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Energy and exergy analysis of industrial fluidized bed drying of paddy

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A B S T R A C T

This paper presents energy and exergy analysis of industrial fluidized bed paddy drying. The maximum design capacity of the dryer was 22 t/h. Existing energy and exergy models developed applying the First and Second law of Thermodynamics are employed to estimate the amounts of energy used, the ratios of energy utilization, magnitude of exergy losses and exergy efficiencies during the drying process. The analysis shows that energy usage and (EUR) energy utilization ratios vary between 38.91 kJ/s to 132.00 kJ/s and 5.24–13.92 %, respectively while exergy efficiency vary from 46.99 to 58.14%. A simple exergy balance reveals that only 31.18–37.01 % exergy are utilized for drying of paddy and the remaining large amount of exergy are wasted. Exergy can be increased through providing sufficient insulation on dryer body and recycling the exhaust air which need to be studied further for investigating the economic feasibility.

1. Introduction

Drying is high energy intensive operation. Overall efficiency of industrial rice dryers is relatively low. Industrial dryers consume on average about 12% of the total energy used in manufacturing processes where the cost of drying can approach to 60–70% of the total cost [1]. Energy is an essential factor in overall efforts to achieve sustainable development [2]. Therefore, it is very important for the drying industry to maximize overall energy efficiency as it indicates how efficiently energy is being used by the dryer. Likewise, exergy (also called availability or work potential) refers to the most work that we can get out of a system and exergy analysis has begun to be used for system optimization within the last several decades. Through analyzing the exergy destroyed by each component in a process, we can see where we should be focusing our efforts to improve system efficiency. It can also be used to compare components or systems to help make informed design decisions. Exergy is defined as the maximum amount of work that can be produced by a system or a flow of matter or energy as it comes to equilibrium with a reference environment [3,4].

In fluidized bed drying, the process is carried out in a bed fluidized by the drying medium. Fluidized drying may be carried out as a batch or continuous process. In batch drying the dryer is charged with wet material, the flow of the drying medium is started, and when the material is sufficiently dry it is removed from the equipment. In continuous drying the wet material enters the dryer as a continuous stream, and the dry material is also removed continuously. In order to find out the energy interactions and thermodynamic behavior of drying air throughout a drying chamber, the energy and exergy analyses of the drying process should be performed [5]. Exergy analyses can reveal where and by how much it is possible to design more efficient thermal systems by reducing the sources of existing inefficiencies. Increased efficiency can often contribute in an environmentally acceptable way to the direct reduction of irreversibilities (where exergy is destroyed) that might otherwise have occurred. This makes the concept of exergy as one of the most powerful tools to provide optimum drying conditions. An investigation on exergy and environmental impact revealed that lower exergy efficiency leads to higher environmental impact [6]. Considering the importance of the cost of energy, the availability of fuel and their impact on the environment, the exergy efficiency model in the drying process becomes a very useful tool of analysis.

Energy conservation schemes are of interest nationwide. Adoption of new policy is necessary to achieve energy supply

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Nomenclature

A	area, m^2
C_p	specific heat, kJ/kg
E	energy/Exergy, kJ
E_x	Exergy, kJ/kg
EU	energy utilization, kJ/s
EUR	energy utilization rate, kJ/s
FBD	Fluidized bed dryer
MR	Malaysian rice
Q	Amount of heat, kJ
$\dot{Q}$	heat flow rate, kJ/s
T	Temperature, °C
U	Overall heat transfer coefficient, W/m^2 °C
W	Rate of work, kj/s
h	Hour or specific enthalpy, kJ/kg
h_{fg}	latent heat of water, kj/kg
m	moisture content or mass flow, kg/s
$\dot{m}$	mass flow rate, kg/s
t	Capacity, ton
w	specific humidity, kg/kg
%	percentage

Subscripts

a	air
ai	inlet air
am	ambient
d	dryer
da	drying air
dc	drying chamber
dci	drying chamber inlet
dco	drying chamber outlet
eva	evaporation
i	dryer inlet
P	Paddy
s	Boundary temperature
sat	saturated
x_y	exergy
m	paddy moisture/mass flow of air
w	water/vapour
wb	wet basis
1	dyer inlet point
2	dryer outlet point
∞	Surface/surroundings

security [7]. With respect to drying, the overall energy efficiency is of interest to dryer manufacturers, as it is a key dryer index of market value. Definitely, low energy efficiency is critical for dryer users who deal with commodity materials and inexpensive products as it affects running costs. Jittanit et al. [8] mentioned that it is important for the rice milling plants to achieve acceptable energy efficiency of their drying processes compared with other similar plants in order to improve their drying operations and to assure their competitiveness.

Energetic and exergetic performance of microwave-assisted fluidized bed drying of soybeans has been studied and found that the application of higher levels of drying air temperature led in higher exergy efficiencies [9]. Although heat and mass transfer in batch fluidized-bed drying of porous particles has been reported [10] and thermal analysis of a fluidized bed drying process for crops was studied [11], very few works [12–14] have appeared on energy and exergy model of grain drying using fluidized bed dryer. Furthermore, energy and exergy efficiencies of industrial dryer like fluidized bed paddy dryer is still not appeared in the literature. Therefore, this study was carried out on energy and exergy analysis of paddy drying with industrial fluidized bed dryer in which the existing energy and exergy analysis approach available in the literature was employed. In addition, the effect of drying air temperature and initial moisture content of paddy on energy and exergy efficiencies were also be evaluated so as to aid in identifying the scope of improvements of energy usage in rice processing industry.

2. Materials and methods

2.1. Materials

The freshly harvested paddy of MR219 variety was dried in fluidized bed dryer available in paddy drying complex of BERNAS at Bukit Besar, Alor Star, Kedah, Malaysia.

2.2. Dryer operating period

Based on two different drying air temperatures and paddy initial moisture contents and the availability of opportunities at the paddy processing site, the industrial fluidized bed dryer was operated on February, 2013 (First operating time) and on October, 2013 (second operating time).

2.3. Description of dryer used for the present study

The fluidized bed dryer (4.85 × 0.97 m^2 bed area) with maximum design capacity of 22 t/h as depicted in Fig. 1 was used. Three backward-curved blade centrifugal injection fans with one starter in sequence start-up of three motors of 15 kW capacity each were used to generate the required airflow, and a rice-husk furnace was used to heat the air to the specified temperature in the dryer.

2.4. Operating the dryer and recording the data

The blower fans of FBD and the cyclonic furnace were run at least 15 min before starting the paddy inflow for drying so that drying air temperature could be raised to desired point. Weir height (bed thickness) was fixed at 10 cm and average air flow of 10.82 m^3/s was used for the present analysis even though it varied slightly depending on paddy loading. Then paddy was passed through FBD to be dried. It is noted that freshly harvested paddy was cleaned first with pre-cleaner then passed through the bed of fluidized bed dryer. The drying air temperature, paddy temperature before and after drying, exhaust air temperature, air flow, temperature and relative humidity of ambient air were recorded when steady state condition of the dryer operation was existed. Average feed rate was calculated as total paddy dried divided by total time elapsed on the day of operation [15]. The moisture content of the paddy was measured by the single kernel moisture meter and Satake digital grain moisture tester. The moisture meter was previously calibrated with standard oven method (temperature 103 °C for 24 h) through determining paddy moisture content in the laboratory. Meanwhile, drying air temperature was measured by K-type thermocouple connected with digital data logger. The Thermocouple was also tested to check their accuracy with another thermometer in the laboratory before using for data recording in this study. The air velocities at the inlets of the dryer were measured by high temperature Anemometer. It is noted that the cross-section area at the point of velocity measurement for each dryer inlet side was