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Using the Waste Heat of a Combustion Engine in Deep Bed Drying of Paddy in Rural Areas of Non-Industrialized Countries

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Abstract: A small (≈1.6 kW) engine powered flat deep-bed rough rice dryer of dimension (0.9×0.9×1.1 m) was designed and constructed on the basis of measured engine waste heat released from the cooling system of the engine. The performance of the dryer was analyzed in drying a 100 cm deep bed of freshly harvested rough rice bulk amounting 480 kg of grain. The engine-waste heat was sufficient to increase the drying air temperature 7 to 23 ^{0}C at an air flow rate of 12.6 to 1.2 kg/min. The engine here acts as sources of energy both for heats up the drying air and the air moving device (fan) of the dryer. The energy requirement was 3.15 MJ/kg of water removed form the grain in 22 hrs in two passes (12 h +10 h) with 12 h tempering between the passes. A seventy to eighty centimeter deep grain bed seems to be optimum in order to avoid over-drying in the bottom and under-drying in the top layers at an engine speed of 3,600 rpm. The small engine and its waste heat can be used as a source of energy for low temperature drying of farm crops, especially rough rice, in non-industrialized countries, like Bangladesh where still 100% grain is sun dried by rural farmers.

Key words: engine waste heat, rough rice, dryer, drying energy.

INTRODUCTION

Rough rice is ordinarily harvested at moisture contents above safe storage levels, with a normal range from 18 to 30 % ((wet-basis)). The excess moisture, therefore, must be removed by some drying process within 48 hours of harvesting, mainly to improve the storability of the grain. Rough rice drying in non-industrialized countries like Bangladesh is commonly achieved by spreading it on beaten earth or mats directly exposed to solar radiation. Considerable losses, from 10% to 25% can often occur (Excell, 1980). Accurate scheduling of farm operations and efficient use of land, labor, machinery, and other resources can not be coordinated well with the sun drying method due to weather uncertainty. The natural sun drying of a high moisture paddy requires little capital cost, but there is a high labor cost in keeping the grain turned regularly and protecting it from wet weather. Most of the farmers in non-industrialized countries operate on a small scale and can not afford sophisticated mechanically powered drying systems. An intermediate solution, that takes advantage of the availability of small engines used for irrigation and rice milling purposes, is the engine-waste heated grain dryer.

Abe et al. (1992) reported a preliminary study on utilization of engine-waste heat for grain drying with a dryer capacity of 140 kg of rough rice. They used a separate power source to drive the dryer fan which was a serious drawback of their work.

Basunia and Abe (1997) reported the performance of the engine-waste heated rough rice dryer with shallow depth of grain beds. This time fan was directly coupled with the engine camshaft. The present study was therefore conducted to analysis the performance of the dryer in drying a 100 cm deep of paddy using engine waste heat at an engine speed of 3,600 rpm.

MATERIALS and METHODS

Figure 1 is a schematic diagram of the drying apparatus used for the experiment. An air cooled four-stroke cycle gasoline engine with displacement of 105 cc, 1.43 kW at 3,000 rpm and 1.85 kW in maximum at 4,200 rpm, 0.34 kg/(kW·h) of fuel consumption and a cooling efficiency of 30% was used. A backward curve centrifugal fan with a maximum air flow rate of 17 m^3/min and static pressure of 260 Pa was directly coupled with the engine camshaft. A PVC pipe, with 125 mm diameter and 1225 mm long, connects the fan housing with the lower part of the gradually expanding plenum chamber via a 90 degree elbow. The upper part of the plenum chamber, 90 cm square, was attached to the lower part of the dryer. The experimental drying chamber was an open-ended plywood box 90 × 90 cm in cross section and 110 cm deep (Fig. 1). A wire screen through which air but not rough rice would pass, was used as the dryer bed supported by a mild steel rod net to hold the grain mass. The waste heat from the engine heats up the air being forced through the duct to the dryer. The performance of the engine-fan combination at different rpm was studied before test with rough rice by controlling the opening of the straight duct. So the engine with straight portion of the duct system was separated from the remaining part of the dryer. The test was conducted with a 100 cm depth of grain bed amounting 480 kg of rough rice. The drying air was supplied in two passes (12 h +10 h) with 12 hour overnight tempering between the two passes.

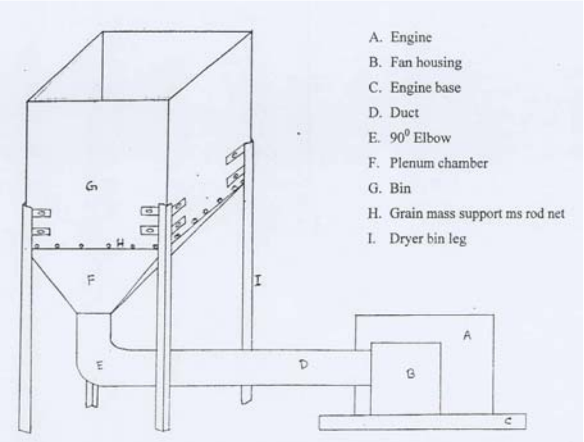

Figure 1. Schematic diagram of the drying apparatus used for the experiment

Moisture content was measured at hourly interval during the continuous application of engine-waste heat. The average moisture content of the entire grain bed was an average of moisture readings from the top, middle and bottom layers.

The moisture content was checked by a single grain moisture meter before drying terminated. The engine was stopped when the average moisture content of the grain bed was found to be approximately 16.5% ((wet-basis)). Finally, the moisture content was confirmed by the oven drying method, according to the standard procedure of the Japanese Society of Agricultural Machinery. After the drying was terminated, the grain was left in the dryer undisturbed for about 15 h. Temperatures were recorded at different locations of the dryer using thermocouples with drying period at an interval of 15 minutes by running a basic program. Air flow rates were also monitored by inserting manometer tubes at the end of the straight duct to avoid the turbulent of air flow.

RESULTS and DISCUSSION

The performance of the engine-fan combination has shown in table 1. The waste heat energy released from the engine cooling system and heat energy received by the drying air were calculated from standard equations. It was observed that within the range of 1.21 to 12.57 kg/min of air flow, engine-waste heat was sufficient to increase the drying air temperature 22.6 to 6.8, while the average temperature and relative humidity of ambient air were 26.7 and 71.1%. It can be observed from Table 1 that about 90% of the waste heat released from the engine cooling system was transmitted to the drying air at 3,600 rpm of the engine. It was observed that drying air temperature varies with the ambient temperature at the same air flow rate but the difference between them remain almost constant from the morning to evening (Fig. 2). The engine-waste heat was applied continuously for 12 h in the first pass to reduce the moisture content of 480 kg of paddy from 21.9% to 19.1.% (wet-basis) followed by a 12 h overnight tempering. The grain was left in the dryer undisturbed during the tempering period.

In the second pass, the engine-waste heat was applied continuously for 10 h to reduce the moisture level to approximately 16.5% (wet-basis). Results showed that the total drying time required to reduce the average moisture content to

16.5% (wet-basis) from the initial 21.9% moisture content (wet-basis) was 34 h.

Table 1 Performance of the engine-fan combination at an engine speed of 3,600 rpm (ambient temperature 26.7^{0}C, relative humidity 71.1% and energy released from cooing system was 5.81 MJ/h)

Air flow (kg/min)	Drying air tem. (^{0}C)	Rise of ambient air tem. (^{0}C)	Energy of the drying air MJ/h)	Effici-ency (%)
1.21	49.1	22.6	1.65	28.25
2.20	46.9	20.9	2.78	47.84
2.95	45.0	18.7	3.33	57.31
4.40	43.7	16.4	4.36	75.04
6.89	38.5	12.1	5.04	86.75
7.74	38.0	11.2	5.24	90.15
9.08	36.7	9.5	5.21	89.67
10.68	34.7	8.1	5.23	90.01
12.57	33.4	6.8	5.16	88.81

But the actual engine operation time was 22 h. The moisture gradients between the top (18.3%) and bottom (9.0%) layers were 9.3% (wet-basis) at the end of drying. Undisturbed, continuous air flow, fixed bed drying has an inherent problem of over-drying where the drying air is introduced, particularly with higher air temperatures which tend to lower the moisture content below the desired 13% (wet-basis) (Angladette, 1963). But in an engine-waste heated dryer, the maximum average temperatures was only 36.7^{0}C while the average ambient temperature for the whole day was 23.5^{0}C. The whole dried grain was mixed thoroughly and stored in paper bags, commonly used by Japanese farmers, for 48 h.

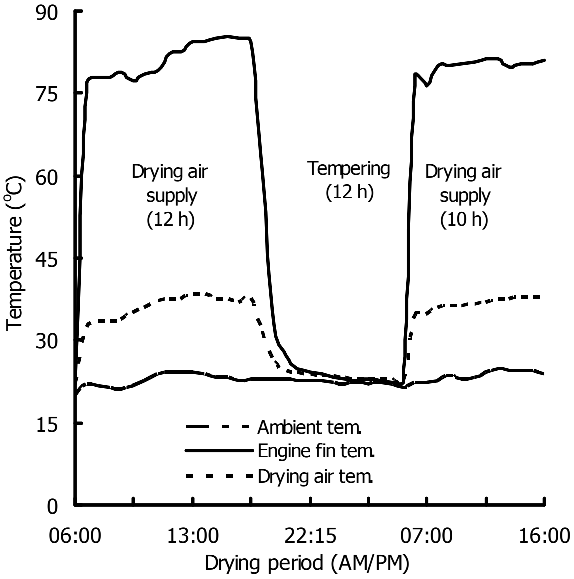

Figure 2. Variations of ambient air, drying air and engine fin temperatures with the drying time including 12 hours tempering (Engine speed = 3600 rpm, depth of grain = 100 cm).

The grain was then milled. The sample of milled rice was inspected for cracking, no cracked kernel was observed in the sample inspected. If a 5 to 7% moisture difference between the top and bottom layers is considered acceptable then a 70 to 80 centimeter depth of grain bed seems to be optimum at an engine speed of 3,600 rpm. The average moisture content of the entire grain bed determined immediately after stopping the engine was 1.5 to 2% more than the moisture content determined after 15 h. This indicates that it is better to under-dry the grain by 1.5 to 2% moisture content (wet-basis) than the safe moisture level for storage and to leave the grain in the dryer undisturbed for few hours to avoid over-drying in the bottom layer. The energy requirement was 3.15 MJ/kg of water removed in drying a 100 cm depth of grain bed which was lower than the average energy requirement of 3.5 MJ/kg (Sharp, 1982) of a highly efficient mechanical dryer. In principle, a low temperature dryer, by using the moisture absorbing capacity slightly over the ambient air, may require less energy than the latent heat of water vaporization (2.5 MJ/kg) to remove moisture from the grains. The waste heat from the engine of power range 0.75 to 7.7 kW, with dryer base area of 0.35 to 3.8 m^2 and air flow rate of 2.5 to 26 m^3/min, can dry about 150 to 1500 kg of rough rice from 23% to 15% moisture content. (wet-basis) in 22 h at an average ambient temperature and relative humidity of 25 and 90%, respectively.

CONCLUSIONS

About 90% of the energy released from the cooling system is possible to harvest. The energy requirement was 3.15 MJ/kg of water removed from the moist grain in a rainy day while the average relative humidity of the ambient air was above 90%. A seventy to eighty centimeter depth of grain bed seems to be optimum in order to avoid the over-drying in the bottom layer and under-drying in the top layer.

Results have shown promise for this type of grain drying unit, especially in the major rice growing regions where the engine used for pumping irrigation water and rice milling purposes can also be used for grain drying. The 30 to 50^0C drying air temperature can be attained under most tropical conditions with waste- engine heat, thus no additional capital investment nor operating cost is necessary for the supplemental heating of drying air. The use of this flat-bed dryer, in rural areas where electricity is not available, should then encourage the harvesting of improved rice varieties with field moisture contents as high as 24% (wet-basis) to minimize harvest shatter losses.

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