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OPTIMUM OPERATION PARAMETERS OF THE COMBINATION OF A MIXED-FLOW DRYER AND CONTINUOUS IN-BIN AERATION FOR PADDY UNDER MALAYSIAN CONDITIONS

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By

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

A	Air Duct Cross-Sectional Area, m^2
AFO	Drying Airflow Rate, $kg/m^2.hr$
AFR	Aeration Airflow Rate, $m^3/mt.min$
ATM	Drying Air Temperature, °C
AREA	Bin Cross-Sectional Area, m^2
B	Air Pressure, mm bar
C	Paddy Variety Effect, Empirical Constant
c	Specific Heat, kJ/(kg.K)
DEPTH	Grain Depth, m
DI	Weather Deterioration Index, Dimensionless
DML	Dry Matter Loss, Percent
DNY	Drying Specific Energy Requirement, MJ/kg of Water Removed
E_d	Drying Efficiency, Percent
E_t	Total Energy Supplied, MJ
EMC	Equilibrium Moisture Content, Decimal Dry Basis
ERH	Equilibrium Relative Humidity of Paddy, Decimal
FGT	Grain Temperature after Aeration, °C
FMC	Grain Moisture Content after Aeration, Percent Dry Basis
G_a	Dry Weight Air Flow Rate, $kg/m^2.hr$
GF	Grain Throughput Capacity, $mt/m^2.hr$
GFO	Grain Throughput Capacity, $mt/m^2.hr$
GT	Grain Temperature, °C
GTO	Grain Temperature Leaving the Dryer, °C
GRM	Grain Germination, Percent

H	Absolute Humidity, kg Moisture/kg Dry Air
HRS	Aeration Period, hr
h	Convective Heat Transfer Coefficient, W/(m.K)
h_{fg}	Heat of Vaporization, kJ/kg
I	Dryer Performance Index, Dimensionless
IGT	Initial Grain Temperature, °C
IMC	Initial Moisture Content, Percent Dry Basis
k	Drying Constant, sec^{-1}
L	Latent Heat of Vaporization, kJ/kg
M	Average Moisture Content, Decimal Dry Basis
MC	Grain Moisture Content, Percent Dry Basis
MCO	Grain Moisture Content Leaving the Dryer, Percent Dry Basis
N	Number of Drying Passes
Pct	Percent
P_s	Saturation Vapour Pressure at a Given Temperature, Pa
POW	Energy Requirement for Aeration, kWh
Q	Volume Air Flow Rate, m^3/s
QP	Quality Factor of Dried Paddy, Dimensionless
R	Grain Dry Matter to Air Ratio, kg Dry Matter/kg Air
R_o	Wet Grain to Air Ratio, kg Wet Grain/kg Air
RH	Relative Humidity, Percent
RHA	Equilibrium Relative Humidity of Air, Decimal
S	Specific Grain Surface Area, m^2/m^3
T	Temperature, °C
T_{ab}	Absolute Temperature, °K
U	Drying Uniformity Factor, Dimensionless

V_c	Corrected Air Velocity, m/s
V_m	Measured Air Velocity, m/s
W_o	Output Weight of Paddy, mt
$\mathbf{X}$	Column Matrix of the Variables X
X	Bed-Depth Coordinate, m
Y	Bed-Width Coordinate, m
YR	Milled Rice Head Yield, Percent
Z	Objective Function
δH	Heat Utilization, MJ
Θ	Grain Temperature, °C
σ^2_{mc}	Variation of Paddy Moisture Content, Percent
ρ	Dry Weight Density, kg/m^3
Δ	Incremental
∇	Gradient

As Subscript / Superscript

a	Air
db	Dry Basis
eq	Equilibrium
f	Final
in	Initial
k	Iteration
p	Product
t	Time
v	Vapour
w	Water
wb	Wet Basis
α	Closeness Value

Abstract of dissertation submitted to the Senate of Universiti Pertanian Malaysia in fulfilment of the requirements for the Degree of Doctor of Philosophy.

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By

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Chairman: Assoc. Prof. Dr. Mohd. Nordin Ibrahim

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The design of a mechanical paddy dryer or any improvement of the dryer can be successfully done by incorporating all significant variables concerned in its operation through an optimization model. All constraints employed in the optimization model should satisfy local requirements and suitabilities.

This study was conducted to determine the optimum parameters for the operation of a mixed-flow paddy dryer followed by continuous in-bin aeration. The aeration was provided to enhance the mixed-flow dryer operation. The optimization study was done by incorporating the working parameters of each operation in two separate empirical non-linear optimization models. The two models were associated in such a way that the optimum results of the mixed-flow drying were the inputs to the aeration stage, and vice versa.

A computer simulation programme was used to obtain all pertinent information of each operation prior to developing the optimization model. A major modification was done to the mixed-flow drying simulation programme to make it suitable for simulating paddy drying under local conditions so that it can be used to evaluate the performance of an existing mixed-flow dryer. The simulated results of this programme agreed reasonably well with the actual tests conducted on the dryer.

The optimum result showed that only two passes of the dryer operation and one period of the in-bin aeration were required for drying fresh wet paddy from moisture content of 30.50 to about 16.00 percent dry basis. Different optimum drying air temperature and airflow rate were obtained from each pass of the drying. The values of 70.48 degree Celsius and 10.00 $kg/m^2.min$ were respectively the optimum drying air temperature and airflow rate of the first drying pass. For the second pass, the optimum drying air temperature of 77.05 degree Celsius and airflow rate of 5 $kg/m^2.min$ were obtained. An optimum aeration period of 32.31 hours with airflow rate of 0.77 $m^3/mt.min$ was required following the first drying pass. The grain germination of 94.71 percent and dry matter loss of 0.6 percent were the optimum grain quality criteria obtained from the study. An average specific energy requirement of 5.13 MJ/kg of water removed at the net grain output capacity of 6.88 mt/hr were recorded for the optimum conditions.

Compared to the status of current operation, the optimum result obtained showed there is some potential towards improving the existing mixed-flow paddy drying and eventually improving the drying capacity of the rice complex.

optimum pengeringan aliran bercampur menjadi input kepada peringkat pengudaraan dan sebaliknya.

Program penyelakuan komputer digunakan untuk memperolehi kesemua maklumat yang berkaitan bagi setiap operasi sebelum sebuah model pengoptimuman dibangunkan. Satu pengubahsuaian penting telah dilakukan bagi mengubahsuai program penyelakuan pengeringan aliran bercampur untuk menjadikannya sesuai untuk penyelakuan pengeringan padi dengan keadaan tempatan supaya ianya boleh digunakan untuk memperoleh pemahaman mengenai prestasi pengering aliran bercampur yang sedia ada. Keputusan penyelakuan secocok dengan hasil dari kajian.

Keputusan optimum menunjukkan bahawa hanya dua laluan melalui operasi pengering dan satu tempoh pengudaraan di dalam pengering tong diperlukan untuk mengeringkan padi basah dari kandungan lembapan 30.50 kepada 16.00 peratus asas kering. Suhu udara pengeringan optimum dan kadar aliran udara yang berlainan diperolehi bagi setiap laluan mengering. Nilai-nilai 70.48 darjah Celsius dan 10.00 kg/min/m^2 masing-masing adalah suhu udara pengering optimum dan kadar aliran udara bagi laluan mengering yang pertama. Bagi laluan kedua, suhu udara mengering 77.05 darjah Celsius dan kadar aliran udara mengering optimum 5 kg/min/m^2 diperolehi. Tempoh pengudaraan optimum selama 32.31 jam dengan kadar aliran udara 0.77 m^3/min/mt diperlukan selepas laluan mengering yang pertama. Percambahan bijian pada kadar 94.71 peratus dan kehilangan bahan kering sebanyak 0.6 peratus adalah nilaitara mutu bijian optimum yang diperolehi dari kajian ini. Purata keperluan tenaga tentu sebanyak 5.13 MJ/kg air pada

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PARAMETER OPERASI YANG OPTIMUM BAGI KOMBINASI PENGERING ALIRAN BERCAMPUR DAN PENGUDARAAN BERTERUSAN DI DALAM PENGERING TONG BAGI PADI DENGAN KEADAAN DI MALAYSIA

oleh

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Rekabentuk pengering padi mekanikal atau sebarang perubahan kepadanya boleh dilakukan dengan jayanya dengan menggabungkan pembolehubah penting yang terlibat di dalam pengendaliannya melalui satu model pengoptimuman. Segala kekangan yang digunakan di dalam model pengoptimuman ini mestilah memenuhi keperluan dan kesesuaian tempatan.

Kajian ini bertujuan untuk mempastikan parameter optimum bagi pengendalian pengering padi aliran bercampur diikuti oleh pengudaraan di dalam tong secara berterusan. Pengudaraan dibuat bagi meningkatkan operasi pengering padi aliran bercampur. Kajian pengoptimuman dilakukan dengan menggabungkan parameter kerja setiap operasi di dalam dua model pengoptimuman tak lelurus ghalib yang berasingan. Kedua-dua model tersebut dikaitkan dengan cara di mana keputusan

muatan keluaran bijian bersih sebanyak 6.88 tm/jam adalah terlibat dengan keadaan optimum.

Berhubung dengan prestasi operasi semasa, keputusan optimum yang diperolehi menunjukkan ada potensi untuk meningkatkan operasi pengering padi aliran bercampur yang tersedia, dan akhirnya meningkatkan kemampuan pengeringan kompleks padi berkenaan.

CHAPTER I

INTRODUCTION

Generally, paddy drying and storage operations will affect unit operation performance as well as grain quality. This implies that each operation will only be achieved if both operation performance and grain quality are simultaneously considered. The general criteria in operating a particular mechanical dryer or storage facility is to try to maximize operation performance with minimum deterioration in paddy grain quality. A major decision in each operation would be to control the operating parameters so as to obtain the best possible return.

Paddy drying is the process of removing moisture from wet paddy to a moisture content in equilibrium with the surrounding atmosphere or to such a level that decreases biological and chemical activities that reduce the quality of the paddy. Drying is a very complex process. It involves the simultaneous transfer of heat and mass. During drying, heated air or near ambient air is blown through the bulk of wet paddy, by means of which the energy required for evaporation is provided to the paddy. Moisture is removed as a result of the difference in vapour pressure between the paddy surface and the ambient air surrounding it. Meanwhile, moisture migrates to the surface of the grain because of the moisture gradient between the inner parts and the surface. Finally, the water evaporating from the paddy surface is removed by the air moving through the grain. Drying will occur until equilibrium is reached between the inner part and the surface, and between the surface and the ambient air. The process takes place simultaneously in a device called mechanical dryer.

Consequently, to achieve the ultimate goal of drying the paddy, the drying parameters must be properly controlled. Basically, they consist of the dimensional specification of the dryer, initial moisture content of the paddy, the drying air temperature, the airflow rate, the grain throughput capacity, the final moisture content and the temperature of paddy, and the energy consumption in the process. Various systems of the mechanical paddy dryer can be employed. With increasing scarcity of energy resources the efficiency of these systems are becoming increasingly important. Incorrect selection and control of a dryer leads to misapplication, excessive utilization costs and loss in quality and quantity of paddy grain. To ensure efficient use, all pertinent working parameters should be controllable. Moreover, for the innovation and improvement of a mechanical paddy dryer, the working parameters necessary for the dryer operation should be predictable in order to achieve the desired goal of efficient drying.

One possible way to increase the efficiency of the paddy drying operation is by providing in-bin aeration. This operation can be accomplished when paddy is in a storage bin for a period of time so that the drying unit can be operated over a longer period. This results in increased drying efficiency and eventually, more profitable use of the facilities in a rice complex. However, during this period the paddy grain quality may decline due to pests and biological activities brought about by unsuitable weather. Dry matter loss is the main substantial loss in the aeration period. In order to increase the efficiency of the drying operation as well as to maintain paddy grain quality, the in-bin aeration should complement the drying operation. Accordingly, paddy grain moisture content and temperature, aeration airflow rate, weather condition, the amount of paddy in the storage bin and the aeration period should be incorporated in the overall consideration. Though the in-bin aeration is considered as a simple operation, its effectiveness is highly influenced by the aforementioned factors. Therefore, it is necessary to know and understand the interrelationship between the factors, and finally, to be able to quantify suitable values for each parameter to achieve the optimum storage working policy.

In order to make optimum use of paddy drying and in-bin aeration, the optimum values of the process parameters should be substantially quantified. Due to the fact that there are many factors affecting the operating performance of paddy drying and storage, the best possible working parameters can be obtained only by performing an optimization study. In this study, the optimization models will be formulated by using the aforementioned parameters subject to the specific domains of each parameter in conjunction with the existing operation of a rice processing complex. Providing the optimum working parameters for both paddy drying and storage operations will increase the drying capacity of a rice processing complex resulting in better quality dried paddy. Generally, a relatively large percentage of energy is consumed in drying cereal grain i.e. about 20 to 30 percent of the total energy consumption in the grain production process (Stevens and Thompson, 1976). Furthermore, the energy consumption in storage using continuous aeration of ambient air could be defined as energy used to force the air to pass through the grain bulk. Thus, the objective function of the optimization models under this study is to minimize energy consumption of the operation.

There are many researches on the simulation of paddy drying and storage whose objectives are mostly aimed at developing computer simulation models of the relevant process mechanism, and eventually, to use the validated model to predict the behaviour of pertinent operating parameters in the process. This study is an attempt to exploit computer simulation models for paddy drying and storage, in order to contribute some improvements towards paddy drying, storage operation and design.

Paddy Drying Situation in Malaysia

During the sixties, Malaysian farmers normally dried their paddy naturally under the sun. At that time paddy production was based on traditional practice. A major change in rice production occurred during the late sixties when the Malaysian Government played a major role in development by allocating a large budget for improving the paddy irrigation system. As a consequence, double cropping, new high yielding rice varieties, and mechanical dryers were introduced into the new paddy production system.

By 1980, the government agency called " Lembaga Padi dan Beras Negara" (LPN) established 28 rice complexes nationwide, equipped with the LSU mixed-flow dryer and milling facilities. Meanwhile, use of batch dryers prevailed. All established rice complexes are controlled by the government. In 1983, 70 percent of total paddy production nationwide was dried by batch and sun drying, while 17 to 20 percent were dried using the continuous-flow dryers available at the rice processing complexes. The rest were still dried naturally by the sun (Hussain, 1990).

By 1984, the total mechanical drying capacity of all commercial mills nationwide was 617,210 metric tonnes per year. However, only 53 percent of the paddy were dried at the government rice complexes (Nordin, 1989). The remaining 47 percent were dried by private commercial mills and the farmers themselves.

Currently, there are four categories of mechanical paddy dryers used in Malaysian rice production. They are the LSU mixed-flow dryer, the flat bed dryer, the moisture extraction unit (MEU), and a new pilot conveyer dryer (Nordin, 1990). In addition, the in-bin counterflow dryer is proposed to be added to the rice complexes (Hussain, 1990).

The LPN rice processing complexes are faced with the problem of over-supply of wet paddy. This is due to the fact that most farmers prefer to sell their wet paddy to the LPN since LPN impose a lower price deduction. About 350 metric tonnes were procured daily by the LPN rice complex at Sungei Besar during the dry season (Nordin, 1989). With this average amount, it is not possible for the rice complex which is most accessible to the farmers to complete the drying of wet paddy on the day of procurement. This results in considerably long queues waiting to unload paddy from the trucks. The waiting time for a truck to finish unloading wet paddy resulted in paddy grain deteriorating due to dry matter loss and damp grain heating.