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Comparison of Drying Characteristics and Quality of Rough Rice Dried With Infrared and Heated Air

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Abstract. *The objective of this study was to study and compare the drying process characteristics and quality of rice dried with a laboratory catalytic infrared (CIR) dryer, a laboratory simulated forced air convection (FAC) column dryer, and a commercial column dryer. Medium grain rice of variety M202 was used for the study. The rice samples were dried by using both the CIR and simulated FAC dryers with single and double passes, at two different temperatures of 36°C and 45°C to remove from 1.5% and 4% moisture at each drying pass. The milling quality, including head rice yield (HRY), total rice yield (TRY) and whiteness of the dried rice were evaluated. The CIR dryer showed much*

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faster heating rate and more uniform heating to rice kernels than the simulated FAC column dryer. It took 28 and 11 minutes, respectively, to remove 2% moisture at 36°C and 45°C. On average, the head rice yields of the CIR, FAC and commercially dried rice were 62.4%, 61.1% and 58%, respectively. Corresponding total rice yields for the different drying methods were 70.2%, 69.5%, and 70%. It was found that for CIR drying, high drying temperature, 45°C, single pass with at least 3% moisture removal can be used to produce dried rice with milling quality equal to or higher than 36°C FAC drying with 1.5% moisture removal by each drying pass. The energy efficiency of CIR dryer was improved when the ratio of rice loading to emitter surface area. It is expected a large scale CIR dryer could have much higher energy efficiency than commercial column dryers.

Keywords. rough rice, infrared drying, milling quality, energy efficiency.

Introduction

Infrared drying has been gaining interest in food processing industry because of its high thermal efficiency and fast heating rate/response time. Infrared (IR) is the most efficient form of electromagnetic radiation for heat transfer and is directly absorbed by the material (Fasina, 2003). Use of infrared radiation for heating and drying agricultural products has been reported by several researchers during last five decades. Schroeder and Rosberg, (1959 and 1960) and Schroeder (1960 and 1961), reported that drying rice by using infrared radiation increased the drying rate without excessive breakage in the laboratory experiments of rice drying. According to their studies, a single layer rice drying had drying rates from 0.49 to 3.6% moisture removal per minute. It was also reported that the rice drying rate increased with the increase in radiation intensity (Abe and Bilowicka, 1960; Afzal, 1998; Abe and Afzal, 1997; Ginzburg, 1969). Dostie et al. (1989) found that intermittent infrared and continuous convection heating of thick porous material resulted in good surface quality and energy efficiency. Intermittent infrared heating reduced energy use, surface temperature rise, and improved the quality of heat sensitive products (Afsal, 2003). This technique improved the quality and reduced the energy consumption of barley drying.

Use of catalytic infrared (CIR) emitters for drying has many advantages compared to conventional electric and flame-type gas emitters. Low operational cost and medium- and far-infrared radiation make catalytic infrared emitters suitable for agricultural product drying. The CIR emitters can emit infrared radiation with peak wavelengths 3.3 - 7 μ m, depending upon the emitter operation temperatures. The wavelengths are in the range of high absorption peaks of infrared radiation by water. Therefore, CIR drying has high potential in increasing the drying rate and energy efficiency and thus reducing the drying cost. Besides the processing and energy efficiencies, the quality of dried rice is another important factor to be considered in rice drying operations. The quality of dried rice is normally evaluated with total rice yield (TRY) and head rice yield (HRY). HRY is the amount of whole kernels in the milled sample and TRY is the amount of whole and broken kernels in the milled sample expressed as percentage of the rough sample (Thompson, 1990).

The objective of this study was to study and compare the drying process characteristics and quality of rice dried with a laboratory catalytic infrared (CIR) dryer, a laboratory simulated forced air convection (FAC) column dryer, and a commercial column dryer.

Materials and Methods

Medium grain rice (variety M202) with average moisture of $21.3 \pm 0.3\%$ (w.b) was dried using a laboratory CIR dryer, a laboratory scale forced air convection (FAC) dryer, and commercial column rice dryer. A large lot of rice sample from CIR and FAC drying was drawn from 33 unloading trucks at the commercial rice drying and storage facility of the California Family Foods. (Arbuckle, CA) in September 2004. The rice moisture was lower than the 22% measured at unloading site which could be due to the moisture loss during the following sample preparation. Rice was fully mixed by passing it through a Boerner-Sampler (Seed Trade Reporting Bureau, Chicago, IL) divider 6 times. Samples were then sealed in polyethylene bags and stored at 23°C until time for the tests. The rice samples were dried using both CIR dryer and FAC dryer at 36°C and 45°C. Table 1 shows the experimental design of the drying tests. The samples were dried down to about 17% moisture using heat with single or multiple passes (double pass) at different moisture removals from 1.5% to 4% at each drying pass. After reaching the desired moisture content the samples were taken out from the dryer and kept in sealed containers and stored inside an incubator (PRECISION 815, Winchester, VA) for

tempering for 4 hours, at same temperature as drying. If double pass drying was needed the rice samples were dried again and tempered. The tempered rice samples were then further dried to a final moisture content of 13.5% using ambient air. All moisture contents reported are in wet weight basis and determined by the air oven method (130°C for 20 hours) (ASAE, 1995).

Catalytic Infrared (CIR) drying

Schematic diagram of the CIR dryer used in the study is illustrated in figure 1 (a). It is equipped with a catalytic infrared emitter (BUREST MODEL 12-24, 12,000 Btu input) and adjustable speed vibrating bed for mixing rice during drying. Infrared emitter is 0.265 m above the rice bed. The average radiation energy intensity at the rice bed surface was 2750 W/m^2 which was measured using OPHIR FL250A Thermal Excimer Absorber Head (OPHIR, Washington, MA 01887, USA). Flexible bottom (0.8 m x 0.4 m) of the CIR dryer, made out of Teflon coated fabric material, is vibrated in four sections. Wave-like vibration is created by rotating Teflon rollers arranged under the flexible bottom. Vibrating frequency was set at 450 cycles/min. Amplitude of the vibration was 2.5 cm in vertical direction. Exhaust turbo blower (DAYTON 4C940) fixed at the top of the dryer exhausted the burnt gas and moist air from the dryer chamber at a rate of $138 \text{ m}^3/\text{h}$. Recirculation of air was created by two blowers (DAYTON 2C9175) sucking air from the top of the dryer and blowing on to the rice bed along the sides of the rice bed. Each blower had a flow rate of $312 \text{ m}^3/\text{h}$. Natural gas was used to power the CIR emitter and its flow rate to the CIR emitter was measured using a flow meter (EQUIMETER MR-5). A computer based data acquisition and control (DAC) system was used to log temperature and gas flow data and to control solenoid valve (UNIVERSAL MODEL36C03) of the gas supply. The CIR emitter temperature was measured by preinstalled eight Type J thermocouples on the surface of the catalytic layer of the emitter. In the CIR drying the measured natural gas consumption of the CIR emitter operated at 190 mm H₂O pressure was $0.42464 \text{ m}^3/\text{h}$. The average IR panel temperature was 500°C. Assuming IR emitter as a black body, the maximum wavelength (wave length that produces the maximum power at 500°C) calculated using Planck's equation was $3.7 \text{ }\mu\text{m}$, which was close to the absorption peak of water in the infrared range.

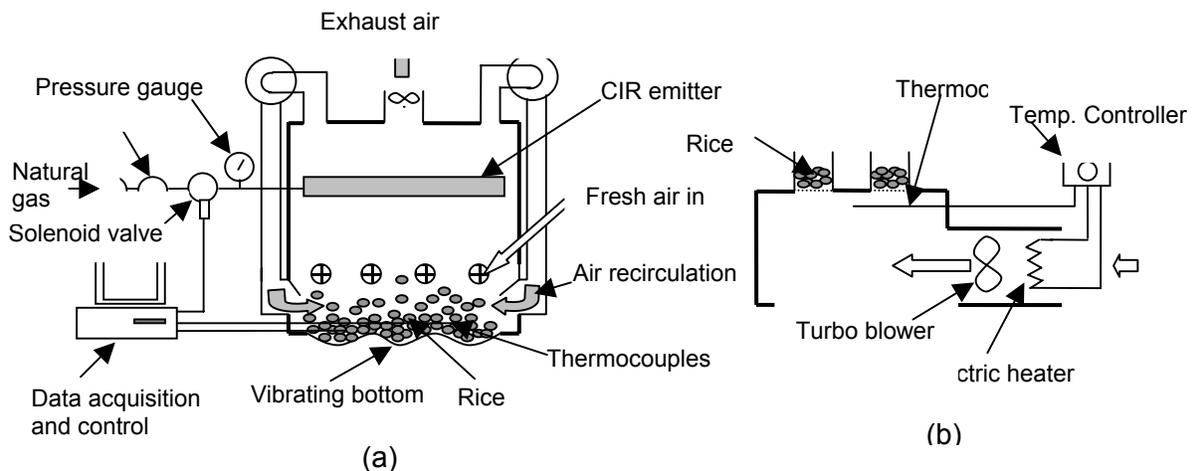


Figure 1. Schematic diagrams of CIR drying (a) and FAC drying (b).

Since infrared radiation directly heats the rice without heating the surrounding air, therefore, the rice bed temperature was used as the drying temperature for the CIR drying. Two thermocouples inserted in to the middle of the rice bed (Figure 1 (a)) were used to measure the rice temperatures and the average of two temperatures is reported as the rice temperature. Gas supply to the IR emitter was controlled (switched on or off) by the DAC comparing the average rice temperature with the preset rice drying temperature.

The sample size for CIR drying was 6kg per batch. This formed a 5 cm thick rice layer on the vibrating bed. Drying curves were obtained at two different drying temperatures. Then the end point of drying for a specific drying test was determined based on calculated drying time from the drying curves.

Table 1. Rice drying experimental design for comparing the dried rice quality

Drying temperature (°C)	Target moisture removal (%)	Drying method (CIR/FAC)	Number of passes	Experiment Code
36	2	CIR	1	T36-M2-CIR-SP
		CIR	2	T36-M2-CIR-MP
		FAC	1	T36-M2-FAC-SP
		FAC	2	T36-M2-FAC-MP
	3	CIR	1	T36-M3-CIR-SP
		FAC	1	T36-M3-FAC-SP
	4	CIR	1	T36-M4-CIR-SP
		FAC	1	T36-M4-FAC-SP
45	1.5	CIR	1	T45-M1.5-CIR-SP
		CIR	2	T45-M1.5-CIR-MP
		FAC	1	T45-M1.5-FAC-SP
		FAC	2	T45-M1.5-FAC-MP
	2.5	CIR	1	T45-M2.5-CIR-SP
		CIR	2	T45-M2.5-CIR-MP
		FAC	1	T45-M2.5-FAC-SP
		FAC	2	T45-M2.5-FAC-MP
	3.5	CIR	1	T45-M3.5-CIR-SP
		FAC	1	T45-M3.5-FAC-SP

Notes: SP – single pass drying; MP- two pass drying

Forced air convection (FAC) drying

A laboratory scale electrically heated FAC dryer (Figure 1.(b)) was used for this study to generate dried rice samples for quality comparison with rice dried with the CIR dryer. The FAC drying simulated the column drying which is widely used for rice drying. The Electric heaters of the dryer were controlled by a microcontroller (OMEGA-E CN132) to keep the air temperature at set temperature. The heated air temperature was considered as the drying temperature for FAC drying. The air velocity was 0.1m/s and the ambient air was at 23°C and 37% relative humidity.

Rice milling quality evaluation

The evaluated rice milling quality included head rice yield (HRY), total rice yield (TRY) and whiteness. The moisture contents of the dried samples before the milling tests were 13.5 ± 0.5%. Two rice samples from each drying treatment were used for the quality determination at the Federal Grain Inspection Services laboratory (West Sacramento, CA) following the standard

rice sample milling procedures. The whiteness of milled rice was measured using KETT digital Whiteness Tester (Model C-300-3, Range 5-70, KETT electronic lab, Japan) and whiteness index was reported. A higher whiteness index indicates whiter milled rice.

Commercial rice drying

To compare the milling quality of rice dried with the CIR and FAC dryers, the same rough rice was dried with a two-column commercial scale cross-flow dryer (Shanzer model 5R6 column dryer, 24.4m tall screens, 0.3m between screens). The dryer has a capacity of 182,000 kg/h and had two air plenums (top and bottom) equipped with direct-fired natural gas burners and blowers. The air temperatures were controlled manually depending on the conditions of incoming rough rice. The typical drying air temperature was 44°C to 54°C. The upper plenum had higher temperature and lower plenum had lower temperature. The air temperature and feeding rate were adjusted to achieve about 2% moisture removal by each pass. The out going grain temperature was kept equal or below 35°C. Dried rice was conveyed to a silo for tempering for at least 4 hours before it is further dried using ambient air. In this test, two drying passes were used to dry the rice from the harvest moisture 22% to 20% and then to 18.5% with heated air before the rice was further dried to 14% using ambient air.

Results and Discussion

Rice temperature profiles and drying rates of CIR and FAC drying

The CIR drying had uniform temperature distribution in the rice bed. But the temperature distribution in FAC drying was not uniform (Figure 2) even though both rice bed thicknesses of

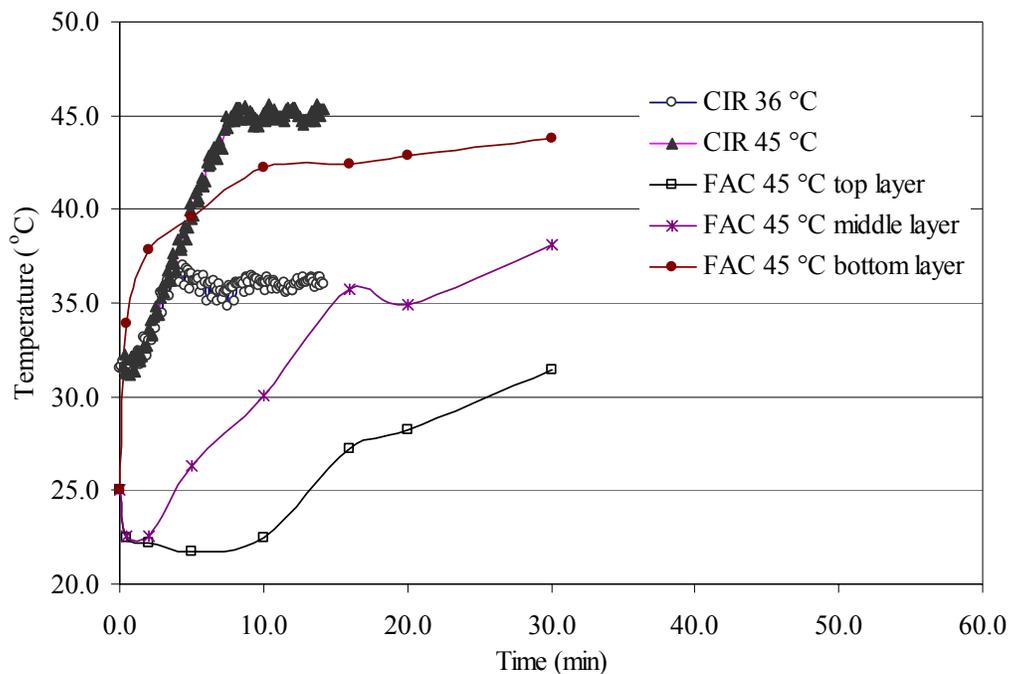


Figure 2. Temperature profiles of rice at different bed locations of rice dried with FAC at 45°C and average rice bed temperature of CIR drying at 36°C and 45°C.

CIR and FAC drying were the same (5 cm). For the FAC drying, the difference between the top and bottom temperatures was at least 12°C for the 30 min drying period. Infrared quickly heated the rice to the set drying temperature and it took only 4 and 8 min to reach the 36°C and 45°C of set temperatures, respectively. The temperature of CIR drying can be controlled at $\pm 2^\circ\text{C}$ of the set temperature. The CIR drying took 28 and 11 min to remove 2% moisture at 36°C and 45°C, respectively (Figure 3). CIR drying at 45°C was faster than FAC drying.

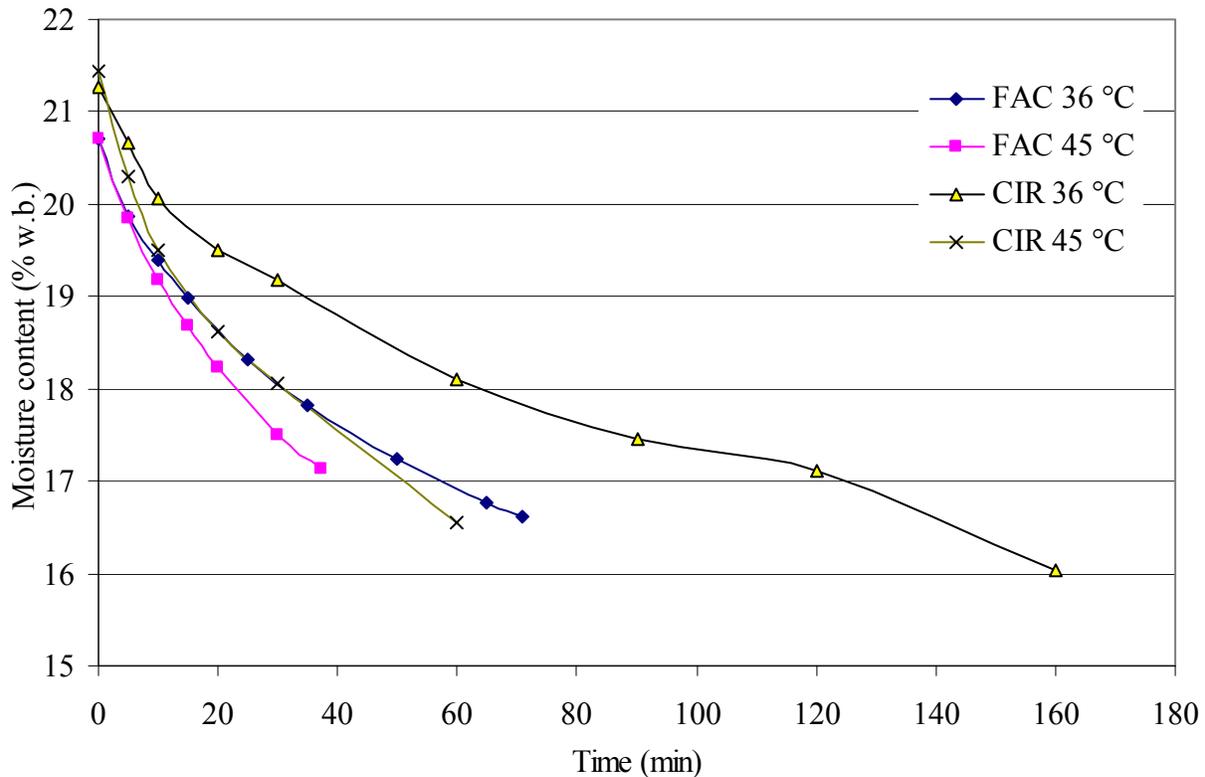


Figure 3. Drying curves of rice dried with different temperatures and methods.

Rice milling quality

In the CIR and FAC drying, the targeted moisture contents were well achieved with an average error of 0.28% and standard deviation 0.2% except experiment No.17 (T45-M3.5-CIR-SP), which was over dried by 2.7% (Table 2). In general, the rice dried using CIR dryer had higher HRY and TRY than that rice dried with the laboratory FAC dryer and the commercial dryer. On average, the HRY and TRY of rice dried with CIR were 62.4% and 70.2%, respectively, compared to 61.2% and 69.5% of rice dried with the FAC dryer and 58 % and 70% of rice dried with the commercial dryer. The differences in HRY and TRY from CIR and FAC drying were 1.2% and 0.7%, respectively. The overall whiteness index values of milled rice from the two different drying methods were not much different even though whiteness index of rice dried with the CIR was slightly higher than that from dried with FAC drying.

For both single and double pass drying, the rice dried with CIR had higher average HRY and TRY, slight higher whiteness index. For the single pass drying, CIR dried rice had HRY of 62.5% and TRY of 70.2% compared to HRY of 61.1% and TRY of 69.6 \pm 0.2% for FAC dried rice. The differences in HRY and TRY were 1.4% and 0.6%, respectively. For double pass drying,

the CIR dried rice also had higher HRY (62.1%) and TRY (70.4%) than FAC dried rice with HRY of 61.1% and TRY of 69.5%. The differences in HRY and TRY were 1.0% and 0.9%, respectively. Therefore, it can be concluded that the CIR drying produced high quality rice.

Table 2. Effect of drying conditions on rice quality.

Drying Temp. (°C)	Target moisture loss (%)	MC after 1 st drying pass (%)	MC after 2 nd drying pass (%)	Drying method	Number of drying passes	Experiment Code	TRY	HRY	Whiteness
36	2	2.3		CIR	SP	T36-M2-CIR-SP	70.50±0.28	62.95±0.07	40.58±0.32
		1.9	2.09	CIR	MP	T36-M2-CIR-MP	70.45±0.07	62.25±0.78	41.35±0.44
		1.6		FAC	SP	T36-M2-FAC-SP	69.40±0.99	61.20±0.57	40.60±0.45
		1.6	2.65	FAC	MP	T36-M2-FAC-MP	69.20±0.57	61.00±0.28	40.65±0.45
	3	2.7		CIR	SP	T36-M3-CIR-SP	70.15±0.35	62.55±0.64	41.05±0.33
		2.7		FAC	SP	T36-M3-FAC-SP	69.35±0.21	61.80±0.28	40.97±0.61
	4	3.1		CIR	SP	T36-M4-CIR-SP	70.05±0.21	62.00±0.57	40.82±0.27
		3.9		FAC	SP	T36-M4-FAC-SP	69.55±0.07	61.40±0.28	40.72±0.26
45	1.5	1.5		CIR	SP	T45-M1.5-CIR-SP	70.35±0.07	63.65±0.35	40.87±0.45
		2.0	2.19	CIR	MP	T45-M1.5-CIR-MP	70.10±0.28	61.60±0.14	40.85±0.35
		1.7		FAC	SP	T45-M1.5-FAC-SP	69.65±0.07	60.95±0.07	40.22±0.52
		1.7	1.88	FAC	MP	T45-M1.5-FAC-MP	69.95±0.21	61.55±0.21	40.07±0.43
	2.5	2.4		CIR	SP	T45-M2.5-CIR-SP	70.20±0.57	62.30±1.13	40.70±0.62
		2.1	2.71	CIR	MP	T45-M2.5-CIR-MP	70.50±0.28	62.55±0.64	40.47±0.37
		2.8		FAC	SP	T45-M2.5-FAC-SP	69.70±0.85	60.90±0.14	39.97±0.63
		2.8	2.94	FAC	MP	T45-M2.5-FAC-MP	69.45±0.92	60.85±0.35	41.27±0.32
	3.5	6.2 *		CIR	SP	T45-M3.5-CIR-SP	69.90±0.14	61.45±0.21	40.40±0.39
		3.6		FAC	SP	T45-M3.5-FAC-SP	69.65±0.21	60.60±0.0	40.22±0.46

SP – Single pass drying; MP- Multiple Pass drying (two drying passes); * Over dried by 2.7%

The drying temperature did not cause significant change in HRY and TRY for either drying method. This indicates that either drying temperature can be used for obtaining high quality rice. But drying with the high temperature (45°C) had much higher drying rate than 36°C. The rice dried with CIR dryer had higher HRY (1.0% - 1.3%) at both drying temperatures than that of FAC dried rice. The TRY of CIR dried rice was also higher by 0.4% - 0.9% than that FAC dried rice. The rice dried with the CIR had slight higher whiteness index value than that dried with FAC.

Energy consumption of laboratory CIR drying and commercial rice drying

The highest energy efficiency for the laboratory scale CIR dryer was 12,136 kJ/kg of water removal for 1.9% moisture removal level at 45°C and 17,285 kJ/kg of water removal for 1.3% moisture removal level at 36°C drying temperature. The energy efficiency at 45°C was higher than that at 36°C for CIR laboratory scale dryer. In a separate test, when the loading rate was increased to 24 kg per batch, the energy efficiency was improved to 7,717 kJ/kg of water removal. This number is close to that obtained from the commercial column dryer, 7,107 kJ/kg. For the laboratory CIR dryer, the ratios of loading rate to emitter surface area were 32.2 kg/m², and 129 kg/m² when the loading rates were 6 kg and 24 kg. Base on the test resulted provided by the Catalytic Drying Technologies LLC, the energy efficiency of a pilot CIR dryer was in the range of 2,900 kJ/kg to 46,000 kJ/kg of water removal for moisture removal from 2.8% to 5.4%. This is significantly higher than the current column commercial dryer. The ratio of loading rate to emitter surface area was 483 kg/m² for the pilot scale CIR dryer. Thus, high ratio is needed to achieve high energy efficiency. To demonstrate the high energy efficiency and high rice milling quality benefits of CIR drying, it is necessary to conduct more tests using the pilot scale CIR dryer.

Conclusions

The results showed that the laboratory CIR drying produced high quality rice with higher drying rate and uniform heating of rice kernels compared to the FAC drying. The tested drying temperatures, 36°C and 45°C, did not significantly affect the milling quality of dried rice. Therefore, 45°C drying temperature is recommended to be used in large scale drying for taking the advantage of high drying rate. At least 3% of moisture could be removed in each drying pass without significantly affecting the rice milling quality. Comparing single pass drying, no advantage from double pass drying was observed for removing the same total amount of moisture. High energy efficiency could be obtained by using large scale CIR dryers with high ratio of loading rate and emitter surface area.

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