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Energy consumption and rice milling quality upon drying paddy with a newly-designed horizontal rotary dryer

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ABSTRACT

Paddy drying is an energy-intensive process which affects final product quality. Energy consumption and rice milling quality upon drying paddy with an industrial horizontal rotary dryer (IHRD) developed in northern Iran were investigated and compared with those of the conventional industrial batch-type bed dryer (IBBD) at five paddy final moisture levels (8.0, 9.0, 10.0, 11.0, and 12.0%, w.b.). The results indicated that the IHRD consumed specific electrical energy between 5.5 and 17.41 MJ kg^{-1} water evaporated compared to 2.64–7.48 MJ kg^{-1} water evaporated in IBBD and specific thermal energy between 11.5 and 36.44 MJ kg^{-1} water evaporated in IHRD compared to 7.78–22.09 MJ kg^{-1} water evaporated in IBBD with a decrease in paddy final moisture content in the range of 12.0%–8.0% (w.b.). Thermal energy use efficiency was estimated to be as 38.8% and 26.3% for IBBD and IHRD, respectively, at moisture drop range of 14.5%–12%, w. b. Major milling quality attributes of the final product of paddy dried with IHRD were significantly superior to those of IBBD. It was concluded that the drying time of IHRD can be cut down about 26% without any significant changes in final milled rice quality; resulting to reduce the IBBD's total specific energy use around 10.43 MJ kg^{-1} water evaporated. Completely discharging the drying air and kick turning the drying drum of IHRD with a suitable time interval were proposed as a subject of investigation to improve the energy efficiency of the tested dryer.

1. Introduction

Paddy drying is a major concern in all rice-producing countries [1]. It is an energy-intensive process which significantly affects the quality of milled rice particularly in terms of head rice yield [2,3]. Paddy drying process requires the most energy, accounting for 55% of the whole energy needed to produce milled rice [4]. The energy required to dry food materials mainly involves the thermal energy of fuel used to remove undesirable moisture from the foodstuffs [5]. The amount of fuel consumed to dry grain will vary widely with the type of method used [6]. There are various methods to dry paddy rice. They involve different drying technologies of different scale and complexity. There is no ideal dryer for drying paddy since each drying technique has its own inherent advantages and disadvantages [7].

The most common dryer for paddy drying in Asia is the batch-type bed dryer that includes rectangular and circular bin dryers [8]. In Iran, more than of 90% of paddy is dried by the rectangular batch-type bed dryer. Due to the high thickness of paddy grain placed in the drying box of batch-type dryers, the bottom layers are dried more compared to the top layers, which leads to excessive milled-rice breakage. Furthermore, to achieve the favorable moisture level for paddy in top layers, a high amount of energy is consumed for paddy drying in industrial batch-type bed dryer (IBBD). Extensive labor requirement is another problem in the use of IBBDs [7].

Review of reports showed that some efforts were made to find energy-efficient drying techniques for improving the milling quality of rice [1,2,9]. The aims of the majority of the studies were to develop and check the performances of the newly-designed dryers and methods for drying the freshly harvested paddy in tropical countries [10]. Most of them were based on laboratory scale experiments and results on industrial scale are seldom reported in scientific publications [11]. Along with these attempts, some new

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designs of paddy dryers were presented to resolve the shortcomings of IBBD in northern Iran. Industrial rotary horizontal dryer is a recently developed paddy dryer which attracted the attention of many researchers and mill owners in northern Iran (Fig. 1). It is a recirculating batch type grain dryer where the grain is loaded as a batch and is constantly mixed during the drying process. Agitation of the paddy bulk during drying operation resulting in higher moisture uniformity of paddy grains, as well as the mechanized unloading of the dryer are the noteworthy benefits of industrial horizontal batch-type bed dryer (IHRD). However, energy consumption and milling quality of the final product of any industrial paddy dryer must be checked to verify its present status and to suggest for further efficient operation [1]. To compare the energy consumption among industrial drying options, the data of drying paddy with the industrial scale dryers must be obtained [12].

All proceedings to minimize the milled rice breakage in paddy drying process may be a solution to mitigate the fuel cost for thermal energy supplied to the paddy dryers [13]. It seems that agitating paddy in drying with newly developed paddy dryer IHRD results in more uniformity in moisture content of individual paddy grains and then minimizing the milled rice breakage compared to that of the traditional IBBD [7]. Moreover, due to recycling a part of the exhaust moist drying air in IHRD, paddy drying process in this dryer is expected to be gentler than that of traditional IBBD; leading to further decrease in milled rice breakage; but the key questions are: How much improvement happens in milling quality of paddy dried by using this dryer? How much is the energy use of drying process with IHRD compared to that of traditional IBBD? Therefore, in this study, the technical specifications of the new dryer IHRD are described in brief at first and then, the key parameters of its drying performance including drying residence time, energy consumption, and milling quality of the final product will be checked and discussed compared to the traditional IBBD.

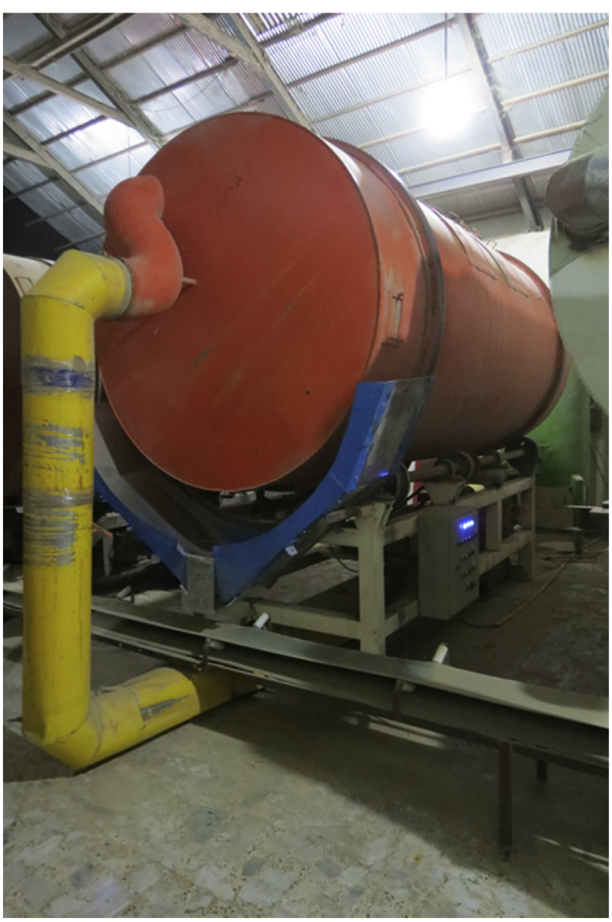

Fig. 1. Industrial horizontal rotary paddy dryer (IHRD).

2. Materials and methods

Rice is the second most important food crop after wheat in Iran. In 2013, approximately 564,000 ha were under rice production in this country, around 273,000 ha of which are located in Guilan Province, making it the second most important rice-producing region in Iran, in terms of cultivated area while, the first in terms of total production [14,15]. This research was conducted in a paddy mill in Sangar district of Rasht, center of Guilan Province, northern Iran. Long grain paddy variety of Hashemi, the most frequently cultivated paddy variety in the Guilan Province, was considered as the test material. To keep the uniformity of paddy mass used for the experiments, the experimental paddy was prepared from a unit farm with the same agronomic practices. Because of semi-mechanized and manual harvesting of paddy in northern Iran, and due to the relative stability of climatic conditions at harvest time, the initial paddy moisture content is around 14–15% w. b.; hence, most of the studies on paddy drying in Iran are based on 14–15% w. b. initial moisture level.

The experiment was conducted as a completely randomized design in a factorial arrangement with four replicates. Factors were the type of dryer at two levels (IBBD and IHRD), and paddy final moisture content at five levels (8.0%, 9.0%, 10.0%, 11.0%, and 12.0%, w. b.). Different levels of paddy final moisture contents were chosen in order to study the behavior of the tested dryers in terms of energy consumption and milling quality of the final product at various final moisture levels.

The experiment location consisted of two tested industrial dryers of 3 tons loading capacity (Table 1). According to Fig. 2, in the industrial batch-type dryer (IBBD), paddy is placed in a rectangular container with a floor fabricated from a perforated screen. Drying air heated by a natural gas burner using a fan powered by an electrical motor is passed through the paddy mass in the drying box. Paddy loading and unlading are performed manually. During the unloading of the drying box, the pressure of labors' feet easily breaks some paddy grains which leads to a decrease in head rice yield. Non-uniform drying of different layers of paddy mass and high energy demand for the process are the main problems in the use of batch-type dryers.

Fig. 3 also shows various elements of IHRD. The inlet air is heated by the natural gas burner (No. 7) and is transferred from the warming box by the vacuum generated by a strong fan (No. 10) powered by a 7.5 hp electrical motor and is then pushed into the drying drum. The heated air is passed through the inlet, which is the perforated curved screen of the drying drum, into the grain mass. The discharged air exits towards the duster cylinder through the curved perforated screen of the outlet; about 50% of the filtered humid discharging air is mixed with some fresh air vacuumed at the warming box and are fed into the burner inlet and re-circulates in the next drying cycle. This action softens the moisture removal of the paddy grains in the drying drum and prevents excessive internal stress in the paddy kernels; which is expected to lessen the broken milled rice. However, due to the increasing the relative humidity of the drying air, the paddy drying rate is expected to be reduced or the paddy residence time in the dryer is expected to be increased. A gear and chain mechanism drives the drying drum at a speed of 0.25 rpm (4 rotations per minute); therefore, paddy is moved and agitated by the inner helix. Agitation of paddy during the drying process, de-awning of paddy grains by small holes of

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