# Seed Drying Using a Heat Pump

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## ABSTRACT

*The objectives of this research were to design, construct and test a heat pump dryer for paddy seed working with a mixed flow (LSU type) dryer. In this study, paddy seed was dried in an open air-loop from initial moisture content of 13.5% w.b. to 22.2% w.b. to final moisture content of about 12% w.b., inlet drying air temperature was 43°C, specific air flow rate was 9* $m^3/min\text{-}m^3$ *paddy and evaporator bypass air ratio was 0%, 30% and 50% . The effects of evaporator bypass air ratio on specific energy consumption, COPhp, SMER, and MER were investigated. Experimental results showed that COPhp and SMER increased to maximum at evaporator bypass air ratio of 0% and decreased with increasing bypass air ratio. Quality of paddy seed was very good with mean germination of sun drying and heat pump drying of 98% and 97% and mean vigor of sun drying and heat pump drying of 96% and 95%, respectively. From cost evaluation of paddy seed drying with an initial moisture content of 22.2% w.b. and final moisture content of 12.4% w.b., it was found that total cost of seed drying was 2.81 baht/kg water evaporation of which Baht 0.63 (US$ 1 = Baht 40) was energy cost, Baht 0.41 was maintenance cost and Baht 1.77 was fixed cost.*

## 1. INTRODUCTION

Seed production should be managed to maintain good quality of original seed that is good in germination and vigor [1]. Drying process is one of seed producing processes with high energy consumption cost. Heat pump drying is becoming popular in several countries because of high energy efficiency. Moreover, water is condensed and separated from air thus results in dry and low temperature air which is good for producing low moisture content product with good quality paddy seed. Some research works on heat pump drying development are briefly introduced in this paper.

Yathip, et al. [2] studied feasibility of drying by using heat pump. A near-equilibrium mathematical drying model was employed to find optimum drying condition. Variables considered were specific air flow rate, drying temperature, ambient air relative humidity, initial moisture content of paddy and height of paddy bed. Details are as follows: specific air flow rate from 10 $m^3/min\text{-}m^3$ to 20 $m^3/min\text{-}m^3$ paddy, drying air temperature from 36°C to 50°C, ambient air temperature of 30°C, relative humidity variation of 70% and 80%, initial moisture content of paddy from 18°C to 24% w.b. and height of paddy bed variation of 0.5 m and 1 m. Simulated results showed that specific air flow rate and drying air temperature affected drying rate. At low specific air flow rate and high temperature, energy consumption was low. Energy consumption increased with height of paddy bed. The best drying condition was as follows: drying air temperature maintained at 49°C, specific air flow rate of 12 $m^3/min\text{-}m^3$ paddy, paddy bed height of 0.5 m, ambient air temperature and relative humidity of 30°C and 70%, respectively. In drying for 2160 hours per year, drying cost in reducing moisture content from 24% to 14% w.b. was Baht 61.50 per 1000 kg (US$ 1 = Baht 40) of paddy.

Sartori [3] studied soybean seed drying in a cross-flow drying chamber to find variables which affected soybean seed quality such as relative drying air humidity, initial moisture content, and drying air and soybean velocities. Soybean qualities were evaluated in both before and after drying as follows: germination, vigor and breakage. Results from experiment showed that with low ambient air relative humidity and high initial moisture content, quality of soybean seed decreased significantly. The best conditions of drying were air relative humidity of 23%, initial moisture content of soybean of 18% w.b., air velocity of 2 m/s and soybean velocity of $1.8 \times 10^{-3}$ m/s.

Meyer and Greyvenstein [4] studied technique and economic analysis of seed drying using a heat pump and compared to electrical heater and diesel fuel systems. It was found that if operating time was less than 3 months, rate of return of heater and fuel systems was higher than that of heat pump. This was due to high initial investment cost of heat pump system. To make a heat pump system more economical, the heat pump should be used for multi-purposes such as for drying and water heating.

Clements, et al. [5] studied continuous drying with heat pump using a mathematical model to find the effect of variables on specific moisture extraction rate (SMER) and coefficient of performance (COP). The variables considered were relative humidity of drying air, air flow rate and evaporator bypass air ratio. Results showed that SMER and COP increased with air relative humidity. Proper bypass air ratio should be 60% to 70%.

Jia, et al. [6] studied performance of continuous drying using heat pump. Results showed that the system performance could increase by 20% as evaporator bypass air was recycled. If exhausted air reduced about 10%, SMER and product quantity could increase by about 15% and 50% respectively.

From the past research, it showed that suitable evaporator bypass air ratio was 60% to 70%. Variables which affected seed quality were initial moisture content, drying air relative humidity, which affected germination quality, and specific air flow rate, which affected energy consumption. Economic analysis showed that initial investment of heat pump drying system was high but the system would be worth for long term operation. In Thailand especially during period of rainy season, air is relatively humid. Consequently, it is difficult and costly to dry seed to a safe storage moisture content with the maximum allowable drying air temperature of 43°C. Heat pump drying is an alternative technology. Therefore, the objective of this research is to design, construct and test a prototype heat pump dryer for paddy seed. The unit was tested in a seed reproducing center.

## 2. MATERIALS AND METHODS

The schematic diagrams of the experimental heat pump dryer and the heat pump unit were shown in Figs. 1 and 2, respectively. It consisted of a 18 kW evaporator, 20 kW internal and external condensers, a 3.7 kW two piston compressor, a 5 kW electrical heater, a 1.5 kW forward curved blade centrifugal fan and a mixed-flow columnar drying cabinet (with 4000 kg capacity of paddy). Working fluid was R-22. Air flow was open-loop. Circulation rate of paddy seed in the drying cabinet was controlled by setting time for fixed seed bed for 20 minutes alternated with flowed bed for 4 minutes.

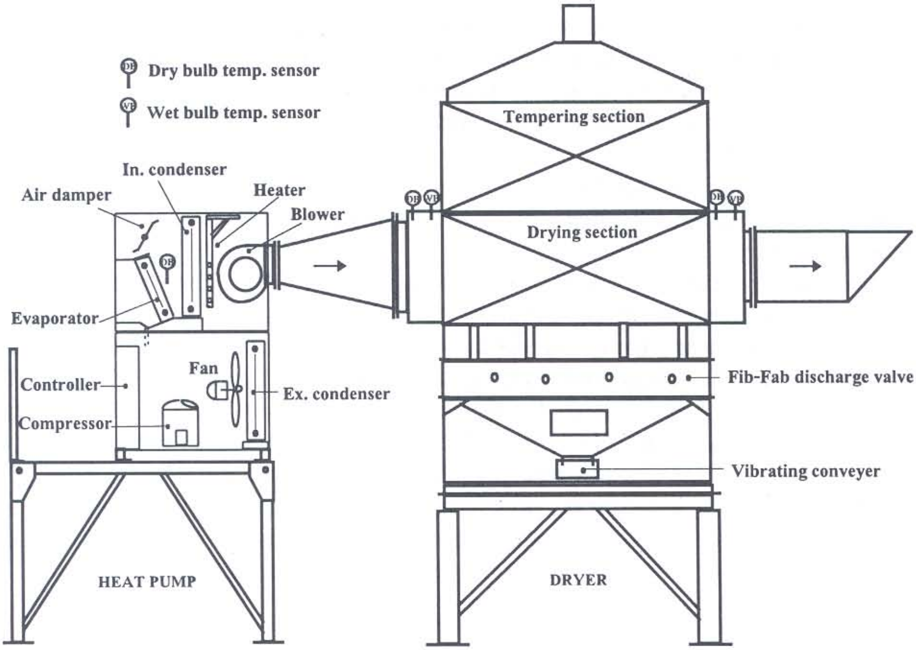

Fig. 1. Schematic diagram of heat pump dryer.

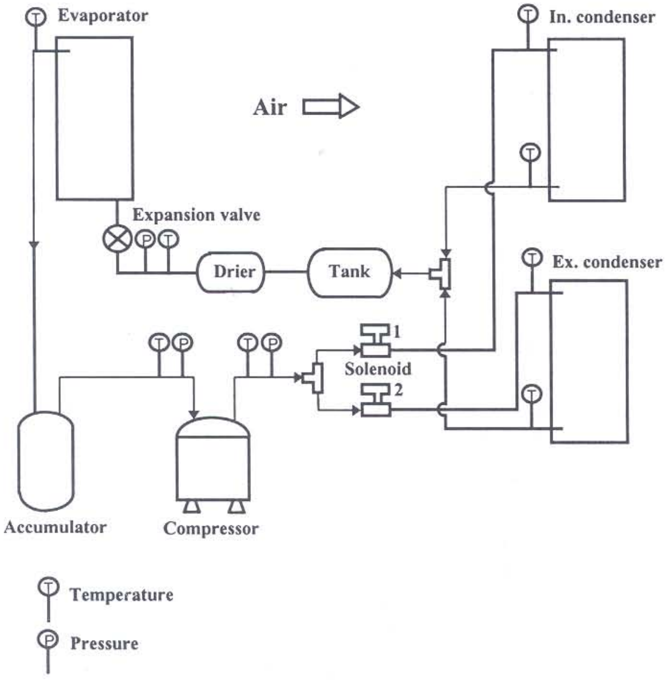

Fig. 2. Schematic diagram of heat pump unit.

Temperatures of air loop and working fluid loop were measured by Chromel-Alumel type K thermocouple connected to a data logger with an accuracy of ±1°C. Bourdon gage (range 0 kPa to 350 kPa, resolution 3.5 kPa) was used to measure pressure in the working fluid loop. At inlet air duct, air velocity was measured by a hot wire anemometer with an accuracy of ±4% and air flow rate was adjusted by a frequency inverter. The quantity of condensed water from the evaporator was measured by a load cell every hour. As energy used in the system was electrical energy, energy consumption was then measured by using a kilowatt-hour meter and a clamp-on meter with an accuracy of ±0.5% .

There were 15 experiments in this research but only four were selected for presentation. In each experiment, air temperature was controlled at 43°C, air flow rate and paddy quantity were 63 $m^3$/min and 4000 kg, respectively. Bypass air ratio was varied at 0%, 30% and 50% in order to study the effect on specific energy consumption. Coefficient of performance of heat pump (COPhp) was defined as the ratio of heat delivered at the condenser to energy input at the compressor, and SMER was defined as water removed from product divided by total energy input.

During drying process, paddy seed of 300 g to 400 g was taken every hour. Moisture content was determined by using air oven method. After a certain storage time, germination and vigor of paddy seed dried by heat pump was tested according to the method used by the Seed Reproducing Center in Surin Province and compared to that obtained from sun drying.

## 3. RESULTS AND DISCUSSION

Results of paddy seed drying from the four experiments are shown in Table 1. Moisture content after drying could be decreased to 11.5% w.b. It was difficult to obtain this moisture level when normal air heating was used (compared to conventional seed dryers operated nearby).

Experimental results showed that COPhp and SMER increased to maximum at evaporator bypass air ratio of 0% and decreased with increasing bypass air ratio (30% and 50%). At zero evaporator bypass air ratio, high flow rate of air passing through the evaporator caused the thermostatic expansion valve open more thus resulted in high flow rate of working fluid entering the evaporator. Consequently, both heat receiving from the evaporator and heat supplying to the internal condenser increased thus reduced energy consumption.

Moisture extraction rate (MER) decreased when adjusting bypass air ratio to 0% and increased when adjusting bypass air ratio to 30% and 50%. It was because the temperature of air which flowed through evaporator at bypass air ratio of 30% and 50% was less than that of 0%. Drying rate was always higher than MER. It could be concluded that open-loop heat pump drying was suitable for paddy seed drying.

The paddy seed used in this research was Kao-Dokmali 105. After drying, paddy sample was stored for approximately 8 weeks before germination and vigour tests, and compared to paddy obtained from sun drying. Results from seed quality testing are shown in Table 2. Quality of paddy seed was very good with mean germination of sun drying and heat pump drying of 98% and 97% and mean vigor of sun drying and heat pump drying of 96% and 95%, respectively.

Total fabrication cost of the prototype of heat pump dryer was Baht 323,407 of which Baht 248,775 was material cost and Baht 74,638 was labor cost. In case of operating time of 24 hours per day and 90 days per year, initial moisture content of 22.2% w.b. and final moisture content of 12.2% w.b., total cost of drying was Baht 2.81 per kilogram water evaporated of which Baht 0.63 was energy cost, Baht 0.41 was maintenance cost and Baht 1.77 was fixed cost. (US$ 1 = Baht 40).

Table 1 Experimental Results of Paddy Seed Drying

| Descriptions | Test nos. | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Ambient conditions | | | | |
| Average temperature, °C | 27 | 27 | 30 | 30 |
| Average relative humidity, % | 70 | 73 | 66 | 67 |
| Conditions of paddy seed | | | | |
| Average moisture content before drying, %w.b. | 22.15 | 13.50 | 13.50 | 13.50 |
| Average moisture content after drying, %w.b. | 12.45 | 11.50 | 11.50 | 11.50 |
| Initial weight, kg | 4000 | 4000 | 4000 | 4000 |
| Drying air conditions | | | | |
| Average temperature, °C | 41 | 43 | 44 | 42 |
| Average relative humidity, % | 24 | 22 | 21 | 21 |
| Specific air flow rate, m$^3$/min-m$^3$paddy | 9 | 9 | 9 | 9 |
| Rate of paddy circulation, ton/h | 1.60 | 1.60 | 1.60 | 1.60 |
| Drying time, h | 23 | 10 | 10 | 10 |
| Evaporator bypass air ratio, % | 50 | 50 | 30 | 0 |
| Performance of heat pump | | | | |
| Drying rate, kg water evap./h | 19.27 | 9.04 | 9.04 | 9.04 |
| MER, kg water condensed/h | 8.43 | 8.23 | 6.98 | 6.31 |
| SMER, kg water evap./kW-h | 1.95 | 1.03 | 1.20 | 1.27 |
| $COP_{hp}$ | 4.18 | 4.39 | 4.79 | 5.18 |
| Specific energy consumption, MJ/kg water evap. | 1.85 | 3.51 | 2.99 | 2.83 |

Remark: MER is moisture extraction rate from evaporator
SMER is specific moisture extraction rate
$COP_{hp}$ is coefficient of performance of heat pump

Table 2 Paddy Seed Qualities

| Test nos. | Germination | | Vigour | |
|---|---|---|---|---|
| | Sun drying | Heat pump drying | Sun drying | Heat pump drying |
| 1 | 99 | 96 | 97 | 92 |
| 2 | 96 | 97 | 95 | 96 |
| 3 | 97 | 97 | 96 | 93 |
| 4 | 100 | 96 | 97 | 99 |
| Average | 98 | 97 | 96 | 95 |
| Standard | >85 | >80 | >80 | >80 |

Comparing to fluidized bed paddy drying with high drying air temperature and higher range of moisture content, i.e., from 24.6% to 20.5% w.b., total cost was Baht 1.48 per kilogram water evaporated of which Baht 0.53 was fixed cost and Baht 0.95 was energy cost [7]. At lower range of moisture content, it would be much higher and it should be noted that it is generally not recommended to dry seed with high air temperature.

## 4. CONCLUSION

Important results of paddy seed drying using a prototype of heat pump working with a mixed flow (LSU type) dryer (capacity of 4000 kg of paddy seed) with air flow rate of 63 $m^3$/min under temperature and relative humidity of ambient air in ranges of 27°C to 30°C and 66% to 73%, respectively could be drawn as follows:

- Open-loop system was suitable for paddy seed heat pump drying.
- The appropriate evaporator bypass air ratio was 0%, which produced maximum values of COPhp and SMER.
- The quality of paddy seed in terms of germination and vigor obtained from heat pump drying was very good.
- Total cost of drying was 2.81 Baht per kilogram water evaporated of which 0.63 Baht was electricity cost, 0.41 Baht was maintenance cost and 1.77 Baht was fixed cost, with an exchange rate of US$ 1 = 40 Baht.

## 5. ACKNOWLEDGMENT

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