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RECOVERY OF WASTE HEAT FROM ENGINE EXHAUST FOR UTILIZATION IN A PADDY DRYER

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ABSTRACT

A major portion of heat from exhaust gas of a diesel engine has been recovered with the idea to use it for drying paddy seeds. From the performance test of the diesel engine, the condition for maximum temperature of exhaust gases have been found. It has been found that the maximum temperature of exhaust gases is 1100C at a load of 6.5kg and speed of 1500 R.P.M. At this condition, the flow rate of exhaust gases has been found as 7.75×10-4m3/sec. A cross-flow heat exchanger (both fluids unmixed) with maximum effectiveness has been designed and constructed on the basis of engine exhaust gas temperature and its mass flow rate. Ambient air was used to recover heat in the heat exchanger from the exhaust gases of the engine. The flow rate of ambient air through the heat exchanger has been determined as 0.05m3/sec. A fixed bed paddy dryer of base area 0.09m2 was designed and constructed to utilize the heat recovered from the exhaust gases. The performance of the dryer was studied in drying 10cm depth paddy volume weighing 6kg At an average ambient air temperature of 270C and 70% relative humidity, the heat of exhaust gas increases the temperature of air to 500 C. The average moisture content (MC) of paddy in the dryer decreased from 26.1% to 15% by one hour drying. The dryer has been so designed that the drying of paddy is almost uniform in the dryer. This study shows that a diesel engine, used for other farm works, can also be used for drying crop grains by utilizing the heat of exhaust gases of the engine, thus requiring no extra cost for drying.

Keywords: Diesel engine, Exhaust gas, Heat recovery, Fixed bed dryer.

1. INTRODUCTION

Paddy is a hygroscopic living and respiring biological material. It absorbs and gives off moisture depending upon the grain or paddy MC, relative humidity (RH) of air and temperature of the surrounding atmosphere. As a living biological material, paddy respires at an increasing rate with MC. Paddy is usually harvested at higher MC of about 24-26% to prevent grain shedding and shattering, higher during the rainy season and lower during the dry season. At this MC at harvest, paddy has a high respiration rate and is very susceptible to attack by microorganisms, insects and pests. The heat evolved during respiration increases the temperature of the grain resulting in increased mould growth, fungi, insects and pests infection, which increases the quantitative loss and qualitative deterioration. Grains become rancid, moulds, yellowish, insect and pest infested. Newly harvested grain with high moisture content must therefore be dried within 24 hours. Paddy must be dried to approximately 13 to 15% moisture level to be suitable for storage. [1].

Slow drying is recommended to preserve the viability and wholeness of the grain. A heated air temperature of 43°C is recommended for drying paddy. High drying air temperature will not only expose the grain to high temperature but also dry the outer surface of the grain faster than the moisture can move from the core to the grain surface. This uneven dryness of the grain results in internal stresses that cause the grain crack. The same is true when water is poured on a dry grain as rain on grain during sun drying. These cracks on the grain are not externally visible but manifest during milling as low grain recovery and high percentage of broken.

About 30% of heat produced by combustion of fuel in a diesel engine is carried away by exhaust gases. This waste heat can be utilized in mechanical drying of crops which offers the advantage of timeliness in drying reducing handling losses, maintaining grain quality, and better control over the drying process.

Many attempts had been made to utilize engine cooling waste heat for grain drying.

Soemangat et al. [2], made an attempt for the utilization of engine cooling waste heat for grain drying with different bed area dryers and grain depth. 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. This research work was used to minimize post harvest losses and for effective utilization of energy resources for crop drying.

It had also been demonstrated that compared to other drying methods, near ambient drying by raising the drying air temperature few degrees above ambient is potentially, the most energy efficient drying technique [3, 4, 5, 6].

Abe et al. [7] reported a preliminary study on the utilization of a petrol engine cooling waste heat for grain drying with a dryer capacity of 140kg of rough paddy. They conducted a single test and less kernel breakage was found than paddy dried in the sun or dried too rapidly with high temperature air. They used a separate electric motor to drive the dryer fan which was a serious drawback of their work.

Basunia et al. [8] reported the utilization of engine cooling waste heat of petrol engine for grain drying with comparatively larger bed area. This time a fan was directly coupled with the engine crankshaft to supply the engine waste heat to the dryer. They found that the heat required for drying per kg of grain was 3.26 kJ/hr with continuous supply of about 93% of the waste heat of engine cooling system to the drying air. They also reported that the waste heat was sufficient to increase the temperature of the ambient air from 7˚C to 12˚C at an air flow rate of 5.7 to 8.8 m^3/min.

In the present work, exhaust gases heat of a diesel engine has been used in a paddy dryer with the help of heat exchanger for drying paddy..

2. THEORY AND DESIGN

2.1 Heat Exchanger

Heat exchangers are commonly used to transfer heat from steam, water, or gases, to gases, or liquids. Some criteria for selecting materials used for heat exchangers are: corrosion resistance, strength, heat conduction and cost. Corrosion resistance is frequently a difficult criterion to meet. Damage to heat exchangers is frequently difficult to avoid.

Some common causes of failures in heat exchangers are: pipe and tube imperfections; faults in welding and fabrication; improper design, materials and operating conditions; pitting, corrosion etc.

There are various types of heat exchangers, e.g., double-pipe, shell-and-tube and cross-flow (mixed and unmixed) heat exchangers.

In this work, a cross-flow heat exchanger with both fluids unmixed was designed considering the following conditions:

exhaust gas inlet temperature, 110˚C; exhaust gas outlet temperature, 100˚C; atmospheric air inlet temperature, 27˚C; atmospheric air exit temperature (to dryer), 50˚C.

On the basis of above data, the heat exchanger was designed as follows:

length of tubes, 25.5cm; diameter of each tube, 1.25cm; number of tubes, 4; material of tubes, copper. To increase the heat transfer area, 14 aluminum fines were provided on the tubes.

In the heat exchanger, the exhaust gases were passed through the tubes and the atmospheric air was blown over the fins to carry out the heat of exhaust gases to dryer.

Fig. 1 shows a drawing of the designed heat exchanger.

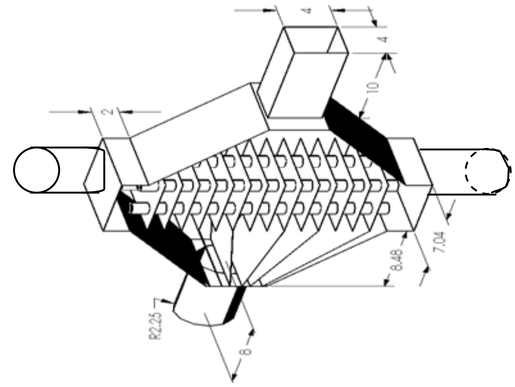


Fig 1: A view of the designed heat exchanger (dimensions are in cm)

2.2 Paddy Dryer

Drying is the universal method of conditioning grain by removing moisture to an MC level that is in equilibrium with normal atmospheric air in order to preserve its quality and nutritive value for food and its viability for seeds. The container shaped box in which drying takes place is called dryer.

When hot air is forced through the grain mass, the hot air evaporates the moisture from the grain, increases the temperature of the grain and carries evaporated moisture from the grain.

Different important factors which affect drying may be classified into 3 general categories and their features may be explained as follows:

(i) grain parameters (initial MC; equilibrium MC; initial temperature, maturity, variety and latent heat of moisture);

(ii) air parameters (initial temperature, relative humidity and volume passing through grains);

(iii) dryer factors (type and drying method, depth of grain through which air moves, feed rate of grain and heat losses in dryer by radiation & convection).

At any given temperature, there is a condition of grain MC and RH of the air, when the moisture retaining tendency of the grain and the moisture withdrawing tendency of the air come into balance. The air and the grain are then said to be in equilibrium. Under this condition, the grain no longer loses moisture to the air nor does it pick up moisture from it. At this condition, the MC of the grain is called Equilibrium Moisture Content (EMC) and the corresponding RH is called Equilibrium Relative Humidity (ERH).

The grain conditions that affect efficiency of the dryer are: the initial moisture content, the final moisture content and the kind of grain being dried.

The second group of factors affecting efficiency is controlled by the way the dryer is operated. These factors include the drying air temperature, air flow rate, drying method (batch or continuous) and uniformity of drying.

In this study, the drying bin was designed as follows: base area, 30cm x 30cm; height, 20cm. The experimental drying chamber was an open-ended box made of GP sheet.

A screen wire through which air but not paddy could pass was used as a dryer bed. To hold the mass of paddy, the screen wire was supported by mild steel rod frame. The mild steel rods were 1.27cm in diameter and spaced 5cm apart.

A schematic view of the paddy dryer has been given in figure 2.

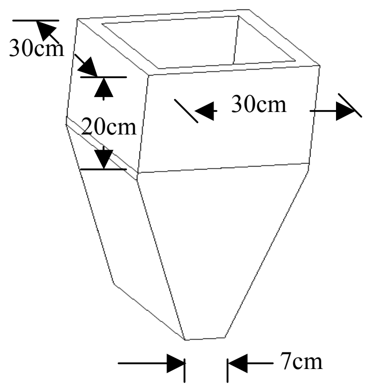


Fig 2: A schematic view of the paddy dryer

2.3 Plenum Chamber

It is a chamber which connects the hot atmospheric air outlet of the heat exchanger to bottom of drying bin by gradual expansion. The upper part of the plenum chamber was attached to the lower part of the drying bin and the lower part of the plenum chamber was fitted to the hot air outlet of heat exchanger. As such, the dimension of upper part of the plenum chamber was 30cm x 30cm and that of lower part was 7cm x 7cm.

3. EXPERIMENTAL PROCEDURE

Figure 3 shows a schematic diagram of the experimental setup. A 13.2 hp, water cooled, 4-stroke DI diesel engine was used in this study. The specification of the engine has been given in Appendix I. The hot fluid inlet side of the heat exchanger was attached to engine exhaust gas pipe outlet horizontally. The exhaust gases left the heat exchanger horizontally from other side after giving heat to atmospheric air. The atmospheric air was drawn in at a rate of $0.05m^3$/sec by a blower to cold fluid inlet side of the heat exchanger. The exit hot air from other side of the heat exchanger entered the dryer to dry the paddy.

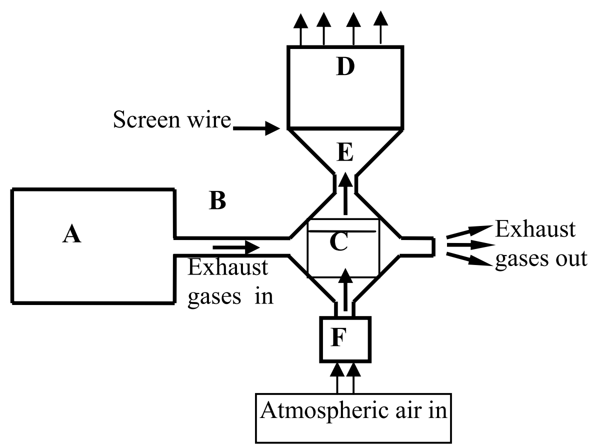
The experiment had been carried out with the procedure as described below:

3.1 Diesel Engine

Firstly, the diesel engine was tested alone (without heat exchanger and dryer) at different conditions to find out various exhaust gas temperatures of the engine. From the performance test, the conditions for maximum exhaust gas temperature of the engine was found out.

3.2 Heat Exchanger

After selecting the operating conditions of the engine, the heat exchanger was fitted to the exhaust pipe of the engine. The inlet and exit temperatures of hot and cold fluids of the heat exchanger were measured by fitting thermometers to respective side.



A= Engine, **B**= Exhaust pipe, **C**= Heat exchanger, **D**= Drying bin, **E**= Plenum chamber, **F**= Blower

Fig 3: Schematic diagram of experimental setup

3.3 Paddy Drier

6kg of paddy with MC of 26.1% was placed in the drying bin of the dryer and it was connected to hot air outlet side of the heat exchanger through the plenum chamber. A single grain digital moisture meter (model: TD 5, China) was used for measuring the MC of paddy. During experiment, the MC of paddy was measured at an interval of 20 minute collecting paddy sample from top, middle and and lower layers at the middle and corner of the bin. MC across different horizontal layers were also measured at different depths of paddy dryer at 20 minute interval. Thus the average MC along different vertical and horizontal layers were calculated out.

The average MC of the entire grain bed at any time was determined by the average of all MC data at that time..

4. RESULTS AND DISCUSSION

Engine exhaust gas temperature at different loads with a constant speed of 1500rpm has been given in Fig.4. The Fig. shows that the temperature increases as the load increases. The maximum temperature of 110^0C reaches at maximum load of 6.5kg. Since the engine was an old one, it could not be operated beyond the speed and load of 1500rpm and 6.5kg respectively which gave the maximum exhaust gas temperature.

The engine was operated at this condition during the whole experiment to recover heat from exhaust gases. Actually, higher exhaust gas temperature may be available in field because the engines are run at higher speed and load there.

Fig. 5 gives the inlet and outlet temperatures of hot and cold fluids of the heat exchanger. From the figure it is seen that the temperature of incoming atmospheric

Fig 4: Effect of load on engine exhaust gas temperature (at a constant speed of 1500rpm)

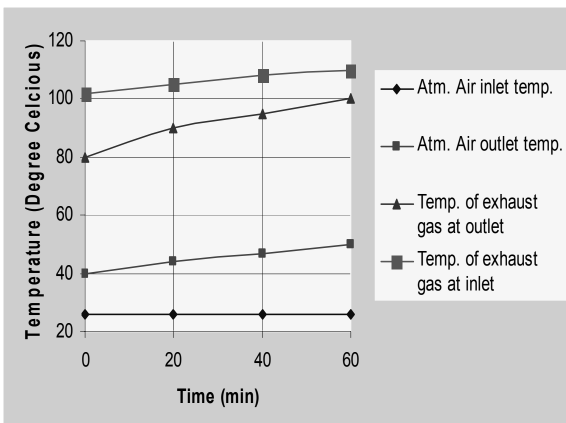


Fig 5: Variation of exhaust gas and atmospheric air temperatures at inlet and outlet of heat exchanger with time

air in the heat exchanger increases from 27^0C to about 50^0C by absorbing heat from exhaust gases, the temperature of which decreases from 110^0C to 100^0C for about 1 hour running of engine.

Fig. 6 shows the decrease in average MC of paddy with time of drying at different horizontal layers of the dryer. It is evident from the figure that MC of lower layers decreases faster than upper layers due to availability of more heat in lower layers for drying. However, after about 1 hour of continuous drying, all paddy are within MC between 12-18%.

Variation of MC of paddy with time at different vertical layers has been plotted in Fig. 7. It is clear from the figure that the average MC along different vertical layers at a certain time of drying is almost same due to equal amount of total heat available to different vertical layers. The ultimate average MC of paddy after 1 hour of drying has been obtained as about 15%.

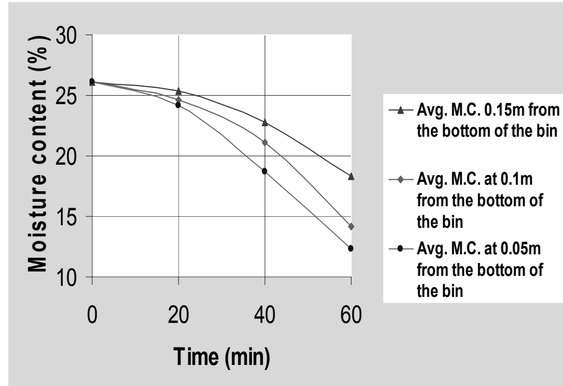


Fig 6: Change in average MC of paddy with time at different horizontal layers of the dryer

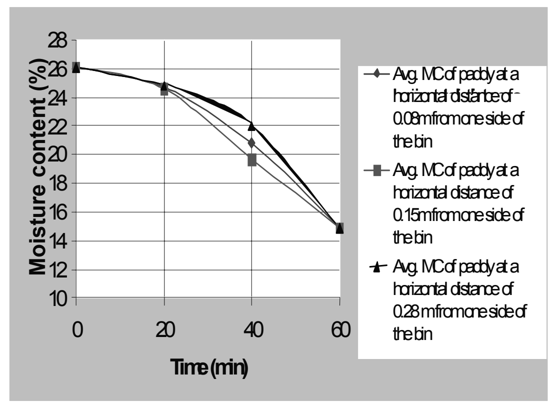


Fig 7: Variation of average MC of paddy with time at different vertical layers of the dryer

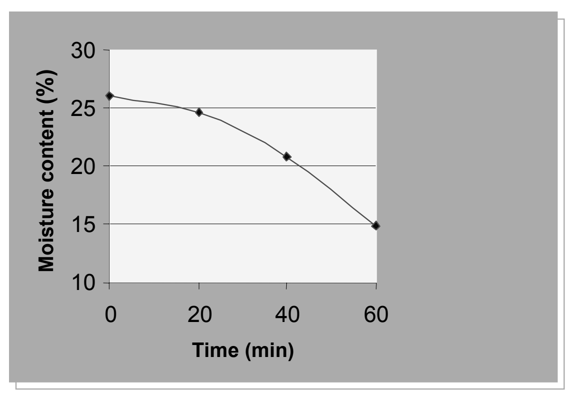


Fig 8: Average moisture content of paddy versus drying time

Change in average of all MC with drying time has been plotted in Fig. 8. The MC decreases with continuous drying and reaches to about 15% from initial MC of 26.1% after 1 hour

5. CONCLUSIONS

From the experimental results, the following conclusions may be drawn:

1. A maximum exhaust gases temperature of the engine was obtained as 110^0C at a speed of 1500 R.P.M. and load of 6.5kg. The flow rate of exhaust gases at this condition was about 7.75×10^{-4} m^3/sec.
2. Under the above engine running conditions, the temperatures of exhaust gases at inlet and outlet of heat exchanger were 110^0C and 100^0C respectively and those of atmospheric air were 27^0C and 50^0C respectively.
3. During 1 hour drying, the average MC of paddy along different horizontal layers decreased to 12-18% from initial MC of 26.1%
4. The average MC of paddy along different vertical layers was almost equal at any particular time of drying and reduced to about 15% from 26.1% for 1 hour continuous drying.
5. Average MC of paddy for 1 hour continuous drying by hot air heated in a heat exchanger by the diesel engine exhaust gases was determined as 15% from initial MC of 26.1%.
6. The dried paddy volume with the MC of 15% may be stored for a long time.

6. REFERENCES

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APPENDIX 1

SPECIFICATION OF TEST BED DIESEL ENGINE

Made:	China
Model:	S 195
Max. rated output:	13.2 HP
Rated speed:	2000 RPM
Net weight:	145kg