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DRYING OF PADDY (RAW-RICE) USING MICROWAVE ENERGY
An Initial Report on Trials in Malaysia and England

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RINGKASAN

Kuasa kepanasan gelombang mikro dapat menghasilkan satu cara pengeringan padi yang lebih cepat dari cara-cara yang biasa didapati. Didalam percubaan yang telah dijalankan, padi dapat dikeringkan dari darjah kelembapan (m.c.) 30.0% kepada 13.0% dalam masa 20 hingga 30 minit. Suhu padi dikekalkan dibawah 45°C dengan cara meniupkan angin menerusinya. Percubaan pengeringan untuk tujuan 'Commercial' telahpun dijalankan secara kecil.

Satu dari sifat-sifat yang terdapat pada rekaan yang ada sekarang ialah penggunaan sistem 'Conveyor' angin dan tarikan 'Gravity'. Anggaran yang dijangka untuk kos modal tahunan bagi tiap-tiap satu tan padi yang dikeringkan dengan kuasa gelombang mikro adalah lebih kurang sama dengan kos cara-cara pengeringan yang biasa digunakan di Malaysia sekarang ini sementara kos tenaga dan kos menjalankan ialah 1/3 hingga 1/2 lebih rendah dari yang biasa.

INTRODUCTION

An important link between the harvesting of padi and consumer is the drying of padi for storage before milling. A substantial quantity of padi is lost each year, and especially during the "off-season" wet harvesting period. Available drying capacity is unable to cope with the country's paddy production within the 4-6 weeks of the harvesting season which is usually during wet weather leaving much of the grain at over 25% moisture content. Endeavours towards developing temporary storage of wet paddy have not been very encouraging so far due to the inevitable rapid build-up of fungal mycotoxins in the high humidity and temperature conditions of Malaysia. The only real solution at present is to dry the paddy as quickly as possible after harvest.

Grain drying by conventional methods is a relatively slow process as paddy, unlike most other cereals, is milled and consumed as whole grains, and drying temperature above about 45°C are known to cause internal stresses which result in a high percentage of broken grains. With this temperature limitation drying is slow, usually requiring some 20 hours to reduce grain moisture content from 26% to the equilibrium level of about 14% necessary for storage. The use of microwave energy offers a faster method of grain drying. Microwave heating employs high frequency alternating current (1-30 GHz) to set up polarisations in the water molecules which consequently attempt to align themselves with the rapidly alternating fields, in the process of which considerable internal frictional heat is generated. It is of interest to note that when a non-uniformly wetted material is subjected to microwave energy, most of the heat is developed at the wettest spots, thus enabling the production of a more uniformly dried product.

In conventional hot-air drying , air is usually heated to decrease its humidity and increase its moisture collection capacity. This heat is transferred to the paddy grain by convection and conduction and causes the grain surface to dry much more rapidly than the interior. With microwave drying, the grains are heated internally; consequently, the conduction does not hinder but help in the movement of moisture to the periphery, thus shortening the drying period considerably.

[1] Microwave Heating Systems Div: Lucas Aerospace Ltd. Luton, England.

Review of Revelant Works

Very little work had been done hitherto on high frequency and microwave drying of grains. The most notable publications are those of KNIPPER (1), HALL (2), HAMID and BAULANGER (3), and WILSON (4).

KNIPPER (1) obtained thermal efficiencies of 18-24 percent when drying wheat with high frequency energy of 10^9 Hz. With combined drying, utilising two-thirds of the energy in the form of electrically heated air forced through the grain, a thermal efficiency of 36-49 percent was obtained.

HALL (2), using microwave energy of 2.45 x 10^9 Hz to dry shelled corn, obtained an overall thermal efficiency of about 23 percent, while the temperature of corn in his experiment exceeded 200°F during drying from 29.4 to 15 percent moisture content. Such a rise in temperature is not acceptable for the drying of paddy.

HAMID and BAULANGER (3) described a practical system for control of insects in wheat and flour using microwave energy. It was suggested that wet grains be raised to a temperature of about 45°C and then subjected to a blast of warm air to lower its moisture content before it was finally subjected to the higher temperature of 55-65°C required for the destruction of insects.

WILSON (4) discussed the theory and application of high frequency and microwave heating, and the problems associated with its use.

MICROWAVE DRYING OF PADDY

First Stage – Initial Experiments in Malaysia

A pre-project evaluation of microwave drying of paddy was initiated in 1973 by MARDI after a preliminary trial was conducted using a modified domestic (Sanyo) microwave oven. Encouraging results were observed where small quantities of paddy were dried in 1-2 minutes from a moisture content of 22% to 14%. Milling output was however poor due to the high grain temperature developed of over 65°C. A microwave oven was subsequently purchased and modified to enable trials to be carried out to relate:

(i) Drying time (time that the grain was subjected to the microwave energy).

(ii) Air-flow rate (air to remove exhausted moisture and limit rise of temperature).

(iii) Intermittent drying and "tempering" (also to limit rise of temperature).

(iv) Milling quality and ' head" (whole-grain) yield.

The procedure was to subject the sample of paddy to 1 kilowatt of microwave energy of 2.45 x 10^9 Hz for the required period (3 mins, 2 mins, etc.); then check the grain temperature with a thermometer. The sample was then removed and allowed to cool (temper) under a portable fan before being placed in the oven for re-heating. In this series of experiments it was found necessary to limit the period within the influence of microwave to 1.5 minutes at a time followed by 5 minutes of cooling in order to restrict temperature rise to 45°C. Eight to ten such series of alternate heating and cooling was adequate to reduce moisture from 25% to 13% and still provide acceptable milling quality of 55-60% whole grain and less than 15% broken grain.

Further trials with laboratory "par-boiled" paddy (i.e. steeped at 70-75°C for 5 hrs., followed by gelatinisation by steaming at 10 psi for 10 minutes) showed that microwave energy would also be very feasible for drying par-boiled paddy very quickly. Due to the gelatinisation a higher rise in temperature is acceptable and hence a much quicker drying. These trials suggested the feasibility of applying microwave energy for drying simultaneously with a (transverse) flow of air **both** to remove moisture as it is exuded from the grain as well as to cool the grain and limit its rise in temperature. The test rig as designed is illustrated in *Fig. 1*. The paddy would be filled into the hopper and its rate of flow through the bottom regulated by the "gate" to maintain grain within the microwave region for between 15 to 20 minutes. A transverse blower would remove moisture as it is exuded and also limit the rise in temperature to the required degree.

An unexpected "spin-off" for microwave drying is the observation that any insects in the paddy and particularly the sytophilus, – are rapidly exterminated when the paddy is subjected to microwave energy. This is particularly observed in the case of insects which bore into the grain to lay their eggs. Their subsequent "back-filling" of the bore prevents the usual fumigants to reach the eggs or larvae. However, microwave energy destroy them from within, very quickly.

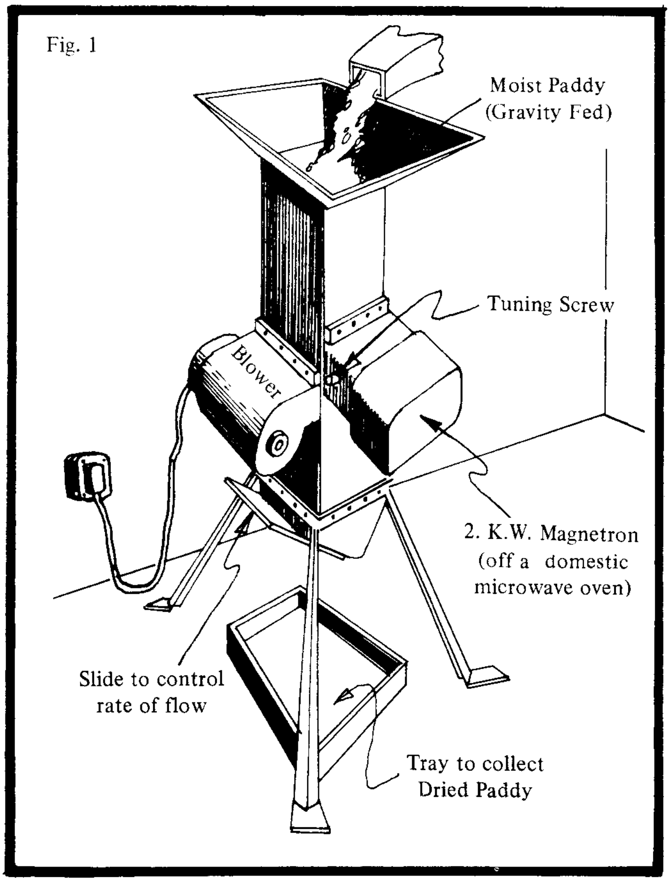

Figure 1. Illustrates the initial design of laboratory test-rig for research into microwave drying of rice. It relies on gravity for flow of grain with its rate controlled by a sliding gate below.

SECOND STAGE – CONTINUATION OF MICROWAVE GRAIN DRYING TRIALS IN ENGLAND

This work was a continuation of the preliminary trials described above and was carried out in collaboration with Lucas Aerospace Ltd. of England (a firm with considerable experience with commercial microwave heating equipment) to evaluate the drying performance under possible commercial drying configurations utilising microwave energy.

Several variations were experimented with, namely:-

a) Using a continous flow conveyor with the heat supplied by microwave and the ambient air flow providing simultaneous cooling and removal of moisture

b) Using a hopper system with alternative heating by microwave and cooling from an ambient air supply.

c) A batch production system of pulling a vacuum on the paddy while heating by microwave.

The humidity of the incoming air and its temperature were controlled to simulate conditions of ambient air in the humid tropics.

Results were very encouraging as shown in *Table 1.* Three kilograms of wet paddy was dried from a moisture content of 30.0% to 13.2% (wet basis) in about 30 minutes with 1.1 kw. of microwave energy. Paddy grain temperatures were kept below 45°C by blowing air at about 78 cubic feet per minute through the grains. The full report of the tests was presented in Application Report No. 3 (5).

TABLE 1. MICROWAVE DRYING OF PADDY RESULTS

Drying Time Mins	Inlet Air Temp. °C	Inlet Air R.H. %	Outlet Air Temp. °C	Weight of Padi gm.	Moisture Content % (wb).
0	25.5	78.0	28.0	3000	30.0
5	26.0	78.0	29.0		
10	25.5	78.0	32.5		
15	26.0	79.0	36.5		
20*	26.0	78.5	37.5	2570	18.0
25	26.75	78.3	38.75		
30	26.0	78.5	40.5	2420	13.2

* Power switch off for 4 minutes during weighing.

It was further discovered during these trials that an upward flow of air could be used to "fluidise" the grain and simultaneously convey it through the microwave energy zone. Fluidising also provided a very effective 'stirring" of the grain and optimised the role of air to remove moisture as well as the excess heat.

Fig. 2 illustrates one possible configuration of a microwave grain drier utilising these principles, and which will enable paddy to be dried from 25-28% to 13-14% moisture content (wet basis) within 20-30 minutes in a single pass.

Arrangements have been made with the National College of Engineering, Silsoe of England for use of their facilities to carry out a series of milling trials with samples dried at various temperatures. These tests are aimed at establishing the maximum heating limit of the paddy grains under microwave drying. It is anticipated that with drying taking place from within, the conventional restraint of 45°C as the maximum allowable temperature may well be exceeded without affecting milling quality. This would enable an even quicker drying than the 20-30 minute presently envisaged. (N.B. it should be remembered that conventional drying installations using continuous flow type of tower-drier and tempering bins usually takes 20 hours to achieve this same degree of drying).

ECONOMIC VIABILITY OF MICROWAVE SYSTEM FOR LARGE SCALE DRYING OF PADDY

In order to ascertain the cost of using microwave energy for drying paddy, estimate was prepared for a microwave installation in comparison with costs for a conventional drying installation. It can be seen from *Table 2* that the annual capital cost per ton of paddy dried using microwave energy is about the same as that of the latest conventional drying complexes set up in Malaysia while fuel and operating cost is about 1/3 to 1/2 that of the latter.

TABLE 2. COSTS COMPARISON OF MICROWAVE DRYING WITH CONVENTIONAL DRYING

Description	300 Kw. Microwave System: 3 ton/per hour Capacity		Continuous flow Drier as installed in Malaysia: 10 ton/hour Capacity	
	Cost ($)	Cost per ton ($)	Cost ($)	Cost per ton ($)
Capital Cost:				
Drier (Machinery) cost	0.96×10^6	0.32	2.9×10^6	0.29
Building Costs	0.84×10^6	0.28	3.4×10^6	0.34
Total Capital Cost	1.80×10^6	0.60	6.3×10^6	0.63
Operating Cost per ton Processed:				
Repair/Maintenance		3.00		7.50
Fuel/Electricity		7.78		21.00

SYSTEM DESIGN

A feature of the present design is to incorporate air blowers into the microwave drying system to serve the treble functions of cooling the padi so that it not does rise too high in temperature (generally below 45°C); also to remove the moisture as it is exuded, as well as to convey the grain through the dryer. A gravity fed pneumatic conveyor system is currently being designed to provide a more efficient way of fluidising the paddy in the air stream and ensuring an even flow of air around each paddy grain. The principle of this pneumatic conveying system is illustrated in *Fig. 2*

The grain is carried through the microwave fields by the cooling air which is blown through the perforated bottom plates. The grain layer is fully reversed between one section and the next, thus resulting in more uniform cooling and moisture removal. The number of stages can easily be determined from theoretical considerations and added to suit the desired capacity of the installation.

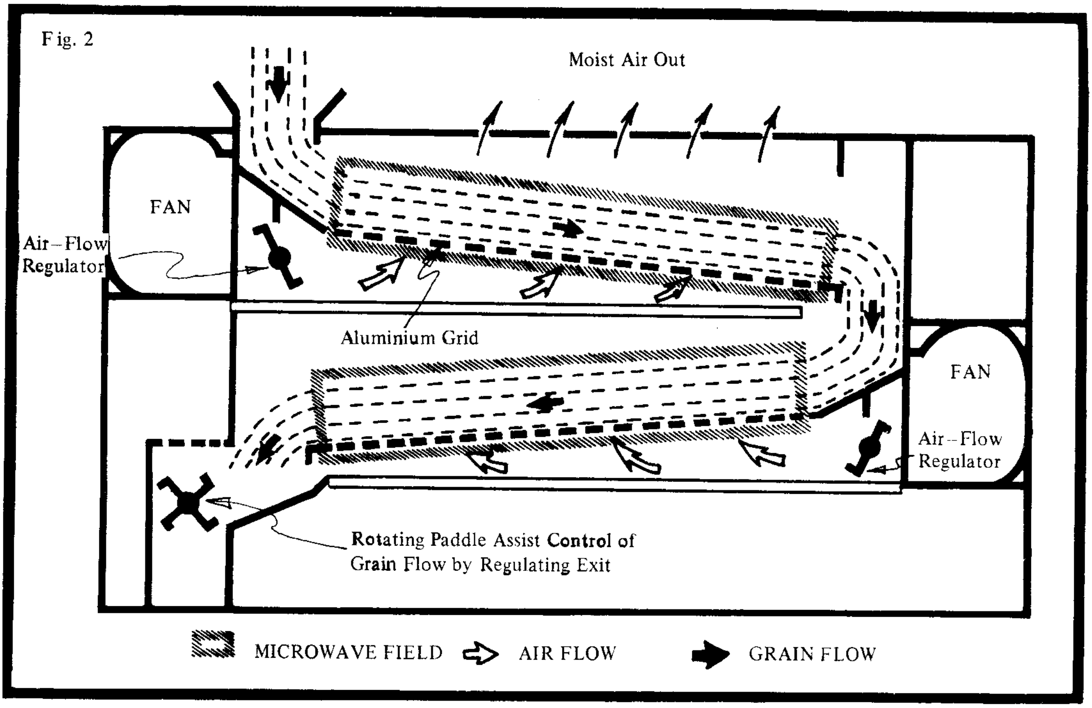

Figure 2. Illustrates one possible configuration of a microwave grain drier utilising fluidised air to convey the grain through the microwave zone; the rate of grain flow is governed by the slope of the lower grid and the pressure of the air.

SUMMARY

Microwave heating offers a much faster method of grain drying than conventional methods. In the trials carried out paddy was dried from moisture content of 30.0% to 13.0% (w.b.) in 20-30 minutes. Grain temperatures were kept below 45°C by blowing ambient air through it. The drying performances under possible commercial drying configurations were evaluated. A feature of the present design was the gravity-fed pneumatic conveyor system. An estimate of cost shows that annual capital cost per ton of paddy dried using microwave energy is about the same as that of the latest conventional drying complexes in Malaysia while fuel and operating cost is about a third to half that of the latter.

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CONCLUDING REMARKS

Microwave drying of grain offers a number of advantages over conventional drying, namely:-

a) Shorter drying time. While conventional drying requires about 16-24 hours to dry paddy from 30-14% moisture content (wet basis), microwave energy takes only 20-30 minutes for the same moisture reduction.

b) Ability to dry non-uniformly moist grains to a uniform final moisture content.

c) Reduction in floor space as microwave units are very compact. This means an appreciable saving in building cost.

d) Simultaneous control of insect pests, even those which bore into the grain.

e) Appreciably lower operating costs.

f) Microwave drying plant can be as small as 100 kw (1 ton per hour) or "ganged" to increase capacity as required.

It may be more appropriate to also mention the disadvantages or problems likely to be faced by designers and user of microwave driers, and among them are:-

a) Irradiation of paddy in bulk cannot be done because of the small penetration of microwave of about 4 inches only.

b) It is important that the microwave drier unit is effectively sealed. Any leakage from the system must be kept below 10 mw/ cm^2 for human safety.