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Thermodynamic evaluation of a rice husk fired integrated steam and hot air generation unit for rice parboiling

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A B S T R A C T

This paper presents a simplified energy improvement system using agricultural waste for local rice processing. An integrated steam and hot air production unit using rice husk energy was evaluated thermodynamically. Besides characteristics of steam and hot air, temperature effectiveness of the fluid streams, energy and exergy flow within system components were also studied. Effect of input operating parameters on steam production and drying air temperature together with their correlation have been shown. Overall system energy and exergy efficiencies were found to be 47.81% and 10.93%, respectively. Although, the combustor showed the highest temperature, energy and exergy efficiencies, it was the main source of exergy destruction contributing more than 60%.

1. Introduction

Rice parboiling is a pre-milling hydrothermal process employed in the gelatinization of starch to enhance the physic-chemical and nutritional properties [1–3]. It takes place in a three-stage process known as soaking, steaming and drying of paddy (rough rice). The process as practiced in rural rice processing is laborious and energy intensive requiring about 1659–2758 MJ/tonne of paddy processed [4]. Soaking is most time consuming process lasting 12–48 h [5]. Traditional soaking occurs in vessels or concrete masonry tank with either cold water or hot water. Steaming, though takes place in a short time is energy intensive since it requires the production of steam. Traditional steaming is done in sub Saharan African by pouring paddy rice into a pot containing water and precooking for 20–30 min on an inefficient (13%) three stone fire stove [6]. This process, besides rendering some paddy fully cooked and others uncooked, resulting in poor rice quality also requires long hours of travelling and wood collection. Recently, Zossou, Van Mele [7] reported an improved steaming process in Benin, West African under a collaboration between the National Agricultural Institute of Benin Republic, AfricaRice Center and local artisans. This improved process prevents the direct contact of paddy with water by placing a perforated steel container with soaked paddy rice over boiling water. The steam generated is use for the starch gelatinization. Although this process avoids a direct contact of paddy with water, it is both operationally and energy inefficient. This is attributed to the following reasons: (1) it requires addition of water after each batch (2) as the water boils to steam there is no way to replenish it which can lead to system damage when water is used up (3) the system uses fuel wood and still requires the long hours of wood collection (4) it still uses the inefficient three stone fire stove.

For every steam production system, such as the one describe above, it is important to maximize the heat transfer process and minimize the heat losses. To improve the performance, it is imperative to locate and quantify the losses. Unfortunately, the first law of thermodynamics, which is conventionally used to evaluate energy systems provides information only on energy consumption and losses without any information on the internal inefficiency of the system. Thus, the quality aspect of the energy is not accounted for. Exergy (2nd law) analysis overcomes this shortfall and provides information on how much is the usable work potential is supplied and consumed.

Besides, the inefficiencies with energy use, local rice processing also suffers poor quality output as a result of drying. Steam paddy usually has moisture content of more than 40% [8] and requires drying to a lower moisture content for storage which is usually achieved by sun drying. In this process, paddy is spread on a flat surface usually on the flour or on a tarpaulins and solar energy is absorbed to dry the grain. This process reduces the quality of rice due to the introduction of foreign material such as stones and dirt.

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It is also dependent on the weather condition, applicable only during the day and also requires large drying space.

This study is an attempt to improve energy use and rice quality through the development of an integrated system. The system replaces wood use with rice husk energy and employs a heat exchanger system for enhance energy efficiency. It also uses the waste heat from the flue gas to heat up air for drying in a simplified LSU recirculating dryer. The objectives of this paper are to evaluate the performances of steam and hot air generators thermodynamically and examine the sensitivity of the operating conditions and their influence on efficiency.

2. Materials and methods

2.1. System description

The integrated steam and hot air generator consist of a continuous rice husk combustor, double-fire tube heat exchangers, a 50 cm high conical chimney and a drying unit. The system components are described in detailed in this section. Steaming and drying as practice in local rice processing is shown in Fig. 1 along the proposed improved system.

2.1.1. Combustor unit

The combustor consists of a firebox (80 × 75 × 55 cm) made from 3/16-inch steel plate with a firebrick (23 × 11.4 × 6.4 cm) lining purchased from Materiaux Refractaires Direct – St-Leonard, QC Canada. The feed material is introduced into the combustor through a triangularly shaped 4.5 kg capacity feed hopper made with a gage 24 steel sheet at rear end. Combustion occurs on a 20 × 20 cm^2 perforated gage 16 steel plate inclined at 45° (angle of repose experimentally found to be 40) and the ash generated is removed from side of the combustor through a 60 cm long, 7.6 pitch, and 7.6 diameter auger. The front section of the combustor has a removable metal sheet that provides secondary air for rice husk combustion and serve as an opening for feeding with other feed material such as wood and briquette. A 25 W fan placed at the lower end of the feed hopper provides primary air. The air enters the combustor through a spout that also serve as the port for starting the fire. The upper part of the combustor is a 50 cm circular opening at the top where the heat exchanger fits.

2.1.2. Heat exchanger (HE) unit

The double decker heat exchanger unit produces steam for paddy gelatinization and hot air for drying. The lower steam heat exchanger consists of a 13 standard 1½ inch nominal tubes arranged to achieve a triangular pitch of length 9.5 cm fitted into a 45 cm diameter shell made of gauge 16 metal sheet. The heat exchangers were designed to achieve an average logarithmic mean temperature difference (LMTD) of 330.9 and 131.3 °C for the steam and hot air generator respectively. This is based on the assumption that the overall heat transfer coefficient remains constant over the heat exchangers flow length. The chosen design parameters ensure the steam generator delivers steam at 0.0045 kg/s to parboil 50 kg of paddy rice. The heat duty for the hot air generation was based on energy required dry 250 kg of paddy in a recirculating dryer, which was estimated to be 2.48 kJ/s. The two heat exchangers are removable which allows for easy cleaning and maintenance.

2.1.3. Drying unit

The drying unit was made of a wooden drying chamber with 21 V shaped channels. The channels were arranged alternately to deliver inlet air at one level and outlet air in the next. Heated drying air from the hot air generator flows into a plenum with aspect ratio

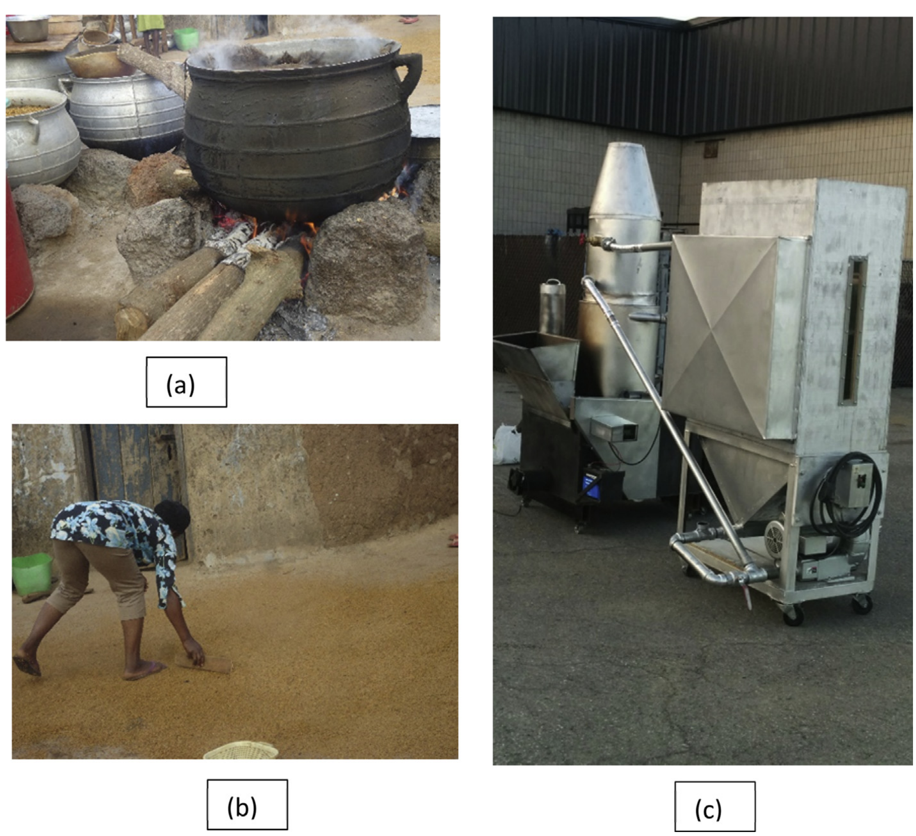

Fig. 1. Current and proposed paddy steaming and drying systems.