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Rotary Dryer of Paddy with Closed-Loop Oscillating Heat Pipe with Check Valves (CLOHP/CV) Heat Exchanger

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ABSTRACT

An experimental study of the rotary dryer of rice paddy with using Closed-loop oscillating heat pipe with check valves (CLOHP/CV) heat exchanger. The CLOHP/CV was made of a copper tube with an inner diameter of 2.03 mm bent into 40 meandering turns with 2 sets. The number of check valves was 2. The combined lengths of the evaporator, adiabatic and condenser sections were equal to 50 mm. The working fluids used were R134a, ethanol and water with a filling ratio of 50 % of the total volume and operating conditions with inlet hot gases from used oil burner. The rotary dryer has inner diameter of 380 mm with length of 2000 mm and the feed rate of the paddy of 1 kg/min. At evaporator section the hot gas velocity was set at 0.5, 1 and 1.5 m/s. Experimental results found that the R134a with 0.5 m/s as appropriate parameter values for using in drying the paddy, the moisture content of paddy with initial moisture content of 24.8% wb decreased to 17.5% wb. The drying experiments were carried out for quality test of the paddy including of the percentage germination and broken rice of rice grain were the result of closed proximity between dry and normal paddy.

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INTRODUCTION

Thailand is primarily an agricultural country. Rice is a dominant crop for almost all farmers more than 46.9 percent of Thailand farmers grow rice (Office of agricultural economic, 2012). Thailand is the world leading rice exporter. The first half of 2014 the volume had been ranked as the number one in the global rice market while India holds the number two with VietNam in at number three (Thai Rice Exporters Association, 2014). The moisture content of paddy is one of the main problems in the post-harvest. A paddy is usually harvested about 20-25% wet basis (wb) of the moisture content (Weerachet Jittanit *et al*., 2010). The moisture content for long and safe storage should be of 14 % db (Yutthana Tirawanichakul *et al*., 2004). Drying is the best method for used to reduce the moisture content from paddy before storage. There are several ways of drying paddy, such as solar drying (Mehdizadeh1 and Zomorodian, 2009), microwave-vacuum drying (Cheenkachorn 2007), fluidized-bed drying (Chaiyong Taechapairoja *et al*., 2003) and rotary drying (Regaladoa and Madambab, 2007). The rotary drum dryer was selected to drying paddy because high efficiency, regular temperature distribution, low energy consumption and convenient for transportation. Many researchers have studied focus on new drying techniques. However, the energy consumption and alternative energy are an important in the drying process. Waste lubricant oils are alternative fuel sources with low cost and high heating value. About 230 million liters of waste lubricant oil discharge from engine parts annually in Thailand (Pollution Control Department, 2014). Generally, the waste lubricant oils used the burner employed to produce hot gases for drying, but the direct hot gas cannot be used for this purpose. Due to the gas may also be contaminated paddy by hydrocarbons. The hot gas must be passes the heat exchanger. The Closed-loop oscillating heat pipe with check valve (CLOHP/CV) is efficient heat transfer device for high heat load. The CLOHP/CV includes simplicity of construction, high thermal performance, no wick structure and operating in any position. There are many research studies based on the CLOHP/CV such as, Pattanapol Meena *et al.* (2013) was designed to test a black galingale dryer working together with a CLOHP/CV heat exchanger. The experimental results showed that the moisture content of the black galingale decreased from 143% wb to 2.88% wb. Supirattanakul (2011) studied the application and working fluid type of a closed-loop oscillating heat pipe with check valves on energy consumption in split type air conditioning system. It was found that the energy consumption in the split type air

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conditioning system using CLOHP/CV was saving more than the split type air conditioning system without CLOHP/CV. Rittidech *et al*. (2009) studied the application of a CLOHP/CV solar collector. It was a very useful device for pre-heat water.

Therefore, this study was conducted to investigate the following objectives:
(1) To study the feasibility of the rotary dryer of rice paddy with using CLOHP/CV heat exchanger to reduce the moisture content of paddy.
(2) To study the effect of working fluids and hot gas velocity on the heat transfer characteristic and effectiveness of CLOHP/CV heat exchanger.
(3) To investigate the effects of drying by rotary dryer with using CLOHP/CV heat exchanger on the quality of paddy.

MATERIALS AND METHODS

2.1 Paddy drying condition:

RD6 rice was chosen for this study because the study area focuses in the northeast region of Thailand. This region is known for the glutinous rice production and consumption. The initial moisture content of harvested paddy during experiments was varied between 20-25% wb.

2.2 Rotary drum dryer:

Normally, rotary drum dryer employs high temperature convective drying to dry large volumes of paddy with a short mean residence time due to the drying cylinder with limit length. However, high temperature causes a starch to be gelatinization, thereby affecting product quality of rice. Jaiboon, *et al*. (2009) presented the effects of high temperatures (90-150 ^{o}C) on qualities of waxy rice. It was found that higher drying temperature fused the starch granules of waxy rice and then the degrees of crystallinity decreased as shown in fig.1. The degrees of starch gelatinization at drying temperatures (90-150 ^{o}C) were in the range of 4.8 - 35.4%. Therefore, this research has chosen temperatures of 90 ^{o}C for drying of the paddy.

The rotary dryer is designed by mathematical model was developed by Kittipong Kullamart (1994) for drying temperature less than 115 ^{o}C. The research describes the effect of design parameters such as, feed rate of paddy, slope of the cylinder, air flow rate, moisture of paddy, speed of rotary drum, length and diameter of drum their relation to the mean residence time of paddy in rotary drum. The mathematical model is expressed as,

$$t_m = t_1 + t_2 \quad (1)$$

$$t_m = A[L/(N^n D \tan\theta)] + BV \quad (2)$$

and

$$A = (0.0930186 - 0.121473F) + (0.00474537 + 0.143728F)\theta$$

$$n = (0.8097406 - 0.492370F) + (-0.033137 + 0.561410F)\theta$$

$$B = -3.96647 + 0.10583\,(F \times t_1)$$

where F is feed rate of paddy (kg/min), θ is slope of the cylinder (degree), L is length of drum (m), D is diameter of drum (m), N is speed of rotary drum (rpm) and V is air flow rate (m/s).

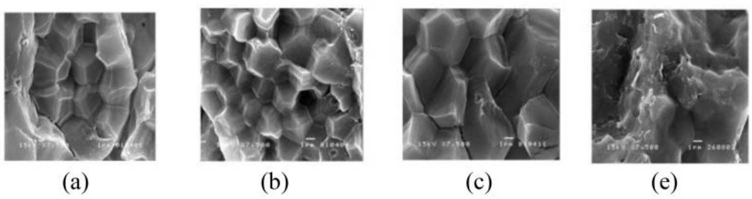

Fig. 1: samples dried at different temperatures by Jaiboon, *et al*. (2009) (a) reference waxy rice (b) Waxy rice dried at 90 ^{o}C (c) Waxy rice dried at 110 ^{o}C (e) Waxy rice dried at 150 ^{o}C**.**

2.3 Closed-loop oscillating heat pipe with check valves (CLOHP/CV) heat exchanger:

The CLOHP/CV heat exchanger in this experiment was designed under condition of the drying temperature (90 ^{o}C) as shown in fig.2. The heat transfer rate required (Q_{dry}) in drying is calculated as follows:

$$Q_{dry} = \dot{m} C_p (T_{dry} - T_a) \quad (3)$$

where $\dot{m}$ is mass flow rate of air inlet (kg/s), C_p is specific heat capacity at constant pressure of air inlet (kJ/kg ^{o}C), T_{dry} is drying temperature (^{o}C) and T_a is ambient temperature (^{o}C).

The Q_{dry} value used to calculate the heat transfer rate of the CLOHP/CV heat exchanger is solved by the correlation from (Rittidech *et al*., 2007). The standard deviation of this equation is ±30%.

$$KU_{90} = \frac{q}{h_{fg}\rho_v\left[\sigma g(\rho_l - \rho_v)/\rho_v^2\right]^{1/4}} \quad (4)$$

and

$$KU_{90} = 0.00041\left[Bo^{2.2}Fr^{1.42}Ja^{1.2}\,\mathrm{Pr}^{1.02}\left[\frac{\rho v}{\rho l}\right]^{0.98} Rcv^{1.4}We^{0.8}\left[\frac{L_e}{D_i}\right]^{0.5}\right]^{0.107} \quad (5)$$

The heat transfer rate calculates from KU_{90} and transfer to heat flux (q, W/m^2) as shown in equation (6):

$$Q_{CLOHP/CV} = q \times A \quad (6)$$

where h_{fg} is enthalpy of working fluid (kJ/kg), σ is surface tension (N/m), g is acceleration of gravity (m/s^2), A is condenser surface area (m^2) and KU_{90} indicates the ratio of heat flux through the CLOHP/CV to the critical heat flux of the working fluid.

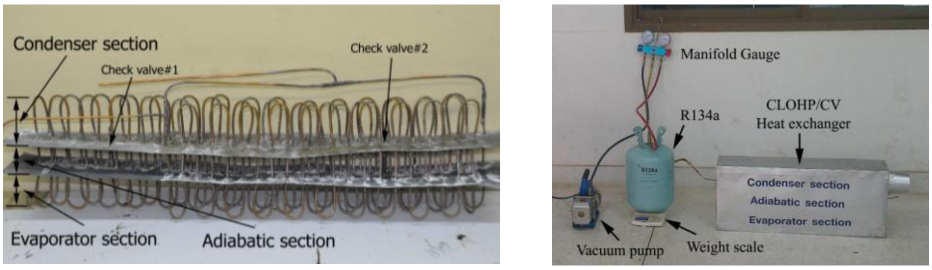

Fig. 2: The CLOHP/CV heat exchanger and working fluid charging.

2.4 Experimental set-up:

Fig.3 shows the experimental setup and measurement procedure. The CLOHP/CV was made of a copper tube with 2.03 mm inside diameter and there were 40 meandering turns with 2 sets. When the number of check valves was 2. The evaporator, adiabatic and condenser section lengths were equal of 50 mm. Water, Ethanol and R134a were chosen as working fluids with a filling ratio of 50% of total volume. A waste oil burner is a device to generate a hot gas to evaporator section (Namphon Papatpaiboon, 2011). The hot gas velocity was set at 0.5, 1 and 1.5 m/s. The air flow rate was measured with an air flow meter (Testo series 445) with ±0.05 ^{o}C accuracy, while the condenser section was connected to the fresh-air section and was beneficial for pre-heating the air to the rotary dryer (diameter of 380 mm and length of 2000 m). The rotary speed was controlled at 20 rpm. The degree of tilt angle was set at 1^o. RD6 rice was initial moisture content of 24.8% wb with the feed rate of the paddy of 1 kg/min. The moisture content can be determined by an oven method. The temperatures were measured using type K thermocouples with an Agilent 34970A (±0.1°C accuracy) system attached to the inlet and outlet of the condenser section (T_{ci} and T_{co}) to calculate the heat transfer rate (*Q*) using the calorific method and the effectiveness (ε) are given by**:**

$$Q = \dot{m}C_p\,(T_{co} - T_{ci}) \quad (7)$$

and

$$\varepsilon = \frac{Q}{Q_{\max}} = \frac{\dot{m}C_p(T_{co} - T_{ci})}{C_{\min}(T_{hi} - T_{ci})} \quad (8)$$

RESULTS AND DISCUSSION

The CLOHP/CV heat exchanger for a paddy dying process was divided into three parts: evaporator, adiabatic and condenser sections, the evaporator section was in contact with the heat source from the waste oil burner, oil flow rate was controlled at 0.1 l/mim, combustion air flow was 20 m/s. The hot gas temperature remains constant at 254.67 ºC as shown in fig.4. The condenser section was connected to the fresh-air section from the blower and outlet temperature of 80.6 ^{o}C from maximum heat transfer rate of R134a with hot gas velocity of 0.5 m/s.

3.1 Effect of hot gas velocity on CLOHP/CV heat exchanger performance

Fig.5 and 6 shows the effect of hot gas velocity on CLOHP/CV heat exchanger performance. In the evaporator section, the hot gas velocities were 0.5, 1 and 1.5 m/s. It can be seen that, when the hot gas inlet velocity decreases, the heat transfer rate and effectiveness also increases. The hot gas velocity of 0.5 m/s with R134a shows the highest the heat transfer and effectiveness of 262.67 kW/m^2 and 0.44, respectively. This is because the capacity to absorb large amounts of heat from the lower hot gas velocity (0.5 m/s). When the hot gas velocity of evaporator increased (1.5 m/s), the CLOHP/CV heat exchanger ability to receive heat is reduced. Thus the decrease of heat transfer rate and effectiveness is the cause of a higher velocity.

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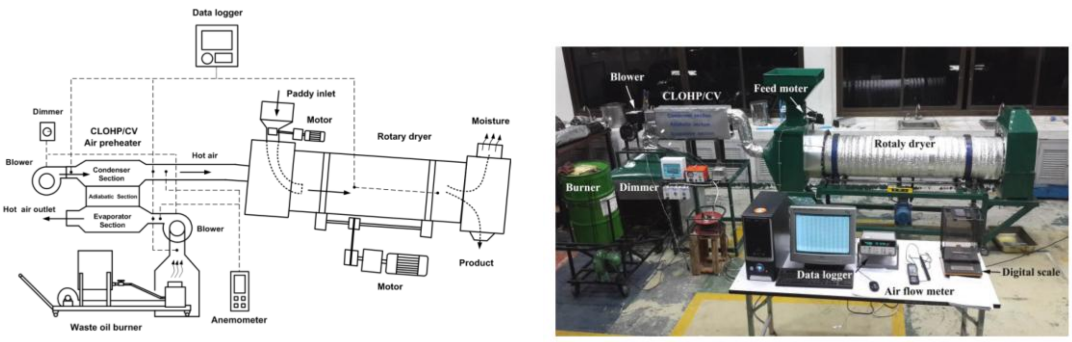

(a) (b)

Fig. 3: (a) Experimental set-up (b) measurement procedure.

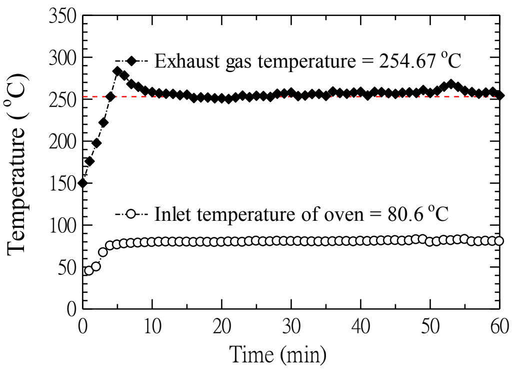

Fig. 4: Inlet temperature of oven and exhaust gas temperature.

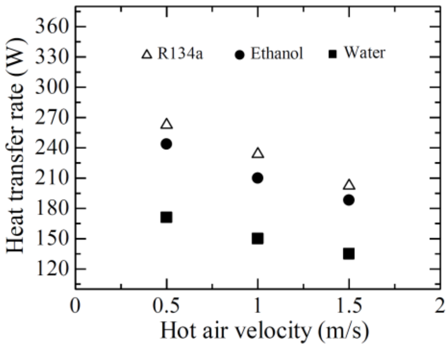

Fig. 5: Effect of hot gas velocity on heat transfer rate of CLOHP/CV heat exchanger.

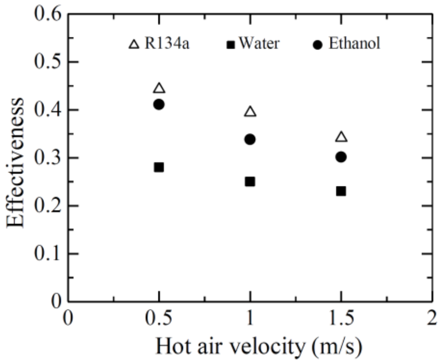

Fig. 6: Effect of hot gas velocity on effectiveness of CLOHP/CV heat exchanger. .

3.2 Effect of working fluid on CLOHP/CV heat exchanger performance:

Fig.7 and 8 shows the effect of working fluids on CLOHP/CV heat exchanger performance. R134a, ethanol and water were employed with the hot gas velocities were 0.5, 1 and 1.5 m/s. It can be seen that the working fluids changed from R134a, ethanol and water with the hot gas velocities were 0.5 m/s, the heat transfer rate and effectiveness were decreased from 262.67, 243.61 and 171 kW/m^2 and 0.44, 0.41 and 0.28, respectively. This is because the relation of boiling and latent heat of R134a, when heat is applied to the evaporator section, the vapor grows rapidly and the vapor sustains fast movement for a short time to transfer heat from the evaporator section to condenser section. As results, the heat transfer rate and effectiveness were increases.

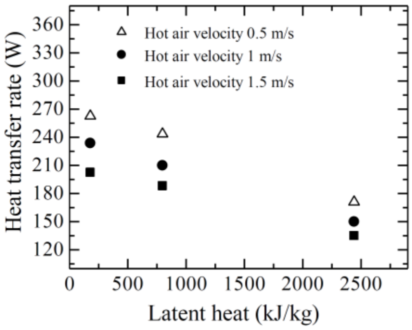

Fig.7: Effect of working fluid on heat transfer rate of CLOHP/CV heat exchanger.

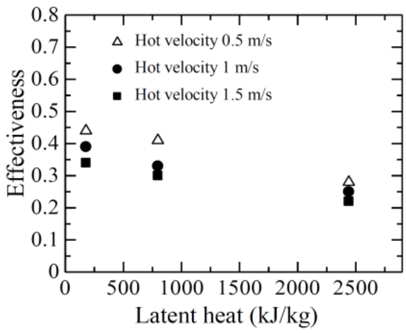

Fig. 8: Effect of working fluid on effectiveness of CLOHP/CV heat exchanger.

3.3 Quality of paddy:

Quality of paddy is an important factor in relation to the drying by rotary dryer of rice paddy with using CLOHP/CV heat exchanger. The quality of paddy considered in moisture content, germination and broken rice. Experiment of rotary dryer of rice paddy with using CLOHP/CV heat exchanger, moisture content is usually determined based on wet basis can be calculated by:

$$Mw = \frac{w_1 - w_2}{w_1} \times 100$$

where w_1 is initial weight (kg) and w_2 is final weight (kg).

The best parameters of heat transfer rate was selected for paddy drying (R134a with the hot gas velocity of 0.5 m/s), the fresh-air outlet temperature of condenser section was 80.6 ^{o}C into the rotary dryer is lower than the design condition (90 ^{o}C). Results showed that was able to dry paddy rice from initial moisture content of 24.8% wb to 17.5% wb.

Germination testing is considered as the important quality of seeds, the standard germination test (ISTA, 1999) can be used. The percentage germination (GP) is calculated from the seeds germinated from the total seeds evaluated. It can be seen that the percentage of germination over seeds drying by rotary dryer of rice paddy with using CLOHP/CV heat exchanger was 69 percent of germination, while normal seeds was 73 percent of germination. This result shown the percentage of germination insignificantly changed with drying by rotary dryer of rice paddy with using CLOHP/CV heat exchanger.

The broken rice testing at laboratory of Sakon Nakhon rice seed center, Thailand. The paddy samples of 250 grams were randomly chosen to milling (Milling, NW 300, Thailand) and a rotary indent separator (SINGHA SIAM, MS 33 CM,Thailand) was used for separating head and broken rice. The broken rice percentage is calculated from the weight of broken rice from the total milled rice in grams evaluated. It can be seen that the broken rice percentage over seeds drying by rotary dryer of rice paddy with using CLOHP/CV heat exchanger was 28 percent of broken rice, while normal seeds was 25.9 percent of broken rice.

4. Conclusions:

It can be summarized that the rotary dryer of rice paddy with using CLOHP/CV heat exchanger to reduce the moisture content of paddy. The maximum heat transfer rate and effectiveness was 262.67 kW/m^2 and 0.44 at R134a with hot gas velocity of 0.5 m/s. The best parameters of heat transfer rate was selected for paddy drying (R134a with the hot gas velocity of 0.5 m/s), the maximum fresh-air outlet temperature of condenser section was 80.6 ^oC into the rotary dryer. Results showed that was able to dry paddy rice from initial moisture content of 24.8% wb to 17.5% wb, the percentage of germination over seeds drying was 69 percent of germination, while normal seeds was 73 percent of germination and the broken rice percentage over seeds drying was 28 percent of broken rice, while normal seeds was 25.9 percent of broken rice. The results show that the rotary dryer of rice paddy with using CLOHP/CV heat exchanger was very useful device for reducing the moisture content of paddy.

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