Performance Study of a Small Engine Waste Heated Bin Dryer in Deep Bed Drying of Paddy

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ABSTRACT

Research into minimizing post harvest losses and the effective utilization of available energy resources for the rural farmers has led to the idea to use small engine and its waste heat in drying of farm crops in the rural areas. An small engine (≈ 1.6 kW) powered flat deep-bed rough rice dryer was designed and constructed with dimension 900 × 900 ×1100 mm on the basis of available harvested engine waste. A part of the engine brake power was used to rotate the dryer fan directly coupled with the engine camshaft which harvest the engine waste heat released from the cooling system to heat up the drying air. The no-load test showed that engine-waste heat was sufficient to increase the drying air temperature 7 to 22^{0}C at an air flow rate of 12.6 to 1.2 kg/min, while the average ambient temperature and relative humidity were 26.7 and 71.1%. The energy requirement was 3.15 MJ/kg of water removed in drying a 100 cm deep grain bed in 22 h in two passes (12 h +10 h) with 12 h tempering overnight between the passes. The drying capacity of the dryer was approximately 22 kg/h (480 kg per batch) of rough rice, while the average ambient temperature and relative humidity were 23.5 and 91% (rainy day). 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. Result have shown promise for this type of grain drying unit especially in major rice growing regions where the same engines which are used for pumping irrigation water and rice milling purposes.

Key words: Engine, waste heat, rough rice, dryer, drying, energy

1. INTRODUCTION

Rough rice is ordinarily harvested at moisture contents above safe storage levels, with a normal range from 18 to 30 % (w.b.). Sometimes it is even higher when rice is harvested in wet weather. Unfortunately, the latter case seems to happen quite frequently in Bangladesh and in other rice producing non-industrialized countries. The excess moisture, therefore, must be immediately removed by some drying process, mainly to improve the storability of the grain. Proper drying of freshly harvested paddy is necessary to maintain grain quality and minimize spoilage losses. In tropical areas, humid weather makes the stored rice more susceptible to organisms and mold, especially when the grain moisture exceeds a high level. Many experiments showed that when initial rice moisture content after harvesting is 24 % or above, drying must start within 24 hours, with 21 to 23% within 48 hours, and with 18 to 20.9 % within three days. In order to avoid the danger of deterioration, the drying operation should be carried out as soon as possible. Drying may be achieved by either the sun or a mechanical drying method.

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. Multiple cropping in the tropics with improved rice varieties forces some harvesting to be done during the wet rainy season when sun drying is not possible. Using the sun drying, there is no guarantee on the final quality of dried rice. This method is slow and susceptible to rainfall, birds, insects, dust and other contamination. Spoilage may also result from occasional rains. 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. Even then, kernel checking and breaking is a serious set back. This unfavorable climate condition dictates the need for a more effective method of drying grain.

Most of the farmers in Bangladesh 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. These huge numbers of small engines are normally used only 30-60 days in a year for irrigation purpose and the rest of the part of the year remain idle.

Many researchers and reports (Ajab and Akingbehin, 2002; Haywood, 1988; Ishil and Takeuchi, 1987; I.S.I., 1980; Ramesh and Sampathraja, 2008; Yuan et al., 2004) mentioned that roughly 30% energy of the burnt fuel is lost though the exhaust system and roughly 30% is lost through the cooling system of the internal combustion engine. These waste energies could be used properly for drying of agricultural products.

An attempt was made for the utilization of engine-waste heat for grain drying with a small dryer bed area and grain depth (Soemangat et al., 1973). They concluded that the energy requirement for grain drying can be minimized with the use of a large bed area, low air temperature and low air velocity.

Abe et al. (1992) reported a preliminary study on the utilization of engine-waste heat for grain drying with a dryer capacity of 140 kg of rough rice. They conducted a single test and less kernel breakage was found than rice dried in the sun or dried too rapidly with high temperature air. They used a separate power source (electric motor) to drive the dryer fan which was a serious drawback of their work. This forced them to cover the whole engine with extra housing which is difficult to make and handle and, therefore, impractical.

Basunia et al. (1996a, 1997) reported the simulation result of the engine-waste heated rough rice dryer for a shallow depth of grain beds (10 - 40 cm) and validated the accuracy of the partial differential equation model (PDE) in low temperature drying of rough rice using engine waste heat. This time fan was directly coupled with the engine camshaft without any extra covering for the whole engine. Basunia and Abe (1996b) also reported the energy saving in intermittent drying of shallow depth (10-40 cm) of grain bed using engine waste heat. They concluded that further study should be carried out with a greater depth of rough rice.

2.1 Objectives

The present study was conducted with the following objectives:

(i) To measure the availability of engine-waste heat at high speed which can be utilized for grain drying; and
(ii) To analyze the performance of the engine waste heated bin dryer in drying a 100 cm depth of grain bed on rainy days.

2. MATERIALS AND METHODS

2.1 Engine-Fan Combination and Dryer Duct System

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 was used for this study. The specific fuel consumption of the engine was 0.34 kg/(kW·h) and the cooling efficiency was 30%. A turbo (sirocco) fan with a maximum air flow rate of 17 m^3/min and static pressure of 260 Pa at a maximum speed of 2,200 rpm 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 (Fig. 1). The waste heat from the engine heats up the air being forced through the duct system to the dryer. The experimental drying chamber was an open-ended plywood box 900 × 900 mm in cross section and 1100 mm deep. A wire screen through which air but not rough rice would pass, was used as the dryer bed. The wire screen was supported by a mild steel rod net to hold the grain mass. The upper part of the plenum chamber, 90 cm square, was attached to the lower part of the dryer. The duct and fan housing were properly insulated so that no heat could be lost by conduction.

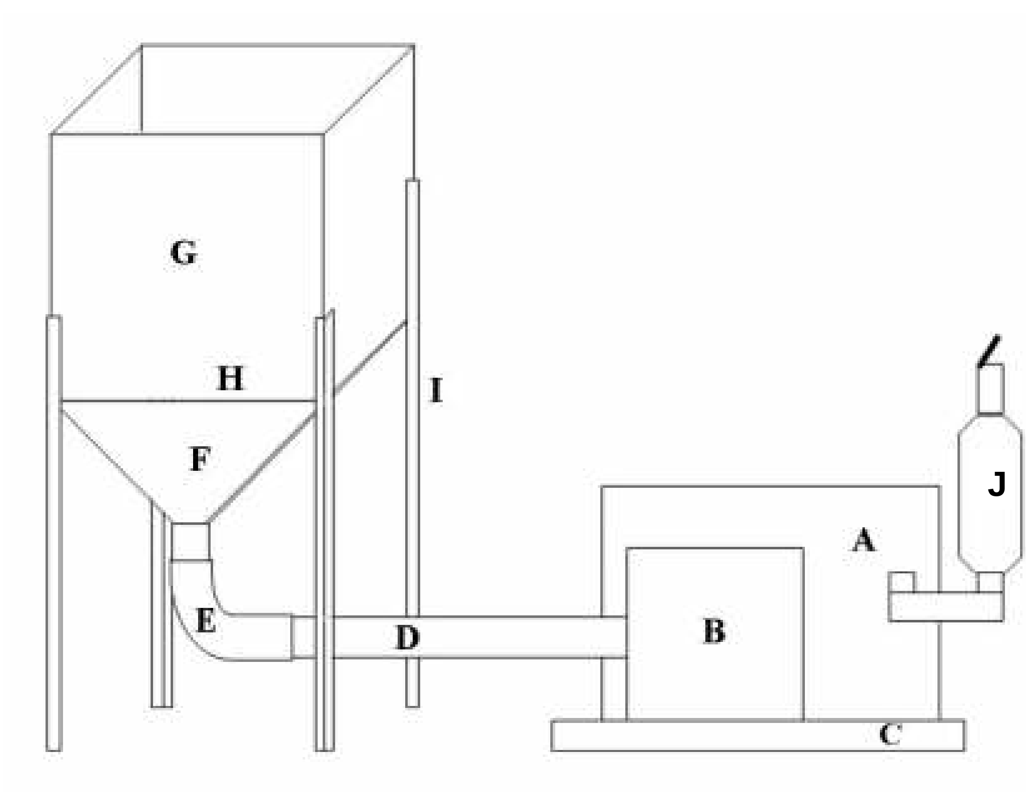

Figure 1. Schematic diagram of the drying apparatus, duct system and engine-fan

combination (**A**. Engine, **B.** Fan housing, **C.** Engine base, **D.** Duct, **E.** Elbow, **F.** Plenum chamber, **G.** Bin to hold grain, **H.** Grain mass support MS rod net, **I.** Dryer bin leg and **J.** Exhaust pipe)

2.2 Measurement of Temperature, Air Flow and Moisture Content

The drying air temperatures at different air flow rates was monitored using copper constantan thermocouples connected to the end of the straight duct, and at three locations at the entrance of the dryer base (Fig. 1). Three thermocouples were connected within the grain bed, each at bottom, middle and top layers through the center of the grain bed. Two thermocouples were connected to the engine fin surfaces to determine fin's temperature at different air flow rates. Two thermocouples were also used to record the ambient dry-bulb and wet-bulb temperatures. Thermocouples were connected through an interface of an AD converter (Green kit 77A model) then to a personal computer for data collection using a BASIC program. The temperature readings from the thermocouples were recorded every 5 min. The thermocouples used for measuring temperatures had an accuracy of $\pm$ 0.5 ^{0}C.

The air flow rates of the drying air were measured by a pitot tube and a glass tubes manometer. One of the tube, 90 degree bent, was inserted at the center of the straight duct keeping one of it's opening opposite to the direction of air flow to measure the total pressure of the drying air flow. The other one (straight) was inserted in such way so that one of it's opening was with the same surface of the inner wall of the straight duct to measure the static pressure of the drying air flow. The other opening ends of the pitot tube were connected to the glass tubes of the manometer by plastic tubes. The pitot tube was inserted 100 cm apart from the fan housing to avoid the turbulent of air flow during measuring by making holes on the surface of the straight duct. One of the glass tubes of the manometer was used to record the atmospheric pressure. Water was used in the manometer. The average velocity pressure of drying air flow was calculated from the difference of the observed average total pressure and the static pressure throughout the drying period. The velocity pressure of the drying air was used to calculate the velocity of the air flow and then air flow rate from the known area of the duct.

After the drying was terminated, the grain was left in the dryer undisturbed for about 15 h. Moisture content was measured at hourly interval during the continuous application of engine-waste heat. Moisture content was measured immediately after stopping air supply using grain samples collected from the top, middle and bottom layers of the grain bed. Grain samples were collected from middle and bottom layers by manual probe and the top layer sample was collected randomly by hand. At each layer, grains were collected from three locations, center, near the wall, and between the wall and the center of the dryer. At each location moisture content was determined individually to determine the moisture gradient across the horizontal direction and then an average was made at each layer. The average moisture content of the entire grain bed was an average of moisture readings from the top, middle and bottom layers. Similarly the moisture content at different layers with drying period and the average moisture content of the entire grain bed were also measured after 15 h of stopping air supply. 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% (w.b.). Finally, the moisture content was confirmed by the oven drying method, according to the standard procedure of the Japanese Society of Agricultural Machinery. Medium grain (Japonica type) rough rice was used for the experimental studies. It was obtained at an average moisture content of 21.9% w.b. and was stored at a low temperature at this moisture level in a cooler for the drying test.

2.3 Engine-waste Heat

Present gasoline fed internal combustion engines are about 30% effective in output from the energy derived from burnt fuel, another 30% is lost through the exhaust, radiation, friction accounts for 10%, and the remaining 30% is lost through the cooling system. The heat energy required to heat up the drying air is mostly derived from the engine cooling system heat loss. The cooling load W_c of the engine at any given rpm can be determined by the following equation

$$W_c = \eta_c \cdot \beta \cdot c_f \cdot \eta_f \cdot P_b \tag{1}$$

where, W_c is the waste heat energy released from the engine cooling system to the air, MJ/h; η_c is the cooling system efficiency, decimal; β is the fuel consumption rate, kg/(kW·h); c_f is the calorific value of fuel, MJ/kg; η_f is the fuel efficiency, decimal and P_b is the break power of the engine at any rpm, kW. Substitution of the values of the different parameters in equation (1) for the engine used in this experiment led to the following equation:

$$W_c = 3.5006\, P_b \tag{2}$$

The total heat energy W_r to be utilized to heat the drying air at any given rpm of the engine is calculated from the following equation

$$W_r = 0.06 \cdot Q \cdot c \cdot \rho \cdot \left(t_d - t_a\right) \tag{3}$$

where, W_r is the amount of heat energy received by the drying air, MJ/h; 0.06 is the units conversion factor; Q is the volume flow rate of drying air, m^3/min; c is the specific heat capacity of drying air, kJ/(kg·); ρ is the density of drying air, kg/m^3; t_d and t_a are the temperatures of drying air and ambient air, respectively.

3. RESULTS AND DISCUSSION

3.1 Performance of Engine-Fan Combination

It was observed that drying air temperature varies with the ambient conditions at the same air flow rate and at the same engine speed. A negligible difference was observed between the temperatures measured at the end of the straight duct and at the entrance of the dryer (Fig. 1). Therefore, the average of the temperatures measured at the end of the straight duct for a particular air flow rate was considered as the drying air temperature for that air flow rate and used in the calculation of energy.

The estimated energy released as waste heat from the engine cooling system, measured heat energy received by the drying air and the energy harvesting efficiency of the drying air at different measured air flow rates at 3,600 rpm of the engine are presented in Table 1. The average ambient temperature and relative humidity were 26.7 and 71.1%, respectively. Waste heat energy released from the engine cooling system and the heat energy received by the drying air were calculated from equations (2) and (3), respectively. Heat energy losses due to various causes were estimated to be the difference between the estimated heat energy released by the engine cooling system at a given rpm and the heat energy received by the drying air. The average energy losses are for comparison purposes only and do not imply that the loss rate will remain constant over the period of the drying experiment. Since no instrument was available to directly measure the system energy losses, one can only speculate about the source of these losses. Although the fan housing, duct system and plenum chamber were properly covered with insulating material, it is probably safe to assume that a portion of the heat was absorbed by the air in the heating fan housing, duct and plenum chamber. Engine-waste heat was sufficient to increase the drying air temperature some 6.8 to 22.4 ^{0}C depending on the measured air flow rate. 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. Efficiency seems to be very high, because part of the exhaust energy was also received by the drying air while the fan was in operation. This was not directly due to harvesting of exhaust gases, rather exhaust waste heat energy was received by drying air from the surface of the exhaust passage. So it was not harmful for the grain, rather it was extra benefit to the system. The fan also helps proper cooling of the engine. It was observed that at the same ambient temperature, and engine speed, engine fin temperature was about 30 higher, than the engine running with a fan coupled at the camshaft. This will help to prolong the operating life of the engine.

Table 1. Estimated waste energy released from the engine cooling system and measured heat energy received by the drying air at an engine speed of 3,600 rpm (ambient temperature 26.7, relative humidity 71.1% (Energy released from the cooling system = 5.81 MJ/h)

Air flow rate	Drying air temperature	Drying air temperature rise	Energy received by the drying air	Energy receiving efficiency of the drying air
(kg/min)	(^{0}C)	(^{0}C)	(MJ/h)	(%)
1.21	48.9	22.4	1.64	28.22
1.39	47.4	21.6	1.81	31.15
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
5.57	42.5	13.2	4.44	76.41
6.19	41.8	12.8	4.79	82.44
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
11.57	33.5	7.5	5.24	90.18
12.16	33.2	7.0	5.14	88.46
12.57	33.4	6.8	5.16	88.81

3.2 Dryer Performance

A sample weighing 480 kg rough rice was dried in two passes to reduce the moisture level from 21.9% w.b. to approximately 16.5 % w.b.. In the first pass, the engine-waste heat was applied continuously for 12 h to reduce the moisture content from 21.9% to 19.1.% w.b. followed by a 12 h overnight tempering. The grain was left in the dryer undisturbed during the tempering period by covering it with thick polyethylene sheet so that no moisture would be absorbed form the ambient air or desorbed to the air. In the second pass, the engine-waste heat was applied continuously for 10 h to reduce the moisture level to approximately 16.5% w.b..

Variations of ambient, drying air and engine fins temperatures and the temperatures at the bottom, middle and top layers of the grain bed with the drying periods are shown in Fig. 2.

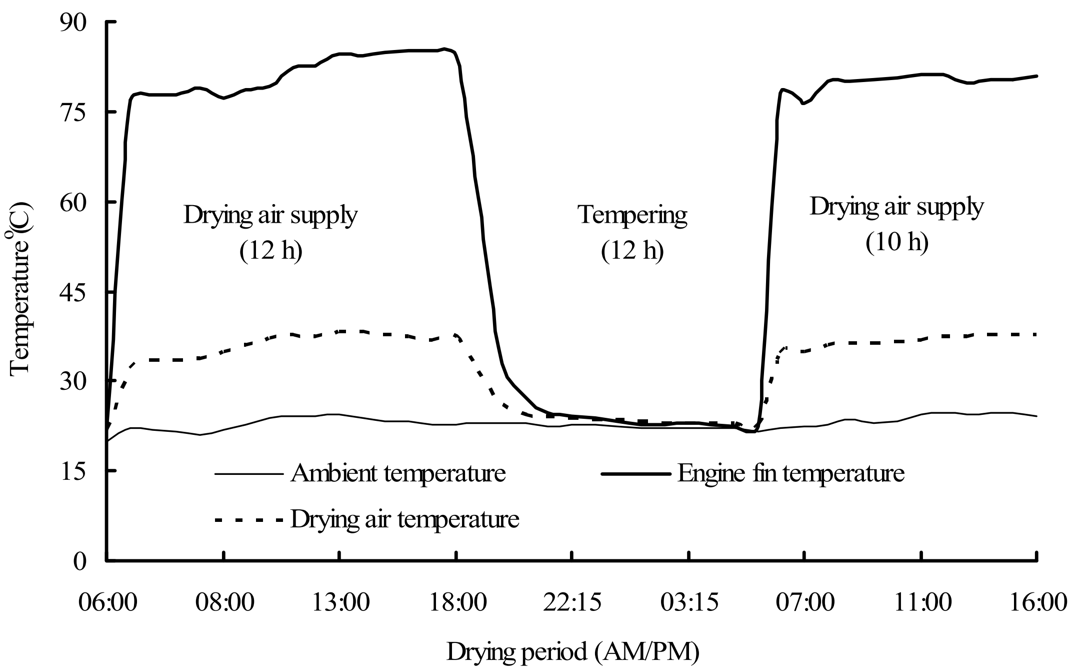

Fig. 2. Variations of ambient air, drying air and engine fin temperatures with the drying periods including tempering.

The temperature difference between the drying and ambient air was almost constant during continuous application of engine-waste heat. As the engine speed was kept constant at 3,600 rpm, the temperature and relative humidity of the drying air also varied depending upon the ambient conditions.

There was a temperature gradient between any two layers of the grain bed throughout the drying period (Fig. 3) even during 12 hours tempering at night. This indicated that there was also a moisture gradient between the layers of the grain bed. This proved that a lot of moisture migration was going on within the grain bed as the grain bed was covered with thick polyethylene during tempering at night. The temperature at the bottom layer fell during the tempering period. This indicated that the grains at this layer absorbed moisture from the adjacent upper layer during tempering. Temperatures at the middle and top layers little increased during the tempering. This indicated that tempering will reduce the energy requirement in drying. 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 22.4 to 6.8, while the average temperature and relative humidity of ambient air were 26.7 and 71.1%. The moisture content of all rice was 21.9% (w.b.) at the beginning of drying and was dried to an overall average of approximately 16.5% m.c.(w.b.). Average bulk density of rough rice was approximately 593 kg/m^3, according to the volume occupied by the grains in the dryer. The initial weight of moist grain was 480 kg.

The moisture content at bottom, middle and top layers and average moisture content of the grain bed with the drying periods are shown in Fig. 4. Rainy days were chosen for the drying test with the idea that the farmers in non industrialized countries would prefer to use these dryers in unfavorable weather conditions. A very slow moisture removal rate was observed in the top layer due to very high humidity of the ambient air. In sunny days, moisture removal rate will be higher than observed. Results showed that the total drying time required to lower the average approximate moisture content to 16.5% (w.b.) from the initial 21.9% m.c. (w.b.) was 34 h. But the actual fan operation time was 22 h. The moisture gradient was found

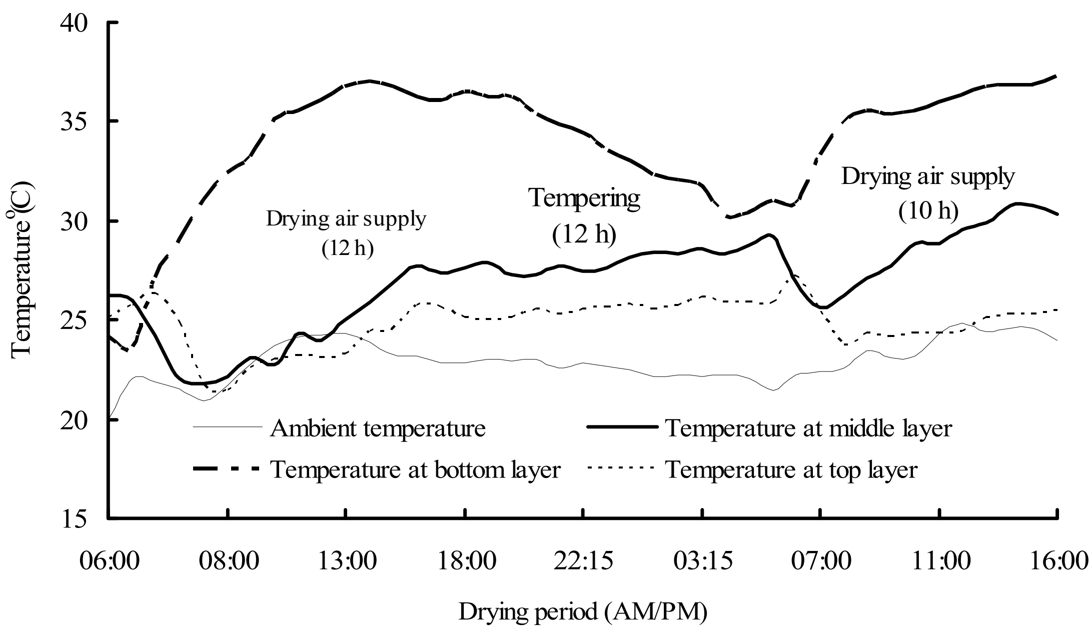

Fig. 3. Variations of ambient air temperatures and the temperatures at bottom, middle and top layers throughout the drying period.

negligible in the horizontal direction at the end of drying. The moisture gradient between the top layer and bottom layer was 9.3% w.b. at the end of drying. These results show that the moisture gradient between the top layer and bottom layer is a problem in a deeper grain bed. The moisture gradient was considerably high. 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% w.b. (Angladette, 1963). But it was only 36.7 ^{0}C at an average ambient temperature 23.5^{0}C. The whole dried grain was mixed thoroughly and stored in paper bags, commonly used by Japanese farmers, for 48 h. 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% m.c (w.b) than the safe moisture level for storage and leave the grain in the dryer undisturbed for few hours to avoid over-drying in the bottom layer. With the measured energy transmitted to the drying air, the energy required to remove one kg of moisture from the grain to bring the final average moisture content at approximately 16.5% (w.b.) were calculated. The energy requirement was 3.15 MJ/kg of water removed in

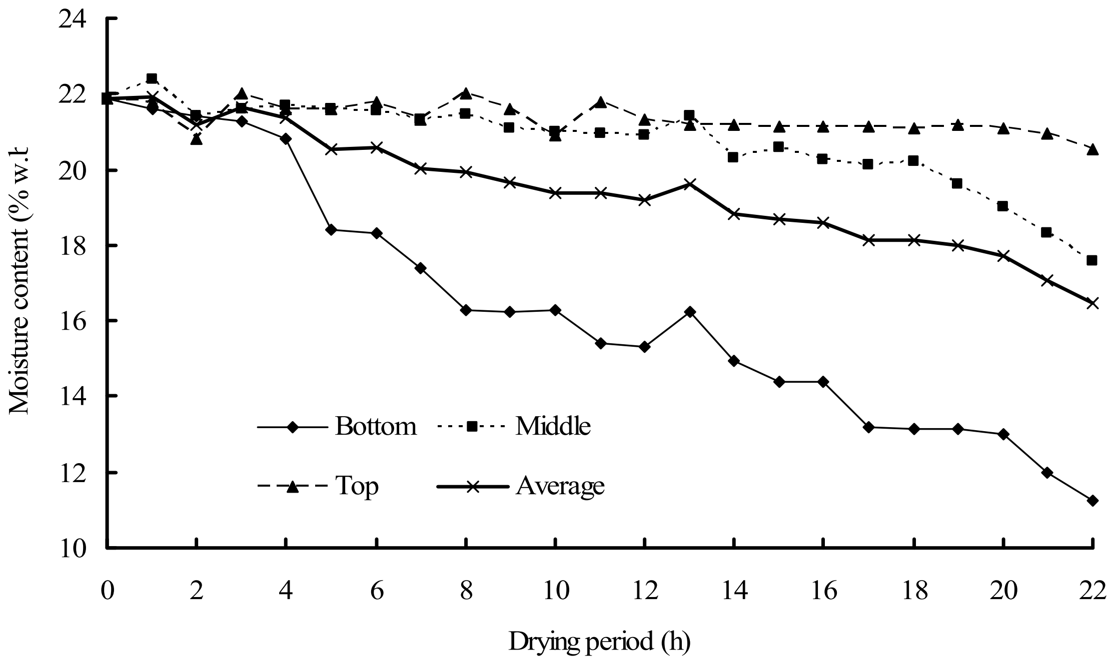

Fig. 4 Moisture content at bottom, middle and top layers and average moisture content of the grain bed with the drying periods

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. On the basis of energy requirement (3.15 MJ/kg) and available engine-waste for drying, estimation was made to find the amount of grain that can be dried by engine-waste heat. 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 145 to 1515 kg of rough rice from 23% to 15% m.c. (w.b.) in 22 h at an average ambient temperature and relative humidity of 25 and 90%, respectively.

4. CONCLUSIONS

An engine-waste heated deep-bed rough rice dryer performance was analyzed at an engine speed of 3,600. The energy requirement was found to be 3.15 MJ/kg of water removed from the moist grain in a rainy day. A seventy to eighty centimeter depth of grain bed seems to be optimum in order to avoid the over-drying (≈ 10.0% w.b.) in the bottom layer and under-drying (≈ 19.5% w.b.) 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 40 ^{0}Cdrying 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 main advantages of the engine-waste heated dryer is that it can be easily built by local technicians using locally available materials, and less kernel breakage and stress checks will occur than when rice is improperly dried in the sun or too rapidly dried with highly heated 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% (w.b.) to minimize harvest shatter losses.

5. REFERENCES

Abe, T., C. E. Ofoche, Y. Hikida and J.Yamashita. 1992. Utilization of engine-waste heat for grain drying. Proceedings of the International Agricultural Engineering Conference, Bangkok, (IV), 1147-1154.

Angladette, A. 1963. Rice drying principles and techniques, FAO, International Bulletin No. 23, 2.

Ajav, E.A. and O.A. Akingbehin. 2002. A study of some fuel properties of local ethanol blended with diesel fuel. Agricultural Engineering International: the CIGR Journal of Scientific Research and Development, Manuscript EE 01 003. Vol. IV. March, 2002.

Basunia, M. A., T. Abe, and Y. Hikida. 1996a. Simulation of engine wasted heat stationary-bed rough rice dryer. Agricultural Mechanization in Asia, Africa and Latin America, 4(27): 37-45, 48.

Basunia, M. A. and T. Abe. 1996b. Energy savings in intermittent drying of rough rice using engine waste heat. Agricultural Engineering Journal, 5(3 & 4): 149-159.

Basunia, M. A., T. Abe, and Y. Hikida. 1997. Utilization of engine waste heat for paddy drying and validation of the stationary-bed grain drying model in variable low temperature drying. Agricultural Mechanization in Asia, Africa and Latin America, 4(28): 47-52.

Excell, R. H. B. 1980. Basic design theory for simple solar rice drier, Renewable Energy Review Journal 1, 1-14.

Heywood, J.B. 1988. Internal combustion engine fundamental, McGraw-Hill, Inc, New York.

I.S.I. 1980. Methods of test for internal combustion engines IS: 10000 Part I-XII. Indian Standards Institute, New Delhi

Ishil, Y and R. Yakeuchi. 1987. Transaction curcas oil blends for farm diesel engines. Transaction of the ASAE, 30(3): 605-609.

Ramesh, D. and A. Sampathrajan. 2008. Investigation on performance and emission characteristics of diesel engine with jatropha biodiesel and its blends. Agricultural Engineering International: the CIGR Ejournal of Scientific Research and Development, Manuscript EE 07 013. Vol. X. March, 2008.

Soemangat, M., M. L. Esmay and W. J. Chancellor. 1973. Autumn, Rice drying with engine-waste heat, Agricultural Mechanization in Asia, Africa and Latin America, 80-85.

Yuan, Y., A. Hansen and Q. Zhang. 2004. The specific gravity of biodiesel fuels and their blends with diesel fuel. Agricultural Engineering International: the CIGR Ejournal of Scientific Research and Development, Manuscript EE 04 004. Vol. VI. September, 2004.