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Energy Requisite and Drying Capacity of a Superheated Steam Dryer

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Energy Requisite and Drying Capacity of a Superheated Steam Dryer.

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Abstract

This research was carried out to determine the energy requisite in terms of the specific thermal energy consumption, the specific electrical energy consumption and the drying capacity of a superheated steam dryer. The superheated stream dryer consists of a boiler housing, steam transfer pipes made of galvanized steel, super-heater made up of two (2) heater bands of 4000W (used to convert saturated steam to superheated steam), superheated chamber made of galvanized steel, the drying chamber made using stainless steel, a PID temperature controller (for regulating the temperature of superheated steam) as well as a water heater of 1500W to raise the temperature of water to saturation temperature. The result observed revealed that, drying capacity ranged from 0.1 to 0.36 kg/h, specific thermal energy consumption ranged from 9.22 to 19.99 kJ/kg and specific electrical energy consumption ranged from 15.41 to 57.17kWh/kg as influenced by temperatures of 160-180 ^{0}C, bed depths of 1 to 5 cm and tempering time of 20 and 40 minutes. Results obtained proves that drying paddy rice in a superheated steam dryer in comparison with hot air dryer has lesser energy consumption and saves operational cost.

Key words: Energy requisite, Drying capacity, Superheated steam, Energy consumption

1. Introduction

The drying cycle is one of the most energy-intensive process that uses thermal energy to evaporate water from wet material. It is not uncommon for a drying system to consume more than 10 percent of its total production energy [1]. According to Jittanit *et al.,* [2] drying of paddy rice is a very energy-intensive method and is very sensitive to the quality of paddy rice. Dryers are one of the most essential food processing-industrial equipment. Most dryers used in the drying of agricultural products have been developed and used to improve their handling, transport and storage conditions [3]. In most developed countries, there has been a growing understanding of the need to conserve energy in all industries, and both voluntary and regulatory initiatives have contributed to a reduction in energy prices and the conservation of finite energy resources [4]. When drying items with a high moisture content in a high humidity setting (moist tropical zone), the question of energy consumption becomes more complicated during drying. Therefore, the choice of a proper drying technique for agro-products is essential [5]. A hot air dryer is traditionally composed of five essential elements: air heaters, air movers, air conduit systems, chimneys, and a product cabinet. Nwakuba [6] noted that the energy consumption of dryers used in drying agricultural products depends primarily on the drying capacity and kind of the air-heating and air-moving equipment (as long as there's no heat loss to the wall and consequently low efficiency), apart from drying air properties and crop variables. Choice of an efficient drying system is essential to necessitate a

reduction in the energy consumption of crop dryers and minimize a reduction in the quality of dried products during dehydration process [7].
The use of superheated steam as a means of drying agricultural products is an emerging technology that is gradually gaining attention and popularity. The hot air is used as a drying medium for most conventional dryers, which thus has adverse impacts on food physical chemical properties and often results in an unacceptably long drying time and low energy efficiency qualities (nutrient degrade, harder texture, discoloration and non-uniform product consistencies). [8]. Superheated steam drying has been proven to have high potential benefits when compared to hot-air drying, these benefits amongst others are energy savings that arise as a result of the provision to reuse latent heat of evaporation [9]. Superheated steam is known to have key benefits in terms of energy use and effect on the climate. As for the energy source, Superheated Steam (SHS) drying allows the latent heat for evaporation to be recuperated with exhaust condensation because latent heat is usually difficult and costly to recover from the release of hot air. [10]. Pilot SHS drying studies have shown that around 85 per cent of the total energy input can be saved [11]. Superheated steam dryer has been recorded in literature to be more energy efficient and environmentally friendly than hot air dryers as it prevents gas emission into the atmosphere. However, documentations on the use of superheated steam dryer for processing paddy rice has been very scanty and an actual study on the specific electrical and thermal energy consumption of a superheated steam dryer has not been carried out as observed from literature.

This study was therefore carried out to assess the drying capacity and overall energy requirements to determine the efficiency of the superheated steam dryer in drying paddy rice.

2. Materials and Methods

2.1 Description of machine and principle of operation

The superheated steam dryer as shown in figure 1 consists of a boiler, a super-heater and a drying compartment. The boiler has a water heater capacity of 1500W powered by electricity while the super-heater was made up of a heater band of 4000W and the drying chamber was made with stainless steel, the thermocouple was used to ascertain the temperature of SHS entering the drying chamber and the PID (proportional integral derivative) temperature sensor was used to control the temperature of SHS entering the drying chamber. Every component of the superheated steam dryer was designed to certify safety and ease of operation. The machine was totally powered by electricity; the boiler is filled with water to three quarter of its length. An electric heater is used to raise the temp of water to produce steam which is transferred to the super-heater through the steam transfer pipe and reheated to produce superheated steam at the required temperature after which it is transferred to the drying chamber. The PID temperature controller regulates and maintains the temperature of SHS going into the drying chamber.

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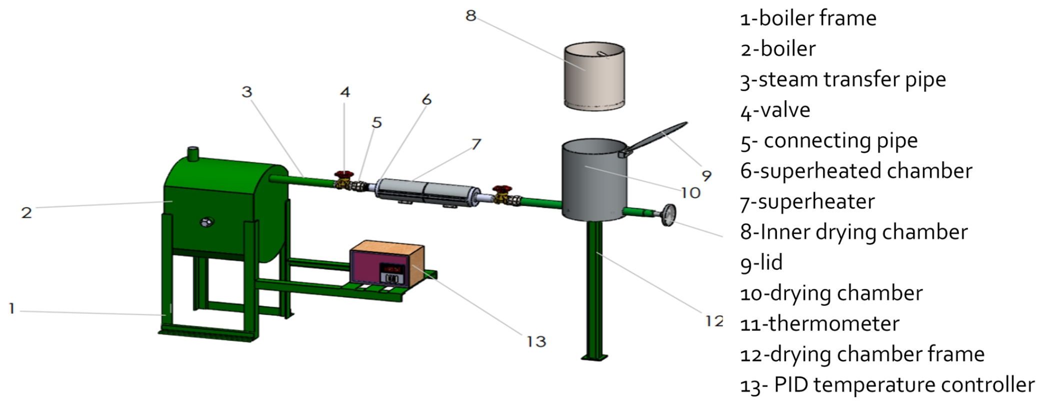

Figure 1: Exploded Diagram of the Superheated Steam Dryer

2.2 Parboiling Conditions

The procedure by Taechapairoj *et al.,* [12] was employed for this study with certain modifications. Different combinations of drying temperatures (160, 170 and 180 ^{o}C, bed depths (1, 3 and 5cm) and tempering time (20 and 40 minutes) in between drying were selected to carry out this experiment and initial moisture content of 26-43% dry basis (d.b.) was used;

2.3 Analysis of Overall Energy Requirements

This is the total energy required for the processing of kilogram (kg) of paddy rice and is very essential in the rice processing industry. Hence, the specific electrical energy consumption was determine in kWh/kg and the specific thermal energy consumption in kJ/kg.

2.3.1 Specific electrical energy consumption (SEEC)

It was determined using the formular as stated by Ibrahim *et al.,* [13];

$$SEEC\ (KWH/Kg) = \frac{E_t}{W_p} \quad 1$$

E_t (total electrical energy in kWh) = $P_h \times t$ and $W_p =$ weight of paddy to be dried (kg) in a batch, P_h = Heaters graded power (KW) and t = overall operating time in hr.

2.3.2 Specific thermal energy consumption (STEC)

It was calculated according to Ibrahim *et al*., [13] as the ratio between the overall thermal energy and the weight of the drying paddy (kg) in a batch;

$$STEC\ (KJ/Kg) = \frac{E_{th}}{W_p} \quad 2$$

$$Where;\ E_{th} = MsCs\Delta T \quad 3$$

Ms = mass of steam (kg), Cs = specific heat capacity of steam (KJ/kg ^{o}C) and ΔT = change in temperature (^{o}C)

2.4 Dryer Capacity

It is an essential factor used in optimizing the rice drying process in the milling industry, according to Islam *et al* [14] an enhancement in the drying capacity of a dryer will lead to improved proceeds for the rice processing industry. The dryer capacity was determined using the equation as stated by Ghiasi *et al.,* [15];

$$Dryer\ capacity\ (kg/m2/h) = \frac{Weight\ of\ wet\ grain\ per\ unit\ area\ (\frac{Kg}{m^2})}{Total\ drying\ time\ (h)} \qquad 4$$

3. RESULTS AND DISCUSSION

3.1 Specific Electrical Energy Consumption

The total specific electrical energy requirement calculated is shown in Figure 1. The results revealed that the electrical energy requirement of the dryer ranged from 15.41 to 57.14 KWh/kg at the various drying conditions. Figure 1 illustrates that the lower the temperature the shorter the drying time and the lower the electrical energy required and vice versa, also a rise in bed depth led to an increase in the electrical energy consumption of the dryer, likewise an increase in tempering time reduced the consumption of electrical energy. According to Ghasi *et al.,* [15] a reduction in the dryer's electrical energy consumption will lead to huge cost savings. When compared to the result obtained by Ghasi *et al.,* [15] who compared the energy utilization of flat bed and inclined bed dryers, the energy consumption of superheated steam dryer seems to be lower than that of the inclined bed dryer (77.81 to 91.27KWh/ton at 38 – 43 ^{o} C) and deep bed dryer (above 200KWh/ton at 38 – 43 ^{o}C). Energy consumption was also lesser than that recorded by Jittanit *et al.,* [2] with energy consumption of 3.874 – 4.421MJ/kg. This results proves that using superheated steam to dry paddy in comparison with hot air had lesser energy consumption and saves operational cost.

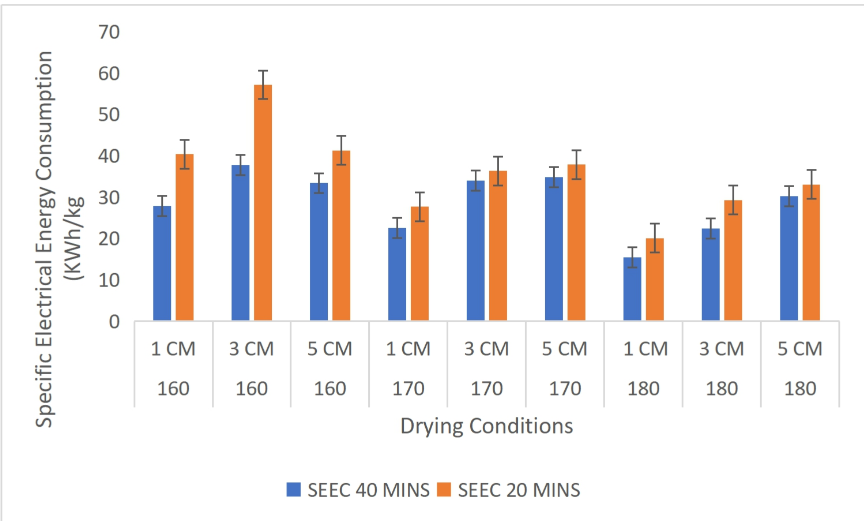

Figure 2: Specific electrical Energy Consumption (SEEC)

3.2 Specific Thermal Energy Consumption

The result obtained showed that the specific thermal energy consumption of the dryer ranged from 9.22 to 19.99 KJ/ kg. Figure 2 illustrates that tempering time had no effect on STEC, but temperature and bed depth had significant effects on it, STEC was higher at temperature increased and reduced as bed depth increased. This was contrary to what was obtained by Ibrahim *et al*., [13] who stated that the higher the temperature the lower the STEC but was in agreement with what some other researchers Zare *et al.,* [16] and Sarker *et al.,* [17] discovered, which was that STEC is higher when using higher temperatures and higher air flow. The differences in the results obtained could be due to differences in the drying conditions employed and also a difference in the initial moisture content as it was noticed during this research that initial moisture content had an effect on STEC. The STEC values are lower than the values of 64 MJ kg-1 for hot air drying at 70 ° C as determined by Jindarat *et al*., [18] and also that found in Sharma and Prasad (2006) between 140 and 215 MJ kg-1 [7].

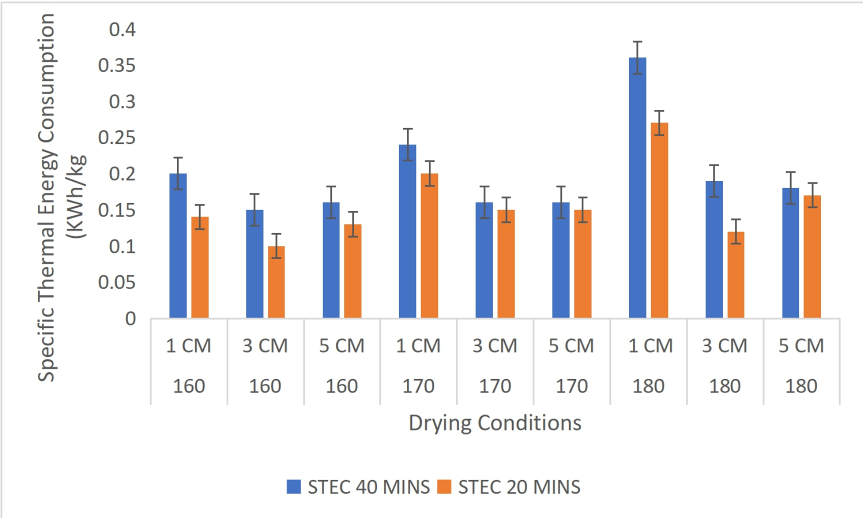

Figure 3: Specific Thermal Energy Consumption

3.3 Drying Capacity

Figure 3 represents the drying capacity of the dryer which ranged from 0.1 to 0.3 kg/h. it was noted that an increase in temperature led to an increase in the drying capacity, this agrees with the result obtained from Ghiasi *et al.,* [15] who stated that a decrease in drying time resulted in an improvement in the drying capacity of the dryer. The results also agreed with Sarker *et al.,* [19] who stated that higher drying temperature resulted in higher dying capacity. It was also noted that bed depth and tempering time had an effect on the drying capacity; an increase in bed depth led to a decrease in drying capacity and an increase in tempering led to an increase in the drying capacity. From literature it has been revealed that an improvement in drying efficiency will lead to a substantial increment in profits made by rice processing industries and would also help in minimizing post-harvest losses [13].

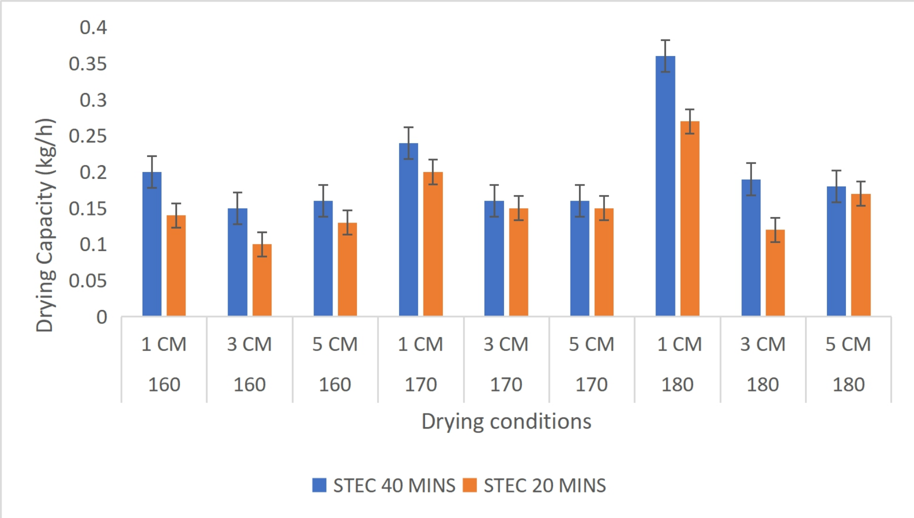

Figure 4: Drying capacity of the dryer

4. Conclusion

The effect of the drying conditions used in this research on the overall energy requirements and drying capacity of a superheated steam dryer were determined and it can be concluded that drying using a superheated steam dryer to process paddy from an initial moisture content of 43% (d.b.) to equilibrium moisture content consumed less than 58 KWh/Kg in terms of SEEC and 20KJ/Kg in respect to STEC and also the drying capacity obtained for this dryer was less than 0.4Kg/h. It was noted that the drying conditions used in this research had a significant effect on the drying capacity and SEEC but only temperature and bed depth had an effect on STEC. Also, the result obtained from this research has proven that superheated steam dryer can be used to reduce the high cost of drying operation by increasing drying capacity and also by reducing the overall energy consumption compared to other dyer types.

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