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Utilization of a Direct Combustion Type Husk Burner for Grain Drying

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Abstract

We conducted grain drying tests using exhaust heat from a direct combustion type husk burner (HB) and compared the results with those of a conventional system using a kerosene burner (KB). The thermal efficiency of the direct combustion type HB was high, and 88 to 90% of the energy from husk combustion was available for grain drying. Grain drying could be properly controlled, and the quality of rice and wheat were almost equivalent to when dried using a conventional KB, but with only 10 to 15% of the CO_2 emission required. Therefore, we considered the system using heat from the HB for grain drying to be useful in reducing the environmental load resulting from fossil-fuel consumption.

Discipline: Agricultural machinery

Additional key words: energy saving, thermal efficiency, odor of dried grain

Introduction

The grain drying process creates the highest CO_2 emission of any stage of paddy-rice production in Japan. According to research, 41.3% of CO_2 emissions within paddy-rice production come from the kerosene consumption required for grain drying[16].

During the oil crisis of the 1970s, many companies developed husk burners (HB) as an alternative to kerosene burners (KB), to reduce kerosene consumption for grain drying facilities. Many Japanese researchers also investigated the heat utilization from an HB for grain drying and the associated economic efficiency[4, 5, 8, 11, 13, 14, 15] and its applicability was proven during a field test[8, 13]. This type of system was analyzed not only for grain drying but also for heating greenhouses. Bekki et al.[1] investigated the operational status of an HB for a facility consisting of five greenhouses in 1981. However, interest was not maintained because the oil crisis was transient.

In 2005, since the adoption of the Kyoto Protocol, an international agreement aimed at preventing global warming, Japan agreed to reduce greenhouse gas emissions by 6% by 2012, compared to the 1990 levels. Additionally, at the 2009 United Nations Climate Change Conference, the Prime Minister of Japan issued a medium-term target of cutting greenhouse gas emissions by 25% below 1990 levels by 2020. A variable approach to reduce the energy consumed from fossil fuel has thus become a national commitment, thereby leading to renewed interest in developing an HB in Japan.

Overseas, particularly in Asia, the application of an HB for grain drying has also been investigated and some HBs have been prevalent[7, 9, 10, 12].

In Japan, rice is mainly stored and distributed in the form of brown rice, with considerable husks, residual products from rice huskers, generated in the grain drying and processing facilities, meaning the utilization of an HB for grain drying remains as useful as before.

Although individual research papers do exist concerning the utilization of an HB for grain drying or the thermal efficiency of an HB at home and overseas, very few reporting both the drying performance and environmental effect are observed. This is because most of the research papers were published before 1998, since which time CO_2 emissions have gained global attention.

Under these circumstances, we re-evaluated a system using an HB for grain drying as an effective utiliza-

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tion of energy in Japanese agriculture. The HB we adopted was a direct combustion type, directly using combustion gas. Although the direct combustion type has advantages in terms of thermal efficiency and size compared to the indirect type (which connects a heat exchanger to a husk furnace), deterioration in grain quality e.g. due to the odor of the exhaust gas is a concern. In this study, we report the following objectives: 1) to build a direct combustion type HB system and evaluate its thermal efficiency, 2) Evaluate the adaptability and utility of the HB for grain drying in terms of drying efficiency and CO_2 emission, and 3) Confirm the grain quality, including measurement of the odor causing concern.

Materials and methods

1. Husk burner system and test drying facilities

We used a fluidized-bed combustion husk furnace (HA-60, Yanmar Green System Co., Ltd.; Fig. 1). For the ignition stage, we used an auxiliary kerosene burner installed in the furnace until the in-furnace temperature had risen to a given level. Stored husks was conveyed to the husk tank by a blower and uniformly supplied to the furnace by a rotary valve. The husk burned while circulating horizontally around the inner wall of the furnace in a fluidized state, with primary air supplied simultaneously from the air ejector. The in-furnace temperature was kept below 800°C to prevent the corrosion of in-furnace material by reacting to the potash component of the exhaust gas[5].

The auxiliary kerosene burner continued to cycle on and off until the in-furnace conditions stabilized (i.e. the stage when the kerosene burner became unnecessary). During the stable stage, external heat is unnecessary, and husk is the only item supplied. The husk charcoal was ejected by a screw auger at the bottom of the furnace and was anticipated to serve as soil conditioner.

The direct combustion HB that we built to utilize the exhaust heat is depicted in Fig. 2, with details included in Table 1. The exhausted hot air from the husk furnace was mixed with ambient air, using the hot air fan installed in the hot air duct to increase airflow and decrease the air temperature. Dust mixed in the hot air was removed by the cyclone separator before the hot air was conveyed to the grain dryer. The grain dryer connected to the HB was a continuous-flow grain dryer (YHC3600TW, Yanmar Green System Co., Ltd.). The hot air duct was connected to the blower inlet of the dryer. At the latter, hot air was mixed with ambient air, which increased the airflow and further decreased the air temperature to make the air suitable for grain drying. We could control the hot air temperature and airflow to the grain dryer by adjusting the husk supply rate and the ratio of dumper opening at the hot air fan.

Figure 3 shows the airflow from the HB to the grain dryer, in contrast to the conventional drying system, in which air is heated by the KB (JSFF7, Yanmar Green System Co., Ltd.) installed beside the blower inlet of the grain dryer. We did not have to use the KB when we provided the hot air from the HB.

2. Methods

(1) Combustion test

To measure the thermal efficiency of the HB, we installed measurement devices in the husk furnace, hot air duct, and air inlet of the grain dryer. Figure 3 depicts the measurement points. We conducted the test three times by changing the preset temperature to the grain dryer and the husk supply rate for each trial.

To calculate the input calories, we measured the

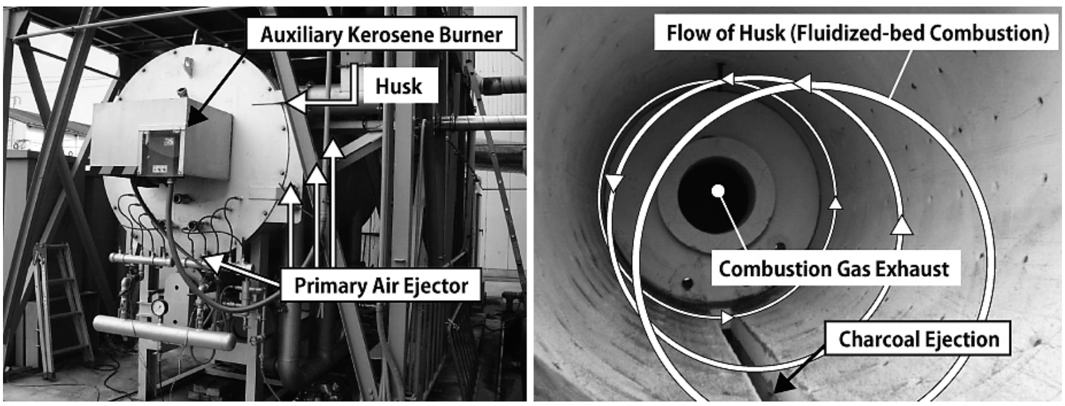

Fig. 1. Husk furnace
Left: External appearance, Right: Inside of furnace.

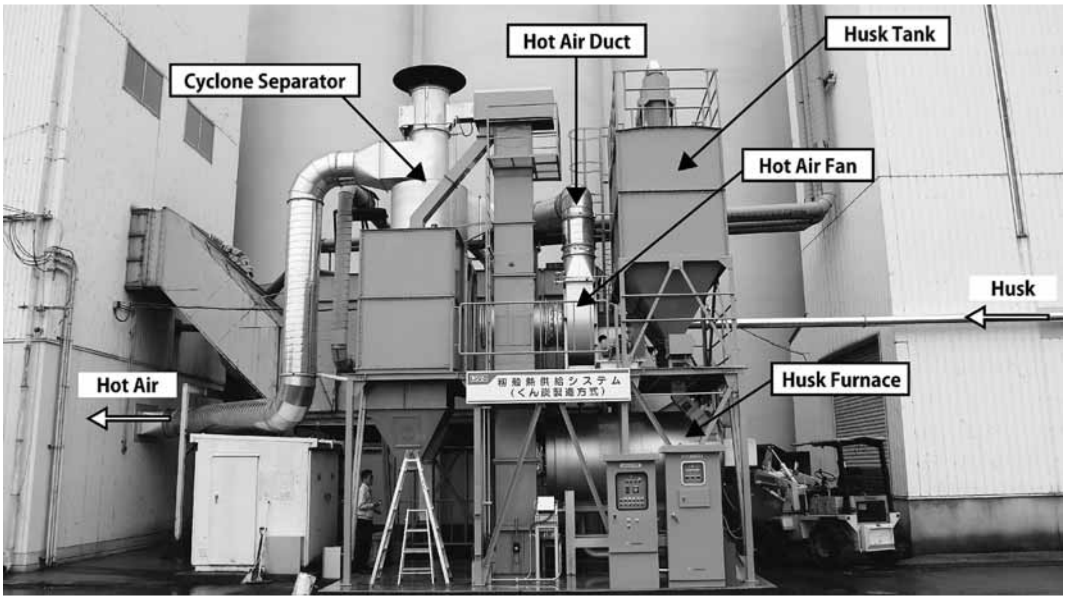

Fig. 2. Husk burner system

amount of husk supplied to the HB. To calculate the output calories, we measured the dry-bulb temperature, ambient temperature, absolute humidity, and airflow at the hot air duct and the air inlet of the grain dryer. The following formula was used to calculate the calories and thermal efficiency:

$$\eta = Q_{out}/Q_{in}\times 100 \quad \cdots(1)$$

$$Q_{in} = H_1\times A \quad \cdots(2)$$

$$Q_{out} = (i_1-i_2)\times V/(v\times 3.6) \quad \cdots(3)$$

$$i_{(1,2)} = Cp\times T+2501\times x \quad \cdots(4)$$

$$Cp = 1.005+1.846\times x \quad \cdots(5)$$

$$v = 0.004554\times(x+0.622)\times(T+273.15) \quad \cdots(6)$$

$$x = 0.00622\times\phi\times Ps/(H-0.01\times\phi\times Ps) \quad \cdots(7)$$

$$Ps = \exp\{11.97-3997.3/(T+234)\}/H \quad \cdots(8)$$

where η = thermal efficiency [%],

Q_{in} = the input calorie [MJ/h]

Q_{out} = the output calorie at the measurement point [MJ/h],

H_1 = low heat value of husk = 15.07 [MJ/kg][8],

A = the husk supply rate [kg/h],

i_1 = specific enthalpy of the measurement point air [kJ/kg],

i_2 = specific enthalpy of the ambient air [kJ/kg],

V = airflow[m^3/s]

Table 1. Main specifications of the husk burner system

Type		YBM-60
Husk Furnace	Model No.	HA-60
	Method	Fluidized Bed Combustion
	Type	Horizontal Type
	Generation Heat Amount	2562 MJ/ h
	Required Power	4.9 kW
Hot Air Fan	Method	Centrifugal Fans
	Airflow	0.08 m^3/s
	Required Power	1.5 kW
Husk Storage	Capacity	8.3 m^3
Cyclone	Diameter	Φ1450
	Equipment	Variable Airflow Damper
	Required Power	0.1 kW
Equipment for Carbonized Rice Husks	Storage Capacity	5.0 m^3
	Bucket Elevator	8.2 m, 1.5 kW
	Relay Conveyer	Φ90, 0.4 kW
	Cooling System	Water Spray

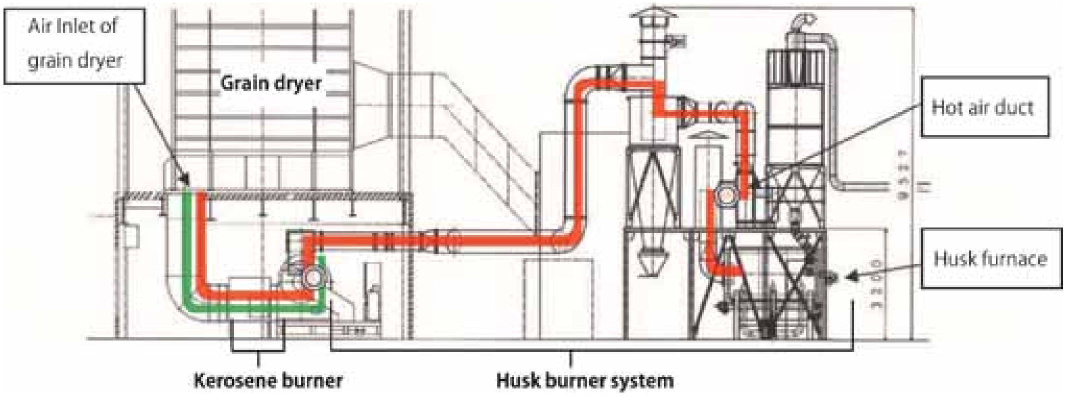

Fig. 3. Layout of the husk burner system,kerosene burner and grain dryer
: Airflow from husk burner system, : Airfrow from kerosene burner,
← : Measurement points of the combustion test, ◎ : Outside air inlet.

v = specific volume [m^3/kg]

Cp = constant pressure specific heat [m^3/kg],

T = dry−bulb temperature [°C],

x = absolute humidity [kg-H_2O/kg],

ϕ = relative humidity [%RH],

Ps = saturated vapor pressure [kPa], and

H = standard atmosphere = 101.325 [kPa].

We conducted the combustion test after the husk furnace condition had stabilized. We also measured the time, kerosene consumption, and electricity consumption required from ignition to the stable stage at the first trial.

(2) Grain drying test

We conducted a grain drying test using the HB and compared it with a conventional system using the KB. The grains used for the test were paddy and wheat. The test conditions are detailed in Table 2. The paddy and wheat drying operations using the KB were in line with conventional means except for the drying and tempering cycle at the continuous-flow grain dryer. It was set up as follows: 1) once the grain had passed through the dryer, it was conveyed to the storage bin and the tempering process started, 2) after all the grain had passed through the dryer, it was reconveyed to the dryer and the drying process restarted. To adjust the hot air temperature of the dryer with the HB to that with the KB, we adjusted the HB husk supply rate to 154.0 kg/h for the rice drying test, and 141.5 kg/h for the wheat drying test.

We calculated the drying rate by measuring the moisture content change, the energy required from the kerosene consumption, and the electricity consumption required for grain drying. In the test section using the HB, we also measured the husk and electricity consumption of the HB and added that of the grain dryer. The caloric value of the kerosene was 34.5 MJ/L, and the electricity was 3.60 MJ/kWh.

In addition, we calculated CO_2 emissions by multiplying the CO_2 emission coefficient of kerosene and electricity by the energy consumption. In the test section using the HB, we assumed that the CO_2 emission from husk combustion was 0 kg because we could consider rice husk a carbon-neutral material.

Based on these calculations, we eliminated the kerosene, electricity, and husk consumption required until the HB stabilized since the grain drying test was done after this point.

(3) Grain quality test

We conducted quality tests for both rice and wheat

Table 2. Grain drying test conditions

Test Section Name	Testing Date	Grain	Amount of Processing (t)	Moisture Content (%w.b.)
HB-Rice1	08’ 10/23-24	Rice *“Nihonbare”*	24.4	22.9
HB-Rice2	08’ 10/28-30	〃	20.7	20.9
KB-Rice	08’ 10/25-26	〃	25.0	19.9
HB-Wheat	09’ 6/23	Wheat *“Norin 61”*	30.1	14.9
KB-Wheat	09’ 6/25	〃	29.5	14.6

Table 3. Thermal efficiency test results

Test Condition		Preset temperature = 35°C Husk supply rate =154.0 kg/h				Preset temperature = 40°C Husk supply rate =154.0kg/h				Preset temperature = 50°C Husk supply rate =141.5 kg/h			
Measurement Point		Ambient	Husk furnace	Hot air duct	Air Inlet of grain dryer	Ambient	Husk furnace	Hot air duct	Air Inlet of grain dryer	Ambient	Husk furnace	Hot air duct	Air Inlet of grain dryer
Test Results	Dry-bulb temperature (°C)	16.2	738	159	34.7	21.6	738	176	38.9	27.2	782	172	51.5
	Relative humidity (%RH)	87.9	−	0.3	29.2	74.1	−	0.2	27.4	56.8	−	0.2	27.4
	Airflow (m^3/s)	−	−	4.95	26.5	−	−	4.95	29.3	−	−	4.58	20.0
	Specific Enthalpy (kJ/kg)	41.8	−	188	60.7	47.1	−	205	64.9	60.0	−	209	84.8
	Calorie (MJ/h)	−	2321	2091	2041	−	2321	2181	2087	−	2132	1914	1904
	Thermal efficiency (%)	−	100	90.1	87.9	−	100	94	89.9	−	100	89.8	89.3

after the drying test. For rice, we checked the cracking ratio, germination, and palatability of the milled rice based on six criteria (appearance, flavor, taste, viscosity, hardness, and overall eating quality)[3]. For wheat, we checked both the grain and flour quality.

In addition, we analyzed the odor of the dried wheat using a Fragrance and Flavor Analyzer (FF-2A, Shimadzu Co., Ltd.). The FF-2A has 10 sensors to numerically measure the strength and quality of an odor, using a scale corresponding to the human sense. The strength of an odor can be represented by an odor index equivalent to that established under the Offensive Odor Control Law, while the quality of an odor is measured by the 9 categories defined by Shimadzu. We put the grain (20 g) into the sampling bag (2L) and filled the bag with N2 gas. We then placed the bag into the incubator set at 30°C for 3 hours to capture the odor of dried wheat into the gas. We used the gas for the odor analysis.

Results and discussion

1. Combustion test

The combustion began to stabilize 3 hours from ignition, by which point 42 kWh of electric power and 49 L of kerosene had been consumed.

Table 3 presents the results of the thermal efficiency measurement. Based on the amount of supplied husk, 141.5 to 154.0 kg/h, the input calories were estimated at 2132 to 2321 MJ/h.

At the hot air duct, the air temperature decreased from more than 700°C to less than 200°C. Although we did not measure it, the airflow likely increased compared to that of the HB due to the mixing of the furnace and ambient air. The energy at that point ranged from 1914 to 2181 MJ/h, with observed heat loss at the hot air fan of 6 to 10%.

At the air inlet of the grain dryer, the temperature was close to the preset temperature, which is adequate for grain drying despite the air volume increasing.

The output energy that we could supply to the grain dryer ranged from 1904 to 2087 MJ/h, representing 88 to 90% of available energy in this system.

2. Grain drying test

Table 4 presents the results of the paddy drying test. The hot air temperatures of the dryer with the HB, HB-Rice1 and HB-Rice2, ranged from 35.0 to 38.9°C, namely 17.0 to 17.3°C higher than the ambient temperature and almost equivalent to that of the conventional section, KB-Rice. The airflow rate was also almost equivalent to that of the conventional section. Therefore, the calories from the HB system, which were mostly dependent on the husk supply rate and the stability of the combustion state, were properly adjusted.

Consequently, the mean drying rates were 0.69%/h for HB-Rice1 and 0.62%/h for HB-Rice2. Indeed, the HBs worked appropriately without a decrease in the mean drying rate.

As for the drying efficiency, HB-Rice1 used 12.8 MJ/kg-H_2O and HB-Rice2 used 16.8 MJ/kg-H_2O, whereas KB-Rice used 12.0 MJ/kg-H_2O. Those values seemed high compared to those written in past reports[2]. This was due to test methods whereby the tempering time of the grain was slightly shorter than in conventional operation. When the HB sections were compared to the KB-Rice, the energy efficiency of the former was generally worse than the latter. This is considered attributable to the following: 1) the thermal efficiency of the HB was lower than that of the KB, and 2) more electricity was needed to operate the HB than the KB.

Although the energy of the HB sections required for grain drying was higher than for KB-Rice, the ratio of husk combustion to energy efficiency was 92%. In

Table 4. Paddy drying test results

Test Section			HB-Rice1	HB-Rice2	KB-Rice
Test Conditions	Grain Weight	Before (t)	24.4	20.7	25.0
		After (t)	22.0	19.2	23.7
	Moisture Content of Grain	Before (%w.b.)	22.8	20.9	19.9
		After (%w.b.)	14.5	14.8	15.4
	Ambient Temperature (°C)		21.6	15.5	20.3
	Ambient Relative Humidity (%RH)		74.1	91.4	81.1
	Hot Air Temperature(°C)		38.9	35.0	37.3
	Airflow Rate (m^3/s•t)		1.83	1.65	1.78
Test Result	Drying Rate (%/h)		0.69	0.62	0.57
	Kerosene Consumption (L)		0	0	429
	Electricity Consumption (kWh)		686	561	327
	Husk Consumption (kg)		1851	1514	−
	Energy Efficiency (MJ/kg-H_20)		12.8	16.8	12.0
	Ratio of Husk Combustion to Energy Efficiency (%)		92.0	92.1	−
	Total CO_2 Emission (kg)		246	201	1190
	CO_2 Emission from 1kg of Moisture Extraction (kg/kg-H_2O)		0.104	0.136	0.896
		Ratio of HB/KB (%)	11.6	15.2	100

Table 5. Wheat drying test results

Test Section			HB-Wheat	KB-Wheat
Test Conditions	Grain Weight	Before (t)	30.1	29.5
		After (t)	28.8	28.4
	Moisture Content of Grain	Before (%w.b.)	14.9	14.6
		After (%w.b.)	11.2	11.4
	Ambient Temperature (°C)		26.6	26.5
	Ambient Relative Humidity (%RH)		63.4	63.0
	Hot Air Temperature (°C)		49.2	52.7
	Airflow Rate (m^3/s・t)		1.02	1.02
Test Results	Drying Rate (%/h)		0.49	0.60
	Kerosene Consumption (L)		0	315
	Electricity Consumption (kWh)		368	191
	Husk Consumption (kg)		1061	0
	Energy Efficiency (MJ/kg-H_20)		13.8	10.8
	Ratio of Husk Combustion to Energy Efficiency (%)		92.4	−
	Total CO_2 Emission (kg)		132	856
	CO_2 Emission from 1kg of Moisture Extraction (kg/kg-H_2O)		0.105	0.804
		Ratio of HB/KB (%)	13.1	100.0

Table 6. Paddy quality test results

Test Section	Increasing Cracking Ratio (%)	Germination Rate[2)] (%)	Palatability Test[1)]					
			Overall Eating Quality[2)]	Appearance	Flavor	Taste	Viscosity	Hardness
HB-Rice1	0.0	98.5	0.05	0.00	−0.10	0.15	0.30	−0.25
HB-Rice2	0.0	99.5	0.00	−0.05	0.10	0.05	−0.05	0.00
KB-Rice	0.2	100	0	0	0	0	0	0

1): KB-Rice is set as the standard
2): *,**,*** show significant levels at 5, 1, and 0.1% respectively.

Table 7. Wheat quality test results

Test Section	Wheat and Milling Test				
	Volume Weight (g/L)	Moisture Content (%W.B.)	Protein Content (%D.M.)	Ash Content (%D.M.)	Yield Ratio in Laboratory Milling (%)
HB-Wheat	820	11.8	8.6	1.7	63.4
KB-Wheat	838	11.9	9.1	1.7	66.1

Test Section	Flour and Dough Test (60% Flour)								
	Moisture Content (%W.B.)	Protein Content (%D.M.)	Ash Content (%D.M.)	Color Grade Value (C.G.V.)	Amylograph	Falling Number	Farinograph		
					Peak Viscosity (B.U.)		Absorption (%)	Valorimeter Value (W)	Weakness (B.U.)
HB-Wheat	14.4	7.6	0.4	−1.85	850	359	54.7	44	80
KB-Wheat	14.1	8.1	0.4	−2.37	850	365	55.7	50	70

other words, the HB could convert most of the energy consumed for grain drying. In terms of CO_2 emission from 1kg of moisture extraction, HB-Rice1 (HB-Rice2) emitted only 11.6% (15.2%) of CO_2 emission for KB-Rice.

Table 5 presents the wheat drying test results, which were generally similar to those of the paddy drying test. The temperature and airflow were controlled appropriately, the drying rate was almost equivalent, the energy consumption was slightly higher, although 92% was from husk combustion, and CO_2 emission was only 13.1% of that of the conventional system.

Therefore, we conclude that a system using heat from the HB for grain drying has considerable potential to reduce the environmental load resulting from fossil-fuel consumption.

3. Grain quality test

Table 6 lists the results of the paddy quality test. Both the increasing cracking ratio and the germination rate indicate the dryer's performance, since cracked grain and decreased germination may be caused by high temperatures during the drying stage[3]. We confirmed that the hot air from the HB was appropriately controlled, based on no increase in the cracking ratio and no drop in the germination rate. Since no significant differences in the palatability test were observed between the HB sections and KB-Rice, we confirmed that no adverse influence occurred in terms of eating quality when the grain was dried by the HB.

Table 7 lists the results of the wheat quality test. Based on the wheat and milling test, we could not confirm any major difference between the samples, although the volume weight and yield ratio index varied slightly. In fact, the flour and dough test results indicated no major difference in any measurement item, such as falling number and peak viscosity in the amylograph measurement (which could measure flour starch

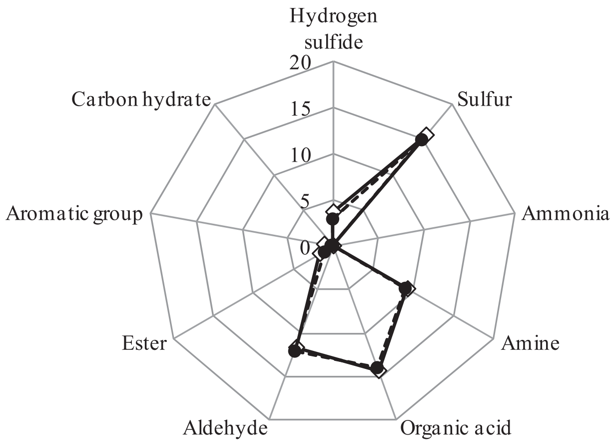

Fig. 4. Test results of odor analysis of dried wheat
Each axis depicts the value of the odor index projected to standard gases of smell. Superscript notation *,**,*** at each axis shows significant levels at 5, 1, and 0.1% respectively.
—◇— : HB-Wheat, --●-- : KB-Wheat

properties and enzyme activity[6]), and absorption and valorimeter value in the farinograph measurement (which could evaluate the effects of the ingredients on mixing properties[6]).

Figure 4 presents the results of an odor analysis of dried wheat. No significant difference was found between the wheat dried by the HB and that dried by the KB.

In this study, no influence on paddy or wheat quality was observed when we used the direct combustion type of HB.

Conclusion

We designed the layout of the HB and grain dryer to utilize the exhaust heat from the HB for grain drying. The test results were as follows:

1) The thermal efficiency of the direct combustion type HB was high, and 88 to 90% of the energy from husk combustion was available for grain drying.

2) The drying performance could be properly controlled, and the quality of rice and wheat was very similar to those dried using a KB.

3) The CO_2 emission required for grain drying was approximately 85 to 90% lower than that of a conventional system using a KB because we could consider rice husk a carbon-neutral material.

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