Cyclonic Rice Husk Furnace and Its Application on Paddy Drying

Somchart Soponronnarit [*], Thanit Swasdisevi [*], Somboon Wetchacama [*], Adisak Shujinda [**] and Boonrueng Srisawat [**]
[*] School of Energy and Materials, [**] Former graduate students
King Mongkut's University of Technology Thonburi,
Suksawat 48 Road, Bangkok 10140
THAILAND

ABSTRACT

The objectives of this research are to design, construct and test a rice husk furnace for a commercial fluidized bed paddy dryer with capacity of 10 000 kg/h. The furnace was cylindrical in shape with inner diameter of 1.37 m and height of 2.75 m. Rice husk was fed into the furnace with a feed rate of 110 kg/h to 136 kg/h. Air and rice husk entered to the combustion chamber in tangential direction with vortex rotation. The experimental results showed that for heights of ash on grate of 300 mm, 450 mm, 500 mm and 600 mm, rice husk feed rates were 110 kg/h to 136 kg/h, and excess air 265% to 350% with combustion gas temperature approximately 523 ℃ to 710 ℃. Thermal efficiency of the furnace system increasing with excess air was approximately 57% to 73% while carbon conversion efficiency was approximately 89% to 97%. The height of ash on grate had no effect on the system performance. Financial analysis indicated that the pay-back period of the furnace was 1200 hours, when used in place of the diesel oil burner. Latest information shows that the rice husk furnace has been commercialized for more than 40 units since the beginning of the year 1999.

1. INTRODUCTION

Singh, et al. [1] designed and tested a cyclonic rice husk furnace for drying 1000 kg of paddy with initial moisture content of 35% down to 14% dry basis. Efficiencies of the furnace were different at various rice husk feed rates and air flow rates. The highest efficiency was 80% with the rice husk feed rate of 20 kg/h and air flow rate of 168 m^3/h. Tumambing [2] investigated the performance of the cyclonic rice husk furnace of Padicor for paddy drying and found that the combustion efficiency was 98%. Xuan, et al. [3] designed and tested two types of rice husk furnace. The first one was a furnace with inclined grate and cylindrical combustion chamber. The upper part of the furnace was a heat exchanger. Inlet air entered at the lower part of inclined grate on which rice husk with a feed rate of 20 kg/h to 25 kg/h was burnt. The efficiency of the furnace was 70%. The second rice husk furnace was a pneumatic-fed cyclonic furnace. It consisted of combustion chamber and rice husk feed system. Rice husk was fed into the combustion chamber with primary air and was burnt. Then it fell down to the lower part of the chamber. The secondary air entered at the upper part of the combustion chamber in tangent direction in order to eliminate dust from flue gas. Rice husk consumption and furnace efficiency were 10 kg/h to 12 kg/h and 75%, respectively.

The past research showed that there were several designs of rice husk furnace, i.e., vortex or inclined grate types and direct use of flue gas or indirect use of thermal energy from combustion via heat exchanger. Acceptance of the furnace was still limited in the experimental sites. Therefore, the objectives of this research were to design, construct and test a commercial-scale prototype of cyclonic rice husk furnace for a commercial fluidized bed paddy dryer with a capacity of 10 tons/h. The dryer has been sold in several countries for more than 5 years [4].

2. MATERIALS AND METHODS

The design of the rice husk furnace started at the determination of the thermal energy required by the fluidized bed paddy dryer and followed by the determination of the feed rate of rice husk. Finally, the volume of the combustion chamber of the furnace was determined by the following equation.

$$v = B\,Q_{wt}/Q_{fr} \quad (1)$$

where v = volume of combustion chamber, m^3
B = feed rate of rice husk, kg/h
Q_{wt} = high heating value of rice husk, kJ/kg
Q_{fr} = design parameter for rice husk, (560 000 - 1 120 000) kJ/h.m^3

Then the dimensions of the furnace were fixed. The furnace consisted of a combustion chamber, feeding systems of air and rice husk, a control system and a suction blower. The combustion chamber was made of steel in cylindrical shape with inner and outer diameters of 1.37 m and 1.76 m, respectively, and height of 2.75 m. Materials inside the combustion chamber at the lower part from inner layer to outer layer were the following: fire brick, steel, glass fiber and covering steel. There was a grate with diameter of 1.37 m, thickness of 9.5 mm (583 holes/m^2, hole diameter 0.0127 m) and ash paddle with cross-section of 50 mm x 50 mm and1.1 m length at the lower part of combustion chamber. The primary air duct was connected to the upper part of the combustion chamber in tangential direction. On the upper part of the combustion chamber, a steel cylinder with inner diameter of 0.8 m and height of 1.6 m was installed and connected to the secondary air duct in tangential direction in order to clean up flue gas. The cylinder was insulated with cement 60 mm thick. Rice husk ash was removed from the combustion chamber by the ash paddle followed by a screw conveyor installed under the combustion chamber. The tertiary air duct was connected to the bottom part of the combustion chamber in order to support complete combustion. The rice husk feeding system consisted of a rice husk hopper with a screw installed at the bottom and driven by a 0.37 kW motor, a 0.152 m diameter primary air duct for pneumatic feed of rice husk and a fan. The secondary air duct was 0.102 m in diameter. The tertiary air duct with diameter of 0.076 m separated from the secondary air duct and then was divided into four ducts with distributors at the bottom of the combustion chamber under the grate. Air suction system consisted of a 15 kW blower, a duct with diameter of 0.254 m and a valve for regulating the fraction of fresh air into the combustion chamber.

The measuring instruments used in this experiment were as follows: a data logger with an accuracy ±1°C connected to type K thermocouple, a clamp-on meter, a manometer of 0 Pa to 2000 Pa (accuracy ±1 Pa), a hygrometer of 0% to100% (accuracy of ±1%), a balance machine of 0 kg to 50 kg (accuracy ±200 g), a gas combustion analyzer of O_2, CO, NO_2 and SO_2 with a range of temperature 0°C to 600°C (accuracy ±3°C for temperature, ±20 ppm for CO, ±0.3% for O_2).

To start the experiment, air flow rates in the primary, secondary and tertiary air ducts were set up. Sample of rice husk was taken for component analysis. Rice husk was weighed and fed into the furnace until it reached the height required. Combustion was started by the aid of burning oil and paper. The fans number 4 and 10 were switched on for supporting the combustion. After 10 to 15 minutes, the fan number 3 and the rice husk feeding system and ash paddle were switched on. Control temperature was set at 325°C. Temperature was measured every 3 minutes and flue gas was analyzed every 10 minutes. Relative humidity, dry bulb and wet bulb temperatures of ambient air were measured. At the end of the experiment, rice husk feeding system and the fans number 3 and 4 were switched off while the fan number 10 was still switched on in order to suck hot air from the furnace. Finally, the fan number 10 was switched off and samples of ash were taken for component analysis. Figure 1 shows the schematic diagram of the cyclonic rice husk furnace.

The efficiency of the rice husk furnace was determined by the following equation:

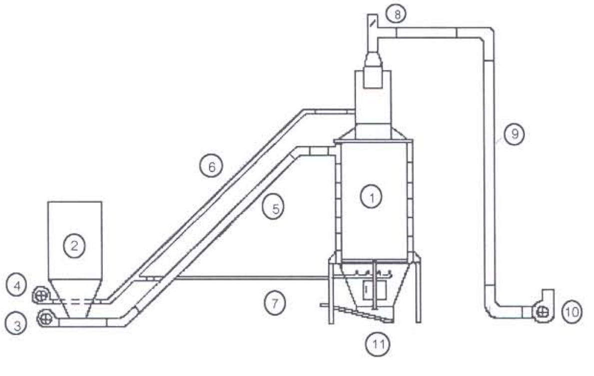
$$\eta_r = [m_a c_p (T_2 - T_1) / m_f HHV]\, 100 \tag{2}$$

where
η_r = efficiency of the furnace, %
m_a = flow rate of mixed air between fresh air and flue gas, kg/h
c_p = specific heat of air, kJ/kg.K
T_1 = ambient air temperature, K
T_2 = temperature of the mixed air between fresh air and flue gas, K
m_f = rice husk feed rate, kg/h
HHV = high heating value of rice husk, kJ/kg

The carbon conversion efficiency was calculated by the following equation:

$$\eta_c = [(c_h - c_a) / c_h]\, 100 \tag{3}$$

where
η_c = carbon conversion efficiency, %
c_a = (percent of carbon in ash).(ash weight, kg)
c_h = (percent of carbon in rice husk).(husk weight, kg)



1 combustion chamber
2 rice husk hopper
3 conveying fan of rice husk feeding system
4 conveying fan of air feeding system
5 primary air duct
6 secondary air duct
7 tertiary air duct
8 butterfly valve
9 exit air duct
10 suction blower
11 screw conveyor

Fig. 1. Schematic diagram of the rice husk furnace.

3. RESULTS AND DISCUSSION

3.1 Air Distribution in Tertiary Air Duct

Table 1 and Table 2 show the efficiencies of the furnace and carbon conversion efficiencies at various heights of ash with four air distributors under the grate. The results of experiment nos. 1/97, 2/97, 3/97 and 4/97 with heights of ash 300 mm, 450 mm, 500 mm and 600 mm were as follows: the carbon conversion efficiencies were 93%, 95%, 96% and 97%, respectively, and the efficiencies of the furnace were 57% to 59%. Table 3 and Table 4 show the efficiency of the furnace and the carbon conversion efficiencies at heights of ash of 300 mm, 450 mm, 500 mm and 600 mm with only one air distributor. The results of experiment nos. 1/96, 2/96, 3/96 and 4/96 showed that the carbon conversion efficiencies were 88%, 93%, 85% and 90%, respectively while the efficiencies of the furnace were 58% to 63%. It can be concluded that the pattern of air distribution in the tertiary duct did not significantly affect the carbon conversion efficiency and the efficiency of the furnace.

3.2 Air Flow Rate in Tertiary Air Duct

Combustion was not complete when air flow rate in the tertiary duct was too high. High air velocity caused the burning rice husk to fall too quickly from the grate. Consequently, combustion was not complete which resulted in low carbon conversion efficiency, as shown in Table 1 and Table 2 (comparison between experiment nos. 6/97 and 11/97).

3.3 Excess Air

The results in Table 1 show that when the excess air of combustion was 260% to 280% (experiment nos. 1/97-4/97), the efficiencies of the furnace was 58% to 59% and the carbon conversion efficiencies were 93% to 97%. When the excess air increased to be 342% to 350% (experiment nos. 5/97-7/97), the efficiency of the furnace increased to 70% to 73% and the carbon conversion efficiency increased to 95% to 97%. The increase of the excess air resulted from the decrease of the rice husk feed rate. The best condition obtained from several experiments was as follows: 500 mm height of ash on grate, 110 kg/h rice husk feed rate, 350% excess air of combustion, and a yield in an average furnace temperature of 628°C. Carbon in ash after combustion was 5.5%. The carbon conversion efficiency was 96% and the efficiency of furnace was 73%. Temperature distribution in the furnace with height of ash 500 mm is shown in Fig. 2.

3. 4 Height of Ash on Grate during Combustion

The height of ash on grate during combustion did not affect the efficiency of the furnace, as shown in Table 3.

3.5 Component Analysis of Rice Husk and Ash

Composition of substances in rice husk before combustion were as follows: carbon 39%, hydrogen 5.4%, oxygen 40.3%, nitrogen 0.19%, sulfur 0.04%, moisture 8.10%, ash 15.1% and calorific value 14927 J/g.

Ash obtained from each experiment was analyzed at the Department of Science Service, Ministry of Science, Technology and Environment. The results showed that the quantities of carbon

Table 1 The Efficiencies of the Rice Husk Furnace (experiment in 1997)

Experiment no.	Height of ash (cm)	Feed rate of rice husk (kg/h)	Air flow rate for combustion (kg/s)	Air flow rate in primary duct (ϕ=0.152m) (kg/s)	Air flow rate in secondary duct (ϕ=0.102m) (kg/s)	Air flow rate in tertiary duct (ϕ=0.076m) (kg/s)	Excess air (%)	Ambient temperature (°C)	Furnace temperature (°C)	Exit * temperature (°C)	Efficiency of furnace (%)
1/97	30	135	0.627	0.400	0.178	0.048	265	34	531	304	58
2/97	45	133	0.627	0.400	0.178	0.048	270	34	530	302	58
3/97	50	136	0.625	0.398	0.178	0.048	260	35	523	304	57
4/97	60	130	0.628	0.401	0.179	0.048	280	33	554	301	59
5/97	30	110	0.628	0.401	0.179	0.048	350	33	571	299	70
6/97	45	112	0.628	0.401	0.179	0.048	342	33	568	306	70
7/97	50	110	0.626	0.400	0.178	0.048	350	34	628	310	73
8/97	50	111	0.621	0.400	0.161	0.060**	342	34	710	311	72
9/97	50	125	0.619	0.400	0.149	0.070**	294	34	598	301	62
10/97	30	133	0.676	0.398	0.178	0.099**	299	35	502	297	57
11/97	45	125	0.674	0.397	0.177	0.099**	323	36	566	297	60
12/97	50	136	0.674	0.397	0.177	0.099**	289	36	527	295	54

* Mixed air between combustion air and ambient air

** Increasing air flow rate in tertiary duct

Table 2 Carbon Conversion Efficiency of the Rice Husk Furnace (experiment in 1997)

Experiment no.	Carbon in rice husk (%)	Carbon in ash (%)	Rice husk consumption (kg)	Ash (kg)	CO value (ppm)	O_2 value (%)	Carbon conversion efficiency obtained from carbon balance (%)	Carbon conversion efficiency Measured (%)
1/97	39	9.9	318	84	1025-1869	17.4-18.6	93	93
2/97	39	7.5	228	70	1129-1999	17.2-18.7	93	95
3/97	39	5.9	320	75	142-1732	17.4-18.4	94	96
4/97	39	4.4	254	60	1083-1982	17.0-19.1	95	97
5/97	39	7.0	259	62	1253-1946	17.9-18.9	96	95
6/97	39	4.9	253	60	1204-1832	17.4-18.4	98	97
7/97	39	5.5	237	53	200-1803	17.4-18.4	96	96
8/97	39	13.4	250	58	1200-1993	17.4-18.4	90	92
9/97	39	14.8	262	74	1232-1879	17.5-18.6	87	89
10/97	39	28.7	220	83	1230-1896	17.4-18.4	81	81
11/97	39	26.3	289	74	1235-1999	17.4-19.0	83	82
12/97	39	22.8	320	79	1260-1988	17.2-18.7	85	85

Low values of NO_2 and SO_2 (NO_2: 1-12 ppm, SO_2: 1-20 ppm)

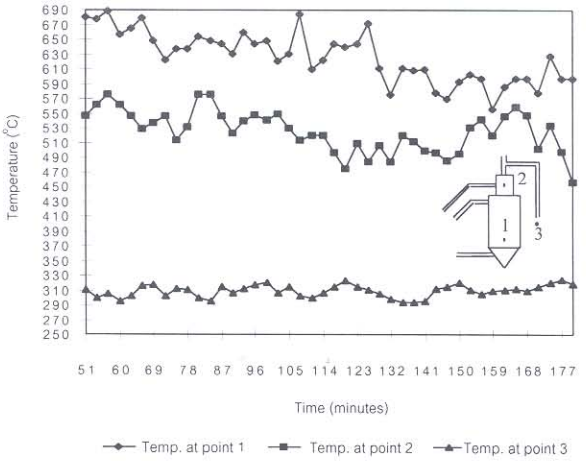


Fig. 2. Relationship between temperature and time in the rice husk furnace at 500 mm height of ash on grate (experiment no. 7/97).

after combustion of 12 samples were as follows: 9.9%, 7.5%, 5.9%, 4.4%, 7.0%, 4.9%, 5.5%, 13.4%, 14.8%, 28.7%, 26.3% and 22.8%, respectively. Carbon content after combustion was high when the air flow rate for supporting combustion in the tertiary duct was increased, as shown in Table 1. The grate hole became larger and the burning rice husk on grate fell down too quickly.

3.6 Power Consumption of Rice Husk Furnace

Power consumption of rice husk furnace was as follows: the fan for primary air 1.25 kW, the fan for secondary air and tertiary air 1.18 kW, the suction blower 8.36 kW, the motor of ash paddle 1.79 kW, the motor of rice husk feeding system 0.66 kW and the screw conveyor for ash unloading 0.72 kW. The total electrical power consumption was 13.96 kW.

Table 3 The Efficiency of the Rice Husk Furnace at Various Heights of Ash (experiment in 1996)

Experiment no.	Height of ash (cm)	Feed rate of rice husk (kg/h)	Air flow rate for combustion (kg/s)	Air flow rate in primary duct (ϕ=0.152m) (kg/s)	Air flow rate in secondary duct (ϕ=0.102m) (kg/s)	Air flow rate in tertiary duct (ϕ=0.051m) (kg/s)	Excess air (%)	Ambient temperature (°C)	Exit * temperature (°C)	Efficiency of furnace (%)
1/96	30	127	0.626	0.400	0.178	0.048	287	34	294	62
2/96	45	133	0.626	0.400	0.178	0.048	269	34	296	59
3/96	50	126	0.628	0.401	0.179	0.048	290	33	296	63
4/96	60	143	0.631	0.402	0.180	0.049	245	32	297	58

Table 4 Carbon Conversion Efficiency of the Rice Husk Furnace at Various Heights of Ash (experiment in 1996)

Experiment no.	Height of ash (cm)	Carbon in rice husk (%)	Carbon in ash (%)	Rice husk consumption (kg)	Ash (kg)	CO value (ppm)	O_2 value (%)	Carbon conversion efficiency obtained from carbon balance (%)	Carbon conversion efficiency Measured (%)
1/96	30	36.8	19.3	381	101.0	1300-1600	18	87	88
2/96	45	36.8	12.6	399	93.0	1700-1800	18	95	93
3/96	50	36.8	24.8	378	102.5	1600-1900	18	83	85
4/96	60	36.8	14.9	429	108.0	1000-1800	18	94	90

Low values of NO_2 and SO_2 (NO_2: 30-60 ppm, SO_2: 3-20 ppm)

Electricity consumption in these experiments was compared to the thermal energy production of the furnace. The results showed that electricity consumption in terms of primary energy (multiplying factor 2.6) was approximately 7% of the thermal energy production of the rice husk furnace, as shown in Table 5.

3.7 Application on Paddy Drying

The rice husk furnace was sold and installed for supplying hot air to the fluidized bed dryers at Koong Li Chan in Ayudhaya province in early 1999. Result from one test showed that the efficiency of the furnace was 75%. The conditions of the experiment were paddy feed rate 9.249 t/h, moisture content reduced from 25.3% to 21.5% dry basis, 147°C drying air temperature, 4.5 m^3/s air flow rate and 142 kg/h feed rate of rice husk. The specific primary energy consumption was 9.3 MJ/kg water evaporated. This value seems to be high as compared to normal value of the fluidized bed paddy drying with diesel oil burner. Reasons for that are: (a) the efficiency of the rice husk furnace was much lower as compared to that of the diesel burner, and (b) the operation without air recirculation in the fluidized bed drying with the rice husk furnace caused lower drying efficiency.

3.8 Financial Analysis and Commercialization

Financial analysis of the rice husk furnace that operates with the fluidized bed paddy compared to the diesel burner was conducted by Samitayothin [5]. The assumptions were as follows: initial cost of the dryer Baht 800,000, initial cost of the rice husk furnace Baht 400,000, initial cost of the diesel burner Baht 50,000, service life of the dryer and the furnace 10 and 5 years, respectively, interest rate 12% per year, salvage value 10% of initial cost, maintenance cost 5% of initial cost, operating time 2400 h/y, drying rate for the case of rice husk furnace and diesel burner are 291 kg/h and 316 kg/h, respectively, electrical power consumption for the dryer and the furnace 29 kW and 4 kW, respectively, rice husk consumption (if rice husk is used) 142 kg/h of which 35 kg ash was obtained, diesel oil consumption (if diesel oil is used) 38.1 l/h, cost of electricity 1.78 Baht/kWh with extra charge 0.33 Baht/kWh and value added tax 7%, cost of rice husk 100 Baht/t, benefit from selling ash 150 Baht/t, cost of diesel oil 9.54 Baht/l.

Table 5 Electricity Consumption (experiment in 1997)

Experiment no.	Feed rate of rice husk (kg/h)	Electricity consumption rate (kW)	Electricity consumption rate in terms of primary energy * (kW)	Heat production rate of rice husk furnace (kW)
1/97	135	13.96	36.30	559.68
2/97	133	13.96	36.30	551.40
3/97	136	13.96	36.30	563.83
4/97	130	13.96	36.30	538.95
5/97	110	13.96	36.30	456.04
6/97	112	13.96	36.30	464.33
7/97	110	13.96	36.30	456.04
8/97	111	13.96	36.30	460.20
9/97	125	13.96	36.30	518.23
10/97	133	13.96	36.30	551.40
11/97	125	13.96	36.30	518.23
12/97	136	13.96	36.30	563.38

* Multiply by factor 2.6

The results showed that the total cost of the dryer with the rice husk furnace was 0.83 Baht/kg water evaporated of which Baht 0.39 was fixed cost and Baht 0.44 was operating cost and that of the dryer with diesel oil burner was 1.61 Baht/kg water evaporated of which Baht 0.19 was fixed cost and Baht 1.42 was operating cost. When using in place of the diesel oil burner, it was found that the pay-back period of the rice husk furnace was 1200 h. Latest information shows that the cyclonic rice husk furnace has been commercialized for more than 40 units since the beginning of the year 1999. All of them were installed in private rice mills.

4. CONCLUSIONS

From this study, conclusions can be drawn as follows:

- Excess air affected the efficiency of the furnace. When excess air increased from 260% to 350%, the efficiency of the furnace increased from 57% to 73%.
- Pattern of air distribution in the tertiary duct did not significantly affect the carbon conversion efficiency and the efficiency of the furnace.
- The height of ash on the grate was observed not to affect the efficiency of the rice husk furnace.
- Too high air flow rate in the tertiary duct did not support combustion because the burning rice husk fell quickly from the grate which resulted in incomplete combustion.
- Pay-back period of the rice husk furnace was 1200 hours when used in place of the diesel oil burner.

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