fyzur Rahman Rice Mill, Pulhat	1.8302	40	0.99224	**1816**	0.915	0.9584	**877**	**939**	2.25	**417**	6.375	**147**

Annex 5. Contd...

Name of rice mill	Initial volume of water (m^3)	Feed water temp. (°C)	Specific gravity of water	**Initial weight of water, kg**	Final volume of water (m^3)	Specific gravity of water at 100°C	**Final weight of water, kg**	**Steam produced, (kg)**	Time required to produce steam, hr	**Steam capacity, kg/hr**	Paddy parboiled (ton)	**Steam use (kg/ton paddy)**
18. M/S Ahmed and Son's Industries, Pulhat	1.5634	28.7	0.99599	**1557**	1.038	0.9584	**994**	**563**	1.863	**302**	3.75	**150**
19. M/S Jamal Industries, Pulhat	1.6097	28.4	0.99623	**1604**	1.016	0.9584	**974**	**630**	1.92	**328**	3.75	**168**
20. M/S Kauser Industries Limited, Pulhat	2.6447	30.2	0.99569	**2633**	1.569	0.9584	**1503**	**1130**	2.25	**502**	7.5	**151**
21. M/S Abul Hossain Husking Mill, Pulhat	1.6445	75.5	0.99485	**1636**	0.601	0.9584	**576**	**1060**	3	**353**	6.75	**157**
22. M/S Shah Newaz Husking Mill, Pulhat	2.4006	30.4	0.99563	**2390**	1.509	0.9584	**1446**	**944**	2.3	**410**	5.625	**168**
23. M/S Hossain Rice Mill, Pulhat	2.5281	30.4	0.99563	**2517**	1.481	0.9584	**1419**	**1098**	2.67	**411**	9.375	**117**
24. M/S Sobhanallah Husking Mill, Pulhat	1.9456	29.6	0.99567	**1937**	1.067	0.9584	**1023**	**914**	2.28	**401**	6.75	**135**
25. M/S Momana Husking Mill, Pulhat	2.2170	29	0.99596	**2208**	1.311	0.9584	**1257**	**951**	3.83	**248**	7.5	**127**
26. M/S Tanvir Husking Mill, Pulhat	1.7491	28.7	0.99599	**1742**	0.949	0.9584	**909**	**833**	2.5	**333**	6.375	**131**
27. M/S Hushmi Rice Mill, Pulhat	2.3630	28.7	0.99599	**2354**	1.381	0.9584	**1324**	**1030**	4.17	**247**	7.5	**137**
28. M/S Satter Rice Mill, Bogra	2.2235	30	0.99567	**2214**	0.561	0.9584	**538**	**1676**	6.5	**258**	12.375	**135**
29. M/S Aktaruzzaman Rice Mill, Jessore	2.7666	29	0.99596	**2755**	1.892	0.9584	**1813**	**942**	4.15	**227**	7.5	**126**
30. M/S Alamgir Rice Mill, Jessore	2.2217	29	0.99596	**2213**	1.348	0.9584	**1292**	**920**	3.92	**235**	6.5625	**140**
31. M/S M/s Amin Ahmed Rice Mill, Jessore	1.4202	32	0.99505	**1413**	0.675	0.9584	**647**	**766**	3	**255**	6	**128**
32. M/S M/s Bhai Bhai Rice Mill, Jadobpur, Jessore	1.9639	32	0.99505	**1954**	1.515	0.9584	**1452**	**502**	3	**167**	3.75	**134**
33. M/S Moniruzzaman Rice Mill, Jessore	2.3856	33	0.99472	**2373**	1.483	0.9584	**1421**	**952**	4	**238**	6.375	**149**
34. M/S Bhai Bhai Rice Mill, PdmaVila, Jessore	1.2124	31	0.99536	**1207**	0.743	0.9584	**712**	**494**	3	**165**	3.375	**146**
35. M/S Jaman Rice Mill, Jessore	1.3996	36	0.99371	**1391**	0.650	0.9584	**623**	**768**	2.5	**307**	5.625	**137**
36. M/S Fajila Rice Mill; Khulna	3.1326	45	0.99024	**3102**	2.051	0.9584	**1965**	**1137**	6	**189**	7.5	**152**
37. M/S Islamia Rice Mill, Khulna	3.2660	37	0.98335	**3212**	2.042	0.9584	**1957**	**1255**	3	**418**	9.375	**134**
38. M/S Arpi Rice Mill, madaripur	1.6915	33	0.99472	**1683**	1.105	0.9584	**1059**	**623**	2	**312**	5.0625	**123**

Annex 5. Contd...

Name of rice mill	Initial volume of water (m^3)	Feed water temp. (°C)	Specific gravity of water	**Initial weight of water, kg**	Final volume of water (m^3)	Specific gravity of water at 100°C	**Final weight of water, kg**	**Steam produced, (kg)**	Time required to produce steam, hr	**Steam capacity, kg/hr**	Paddy parboiled (ton)	**Steam use (kg/ton paddy)**
39. M/S Baba Rice Mill, Kaliakoir	1.9255	58	0.98425	**1895**	1.205	0.9584	**1155**	**740**	1.45	**510**	9	**82**
40. M/S Mohanagar Rice Mill, Kaliakoir	1.4719	40	0.99224	**1460**	1.015	0.9584	**972**	**488**	2.5	**195**	7.5	**65**
41. M/S Mitali Auto Rice Mill, Mawna	2.3962	35.1	0.99405	**2382**	0.541	0.9584	**518**	**1864**	7.33	**254**	17.25	**108**
42. M/S Nisha Rice Mill, Kahalu	0.9493	29	0.99596	**945**	0.297	0.9584	**284**	**661**	3.5	**189**	5.625	**118**
43. M/S Karnofuli Rice Mill, Kustia	0.8833	30	0.99567	**879**	0.437	0.9584	**418**	**461**	3	**154**	3.75	**123**
44. M/S Hasina Rice Mill, Jessore	1.3161	34	0.9944	**1309**	0.284	0.9584	**272**	**1036**	4	**259**	7.5	**138**
45. M/S Ashrafi Rice Mill, Bormi	3.2464	75.8	0.97428	**3163**	2.180	0.9584	**2090**	**1073**	1.33	**807**	6	**179**
46. M/S Rubel and Brothers Boiler Rice Mill, Comilla	3.6133	50	0.98807	**3570**	1.463	0.9584	**1402**	**2168**	3.13	**693**	21	**103**
47. M/S Amanat Rice Mill, Pulhat	2.4060	28.6	0.99599	**2396**	1.476	0.9584	**1414**	**982**	2.13	**461**	7.5	**131**
48. M/S Rafiq Rice Mill, Habiganj	5.2418	30	0.99567	**1517**	0.124	0.9584	**119**	**1398**	3.42	**409**	11.25	**124**
49. M/S Intaz Rice Mill, Habiganj	6.4515	32	0.99505	**1962**	0.142	0.9584	**136**	**1825**	4.6	**397**	18	**101**
50. M/S Sheik Rice Mill, Habiganj	7.3734	30	0.99567	**2176**	0.0175	0.9584	**17**	**2159**	6.25	**345**	15	**144**

Annex 6. Husk fuel consumption and efficiencies of rice parboiling systems

Name of Rice Mill	Husk consumed, W_{fuel} (kg)	Total energy supplied, [4]E_{in} (MJ)	Weight of feed water, W_f (kg)	Initial Temp. °C	Sensible heat in feed water, h_{feed} (kJ/kg)	Steam produced, W_s (kg)	Sensible heat in hot water, h_f (kJ/kg)	Latent heat of steam, h_{fg} (kJ/kg)	Heat addition to steam, [5]q_1 (kJ/kg)	Heat retained in hot water in vessel, (%)[6]	Heat addition to steam, (%)[7]	Overall thermal efficiency, (%)[8]
1. M/S Momtaz Rice Mill, Bormi	982.8	13759	1892	52	218	1227	467	2226	2364	1.21	21.08	22.28
2. M/S Amzad Rice Mill, Muktagacha	1292	18088	2698	32	134	1940	467	2226	2448	1.40	26.25	27.65
3. M/S Khandaker Rice and Flour Mill, Muktagacha	1124	15736	2422	33	138	1513	467	2226	2444	1.90	23.49	25.39
4. M/S Syedpara Rice and Flour Mill, Muktagacha	1259	17626	2486	36.4	152	1591	467	2226	2429	1.60	21.92	23.52
5. M/S Islam Rice Mill, Muktagacha	1211	16954	2227	28	117	1363	467	2226	2464	1.78	19.81	21.59
6. M/S Madina Rice Mill, Muktagacha	1072	15008	2020	28.6	120	1384	467	2226	2462	1.47	22.71	24.18
7. M/S Agomoni Auto Rice and Flour Mill, Muktagacha	1285	17990	3189	31	130	1828	467	2226	2452	2.55	24.91	27.47
8. M/S Milon Rice and Flour Mill, Muktagacha	1100	15400	2436	30	126	2015	467	2226	2456	0.93	32.13	33.06
9. M/S Anwar Rice and Flour Mill, Muktagacha	995	13930	2245	29	121	1843	467	2226	2460	1.00	32.55	33.54
10. M/S Hisbul Bahar Rice Mill, Muktagacha	1012	14168	2436	35	147	1552	467	2226	2435	2.00	26.67	28.67
11. M/S Sarker Rice and Flour Mill, Muktagacha	1625	22750	3109	35.4	148	2072	467	2226	2433	1.45	22.16	23.62
12. M/S Khan Rice Mill, Ashuganj	1876	26264	6378	75.1	314	1743	623	2121	2324	5.45	15.42	20.86
13. M/S Mocca Rice Mill, Ashuganj	1475	20651	5207	53.9	226	1551	561	2164	2391	5.94	17.96	23.89
14. M/S Bhai Bhai Rice Mill-1,	362	5068	3140	50	209	329	467	2226	2372	14.29	15.38	29.67

[4] $E_{in} = W_{fuel} \times C_{fuel}$ (MJ), where C_{fuel} = calorific value of rice husk (14000 kJ/kg)
[5] $q_1 = h_f + 0.95\times h_{fg} - h_{feed}$ (kJ/kg), assume quality of steam = 0.95
[6] $[(h_f - h_{feed}) \times (W_f - W_s)] / E_{in} \times 1/1000 \times 100$
[7] $[q_1 \times W_s]/E_{in} \times 1/1000 \times 100$
[8] $[(h_f - h_{feed}) \times (W_f - W_s) + q_1 \times W_s / E_{in} \times 1/1000 \times 100$

Annex 6. Contd....

Name of Rice Mill	Husk consumed, W_{fuel} (kg)	Total energy supplied, [4]E_{in} (MJ)	Weight of feed water, W_f (kg)	Initial Temp. °C	Sensible heat in feed water, h_{feed} (kJ/kg)	Steam produced, W_s (kg)	Sensible heat in hot water, h_f (kJ/kg)	Latent heat of steam, h_{fg} (kJ/kg)	Heat addition to steam, [5]q_1 (kJ/kg)	Heat retained in hot water in vessel, (%)[6]	Heat addition to steam, (%)[7]	Overall thermal efficiency, (%)[8]
Comilla												
15. M/S Bhai Bhai Rice Mill-2 Comilla	539	7546	4052	50	209	545	561	2164	2407	16.34	17.40	33.74
16. M/S Fuad Rice Mill, Pulhat	783	10962	2095	51.1	214	1233	467	2226	2368	1.99	26.64	28.62
17. M/S Fyzur Rahman Rice Mill, Pulhat	650	9100	1816	40	167	939	467	2226	2414	2.89	24.91	27.80
18. M/S Ahmed and Son's Industries, Pulhat	557	7798	1557	28.7	120	563	467	2226	2462	4.42	17.76	22.18
19. M/S Jamal Industries, Pulhat	572	8008	1604	28.4	119	630	467	2226	2463	4.23	19.37	23.60
20. M/S Kauser Industries Limited, Pulhat	682	9548	2633	30.2	126	1130	467	2226	2455	5.36	29.05	34.42
21. M/S Abul Hossain Husking Mill, Pulhat	550	7700	1636	75	314	1060	467	2226	2268	1.15	31.20	32.35
22. M/S Shah Newaz Husking Mill, Pulhat	528	7392	2390	30.4	127	944	467	2226	2454	6.65	31.33	37.98
23. M/S Hossain Rice Mill, Pulhat	710	9940	2517	30.4	127	1098	467	2226	2454	4.85	27.10	31.96
24. M/S Sobhanallah Husking Mill, Pulhat	458	6412	1937	29.6	124	914	467	2226	2458	5.47	35.05	40.52
25. M/S Momana Husking Mill, Pulhat	906	12684	2208	29	121	951	467	2226	2460	3.42	18.45	21.88
26. M/S Tanvir Husking Mill, Pulhat	720	10080	1742	28.7	120	833	467	2226	2462	3.13	20.34	23.47
27. M/S Hushmi Rice Mill, Pulhat	730	10220	2354	28.7	120	1030	467	2226	2462	4.49	24.80	29.29
28. M/S Satter Rice Mill, Bogra	1250	17500	2214	30	126	1676	467	2226	2456	1.05	23.52	24.57
29. M/S Aktaruzzaman Rice Mill, Jessore	1050	14701	2755	29	121	942	467	2226	2460	4.26	15.77	20.03
30. M/S Alamgir Rice Mill, Jessore	970	13582	2213	29	121	920	467	2226	2460	3.29	16.67	19.96
31. M/S M/s Amin Ahmed Rice Mill, Jessore	787	11021	1413	32	134	766	467	2226	2448	1.95	17.02	18.97
32. M/S M/s Bhai Bhai Rice Mill, Jadobpur, Jessore	478	6695	1954	32	134	502	467	2226	2448	7.22	18.36	25.58
33. M/S Moniruzzaman Rice	865	12116	2373	33	138	952	467	2226	2444	3.86	19.20	23.06

Annex 6. Contd..

Name of Rice Mill	Husk consumed, W_{fuel} (kg)	Total energy supplied, [4]E_{in} (MJ)	Weight of feed water, W_f (kg)	Initial Temp. °C	Sensible heat in feed water, h_{feed} (kJ/kg)	Steam produced, W_s (kg)	Sensible heat in hot water, h_f (kJ/kg)	Latent heat of steam, h_{fg} (kJ/kg)	Heat addition to steam, [5]q_1 (kJ/kg)	Heat retained in hot water in vessel, (%)[6]	Heat addition to steam, (%)[7]	Overall thermal efficiency, (%)[8]
Mill, Jessore												
34. M/S Bhai Bhai Rice Mill, PdmaVila, Jessore	455	6374	1207	31	130	494	467	2226	2452	3.77	19.02	22.79
35. M/S Jaman Rice Mill, Jessore	659	9232	1391	36	151	768	467	2226	2431	2.13	20.22	22.36
36. M/S Fajila Rice Mill; Khulna	879	12315	3102	45	188	1137	467	2226	2393	4.45	22.09	26.54
37. M/S Islamia Rice Mill, Khulna	986	13815	3212	37	155	1255	467	2226	2427	4.42	22.04	26.46
38. M/S Arpi Rice Mill, madaripur	595	8337	1683	33	138	623	467	2226	2444	4.18	18.27	22.45
39. M/S Baba Rice Mill, Kaliakoir	968.4	13558	1895	58	243	740	467	2226	2339	1.91	12.77	14.68
40. M/S Mohanagar Rice Mill, Kaliakoir	835.1	11691	1460	40	167	488	467	2226	2414	2.49	10.08	12.57
41. M/S Mitali Auto Rice Mill, Mawna	1586.3	22208	2382	35.1	147	1864	467	2226	2435	0.75	20.43	21.18
42. M/S Nisha Rice Mill, Kahalu	600	8400	945	29	121	661	467	2226	2460	1.17	19.36	20.53
43. M/S Karnofuli Rice Mill, Kustia	406	5685	879	30	126	461	467	2226	2456	2.51	19.92	22.43
44. M/S Hasina Rice Mill, Jessore	930	13025	1309	34	142	1036	467	2226	2439	0.68	19.41	20.09
45. M/S Ashrafi Rice Mill, Bormi	763.5	10689	3163	75.8	317	1073	561	2164	2299	4.76	23.08	27.85
46. M/S Rubel and Brothers Boiler Rice Mill, Comilla	1240	17360	3570	50	209	2168	683	2077	2447	3.82	30.56	34.39
47. M/S Amanat Rice Mill, Pulhat	438	6132	2396	28.6	120	982	640	2749	3132	0.00	50.16	50.16
48. M/S Rafiq Rice Mill, Habiganj	946.4	13250	1523	30	126	1398	561	2164	2491	0.00	26.28	26.28
49. M/S Intaz Rice Mill, Habiganj	1430	20020	1971	32	134	1825	561	2164	2483	0.00	22.64	22.64
50. M/S Sheik Rice Mill, Habiganj	1593	22302	2185	30	126	2159	640	2749	3126	0.00	30.26	30.26