Agricultural Sci. J. 37 : 5 (Suppl.) : 300-308 (2006) ว. วิทย. กษ. 37 : 5 (พิเศษ) : 300-308 (2549)

# Performance Analysis of Adsorption / Regeneration of Desiccant Tray for Energy Saving in Bed-type Longan Hot-air Drying

B. N. Hung[1], A. Nuntaphan[2] and T. Kiatsiriroat[3]

## ABSTRACT

Longan is an economic fruit in the northern part of Thailand. Dried longan is also one main product which is very popular in the region. The common technique to produce dried longan is bed-type hot air drying of which the air is heated directly with LPG before feeding to the longan bed for drying. However, this kind of dryer has low thermal efficiency. One method for increasing its efficiency is to reduce the humidity of air and increase its temperature before entering the combustion chamber.

In this work, a set of tray-typed silica gel with three different sizes of tray thickness which are 2.5, 5.0 and 7.5 cm is presented. Each size of the desiccant tray is tested the adsorption/regeneration performances in a wind tunnel. The parameters related such as the tray thickness, the air velocity and the air moisture content including the air temperature are related. The experimental model is also used to design a desiccant unit of bed-type longan dryer. It could be found that performance of the modified longan dryer is better than the common one.

**Keywords**: Desiccant bed, Bed-type longan drying, Performance analysis

## Introduction

Currently, the farmer in the northern part of Thailand produces enormous longan. According to the report of Office of Agricultural Economics [1], it has been shown that Thailand produces longan more than 600,000 tons in 2004. It is estimated that more than 60% of the fresh longan is transformed to dried longan and is exported to other countries

Regarding the drying process of longan, most of farmer prefers to use the bed-type dryer because of its cheaper than other dryers. The Cooperative Promotion Department [2] reported in 2004 that the total number of this bed-type longan dryer is more than 24,000 units in the northern part of Thailand. This longan dryer uses LPG (Liquid Petrol Gas) or diesel oil as a fuel. From the previous study [2], it was found that the thermal efficiency of bed-type longan dryer is about 30%. Many attempts have been made to increase the performance of longan dryer. One method to improve the dryer efficiency is the application of solid desiccant for reducing the moisture of air before entering the combustion chamber of longan dryer. When the moisture of air is decreased, the fuel energy for increasing the air temperature is reduced. Moreover, the adsorption process of desiccant is the exothermic process. Therefore, the outlet temperature of air leaving the desiccant unit is raised and thus this phenomenon promotes the fuel saving too.

Several reports described the increase of efficiency when using the solid desiccant for reducing the moisture of air. Kiatsirioat et al [3] used a solid desiccant formed in a staggered tube bank arrangement for the reduction of energy consumption in a heat pump dehumidifier. The results of this study indicated that there was a high potential in reducing the moisture contents of the air before entering the evaporator and the energy consumption of the heat pump by using the solid desiccant. Ming et al [4] pointed out the reduction of fuel consumption approximately 15% for agricultural product dryer. Nuntaphan et al [5] indicated the increase of longan efficiency by 4% when using tray-type desiccant unit with longan dryer.

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However, there is very few discussion about the suitable size of desiccant unit. Although Nuntaphan et al [5] recommended using the tray-type unit, unfortunately their research did not report the suitable size of tray, in particular the tray thickness. Therefore, in our research, the performance of adsorption and regeneration process of tray type desiccant unit with different tray thickness has been investigated. In addition, the performance of longan dryer with desiccant tray is calculated by using the simulation program.

## Research Methodology

Since, the objective of this research is to find out the adsorption/regeneration performance of longan dryer with tray-type desiccant unit. Therefore, this work can be divided into two parts. For the first part, the performance of desiccant tray with different tray thickness is investigated and the models for predicting the adsorption/regeneration processes are also developed. The second part studies the performance of longan dryer with tray-type desiccant unit by using computer simulation. The research method and instrumentation of each part is as follows:

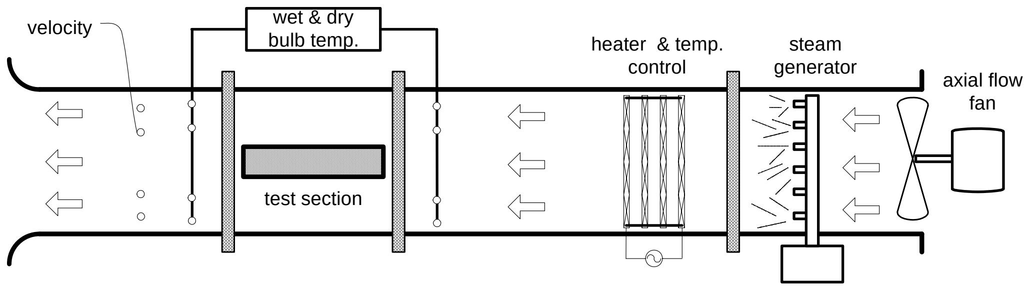


**Figure 1** Experimental apparatus.

For the first part, the effect of tray thickness on the adsorption/regeneration performances is observed by experimental tests in a wind tunnel. Figure 1 shows the experimental apparatus of this part. The desiccant tray is mounted in the wind tunnel. For the testing, the air is fed by an axial flow fan and flowing along the tunnel. The temperature and humidity of air are adjusted by an electric heater and a steam generator respectively. Then the air flows through the desiccant tray while the desiccant adsorbs or rejects the moisture to the air stream. It should be noted that the inlet and outlet temperatures and the humidity of air at the desiccant unit are collected by a set of K-type thermocouple and a humidity multi-meter (Testo 615 with a measuring range of 5 to 95 %, accuracy of $\pm$ 3% RH), respectively. Furthermore, the velocity of air is measured by a hot wire anemometer (Testo 405-V1 with a measuring range of 0 to 10m/s, accuracy of $\pm$ 0.05m/s) and the mass of desiccant is recorded every half an hour using a digital balance of 2g resolution with a measuring range of 0.04 to 15 kg.

Table 1 presents the testing conditions of both adsorption and regeneration processes and the photograph of tray is illustrated in figure 2.

The results of the first part are employed for developing the correlations to predict the adsorption and regeneration rates of the desiccant tray. The multiple regression method is selected as a tool for constructing these models.

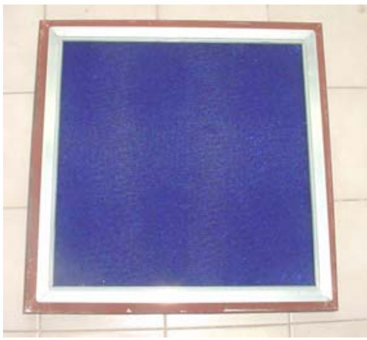

**Figure 2** Photograph of desiccant tray.

**Table 1** Operating conditions during adsorption and regeneration operation

| Items | Data |
|---|---|
| 1. Tray characteristics | |
| - dimensions | square tray with 48cm width and 2.5, 5.0, 7.5 cm thicknesses |
| Silica gel | |
| Size | 3.5mm |
| Surface area | $750 m^2/g$ |
| Pore volume | $0.35 cm^3/g$ |
| Bulk density | 0.8kg/l |
| 2. Adsorption process | |
| - air mass flow rate | 0.1-0.5 kg/s |
| - air inlet temperature | 25-40 °C |
| - moisture content of inlet air | $0.009\text{-}0.015\ kg_{water}/kg_{dry\ air}$ |
| - testing interval | 6 hr |
| - mass of desiccant | 3,628, 7,526, 10,884 g for 2.5, 5.0, 7.5 cm tray thicknesses |
| 3. Regeneration process | |
| - air mass flow rate | 0.1-0.5 kg/s |
| - air inlet temperature | 55-80 °C |
| - moisture content of inlet air | $0.009\text{-}0.015\ kg_{water}/kg_{dry\ air}$ |
| - testing interval | 6 hr |
| - mass of desiccant | 3,628, 7,526, 10,884 g for 2.5, 5.0, 7.5 cm tray thicknesses |

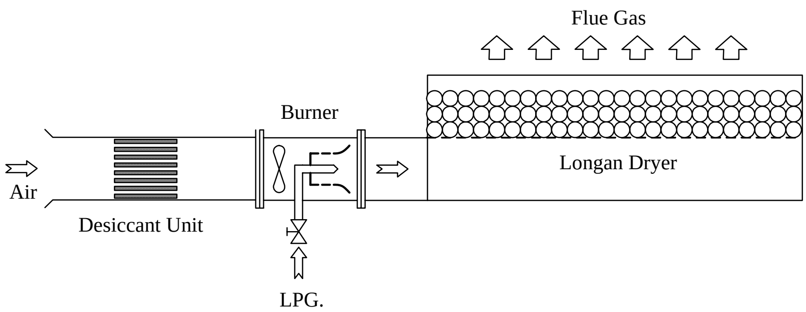


**Figure 3** Longan dryer with desiccant unit.

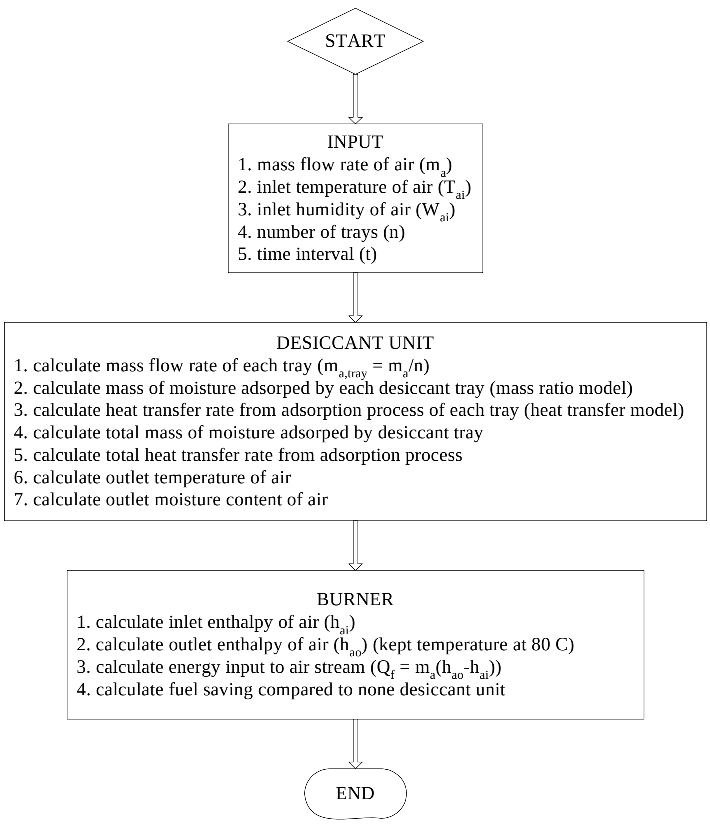


**Figure 4** Flow chart for evaluating the energy saving of longan dryer having desiccant unit.

For the second part, a set of the desiccant trays is assumed to integrated in a bed-type longan dryer. The computer program is constructed for calculating the energy saving of the interested system. Firstly, the air flow through the desiccant unit is assumed uniform flow pattern. In case of using multi-trays, the air stream acting with each tray is assumed to have equal mass flow rate, temperature and humidity. Moreover, the inlet temperature of the longan dryer is kept constant at 80 ºC with 60 hrs operating time for each drying batch. Figure 3 shows the schematic sketch of the longan dryer having desiccant unit. From this figure, the ambient air is flowed through the desiccant unit via the burner air fan. When the air passes the desiccant unit, the moisture is absorbed by the desiccant. The temperature of the leaving air is higher than that of the entering air as a result of the exothermic reaction during the adsorption process. After that the air flows into the combustion chamber and the air temperature is raised up to 80 ºC. The hot and dry air then flows into the dryer and releases the heat to longan. The flue gas leaves the dryer at the upper part of the longan bed.

The flow chart for evaluating the energy saving of longan dryer having desiccant unit is shown in figure 4. The inlet conditions of air stream and number of trays are input to the simulation program. Then the conditions of air leaving the desiccant unit are calculated. These conditions are used for calculating the inlet enthalpy of the air entering the burner. After that, the energy input for rising the air temperature is predicted by assuming the outlet temperature of air leaving the burner at 80 ºC. The energy saving of this system can be evaluated by compares this result with the non-desiccant unit.

## Results and Discussion

### 1 Performance of Desiccant Tray

In this work, the performances of desiccant tray in case of adsorption and regeneration processes are shown in term of mass ratio. The mass ratio is defined as the mass of water adsorbing or rejecting from the desiccant divides by the mass of dry desiccant.

The effect of tray thickness on the performance of desiccant tray is shown in figures 5-6. In case of adsorption process (figure 5), it is found that the mass ratio in case of the tray thickness equals to 2.5 cm is higher than those of 5.0 and 7.5 cm. This result comes from the effect of air entering into the desiccant bed. Lower thickness of the tray, easier the air penetrates into the desiccant bed. Hence, the mass transfer rate of moisture to the desiccant is increased. This phenomenon also occurs with the regeneration process shown in figure 6 that the 2.5 cm tray thickness gives the highest performance.

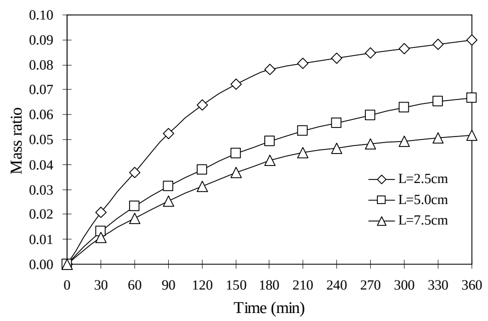


**Figure 5** Adsorption performance of desiccant unit with difference tray thickness.
($T_{ai}$ = 26.6 $^{o}$C, $m_a$ = 0.28 kg/s, $W_{ai}$ = 0.00973 kg water/kg dry air)

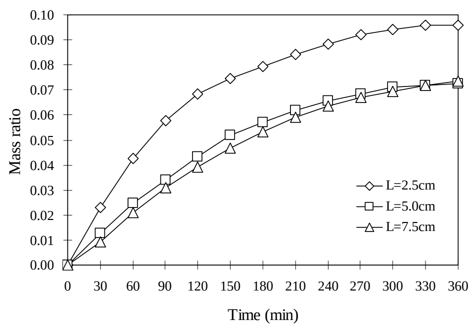


**Figure 6** Regeneration performance of desiccant unit with difference tray thickness.
($T_{ai}$ = 65.0 $^{o}$C, $m_a$ = 0.28 kg/s, $W_{ai}$ = 0.00973 kg water/kg dry air)

From the above results, the 2.5 cm tray thickness is selected as the specimen for studying the effect of various parameters because of its best performance.

Figures 7-9 show the effects of the air mass flow rate, the inlet temperature of air and the air humidity on mass ratio in the adsorption process. In overall, there is a clear trend of increasing of mass ratio with time. This result is the normal characteristic of the desiccant. However, as shown in figures 7-9, the increasing rate of mass ratio tends to decrease time more than 120-150 min. This condition reveals that the desiccant is nearly saturated with moisture.

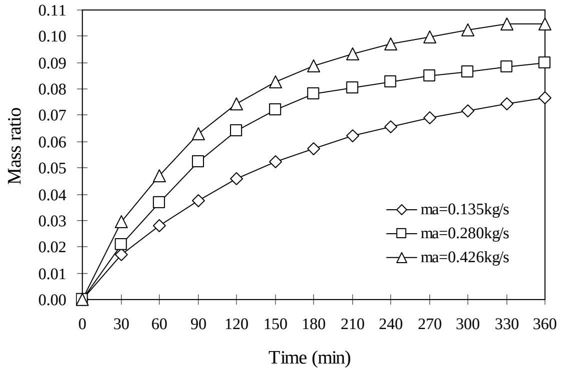


**Figure 7** Adsorption performance of desiccant unit with difference air mass flow rate. ($T_{ai}$ = 26.6 $^{o}$C, $W_{ai}$ = 0.00973 kg water/kg dry air).

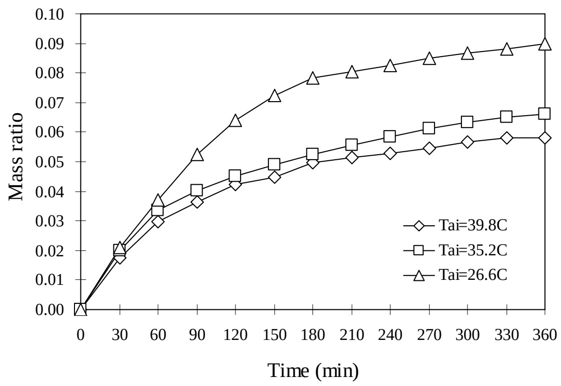


**Figure 8** Adsorption performance of desiccant unit with difference air inlet temperature. ($m_a$ = 0.28 kg/s, $W_{ai}$ = 0.00973 kg water/kg dry air).

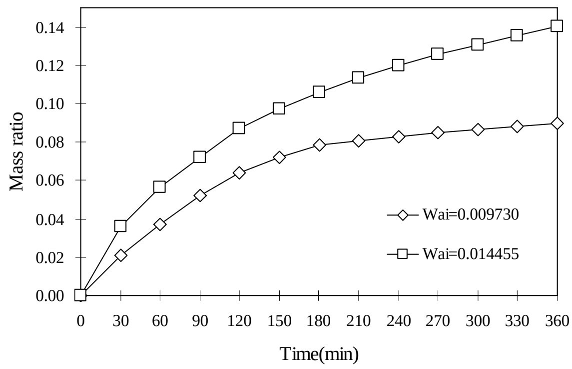


**Figure 9** Adsorption performance of desiccant unit with difference moisture content in air. ($T_{ai}$ = 26.6 $^{o}$C, $m_a$ = 0.28 kg/s).

From figure 7, it can be assumed that higher mass flow rate gives higher performance. The observed increased in mass transfer coefficient could be attributed to the increase of air mass flow rate. However, if the inlet temperature is increased, there is a decrease of adsorption performance (as shown in figure 8).

Normally, the mass transfer of moisture from the air into the desiccant is strongly depended on the density difference of moisture between the air and desiccant. This relation is shown in equation 1.

$$R = h_m A_s (\rho_{ma} - \rho_{ms}). \quad (1)$$

$R$ is mass transfer of moisture from the air stream to the desiccant, $h_m$ is mass transfer coefficient, $A_s$ is surface area of desiccant, $\rho_{ma}$ and $\rho_{ms}$ are densities of moisture in the air and desiccant respectively.

In case of increasing the inlet air temperature, the temperature of desiccant is increased correspondingly. Then the density of moisture in the desiccant is also increased and lower mass transfer rate of moisture from the air to desiccant is obtained.

The effect of moisture content in the air is presented in figure 9. It shows the increase of mass ratio with the moisture content. This result may be explained by using equation 1 that the increase of moisture content in the air stream leads to the increase of density of moisture in the air. In this scenario, the mass transfer of moisture from the air to desiccant is increased.

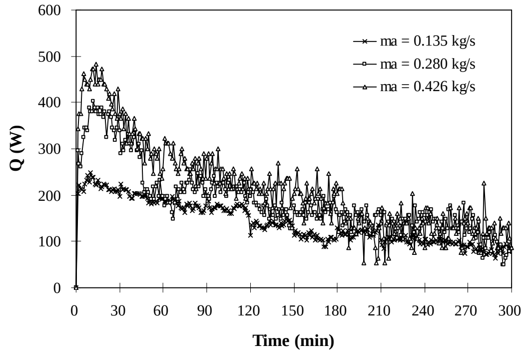


**Figure 10** Heat transfer rate from adsorption process with different mass flow rate of air.
($T_{ai}$ = 26.6 °C, $W_{ai}$ = 0.00973 kg water/kg dry air).

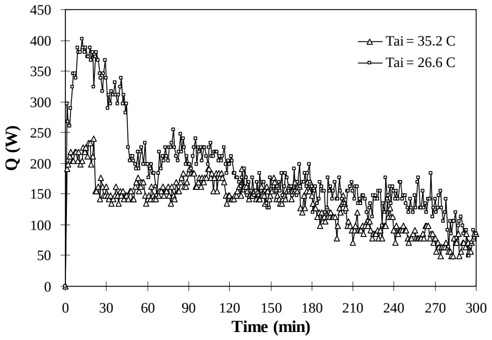


**Figure 11** Heat transfer rate from adsorption process with different air inlet temperature.
($m_a$ = 0.28 kg/s, $W_{ai}$ = 0.00973 kg water/kg dry air).

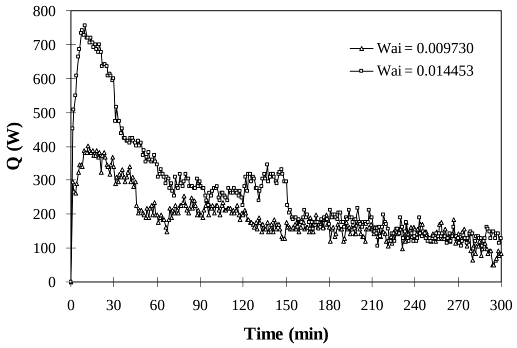


**Figure 12** Heat transfer rate from adsorption process with different air moisture content.
($T_{ai}$ = 26.6 °C, $m_a$ = 0.28 kg/s).

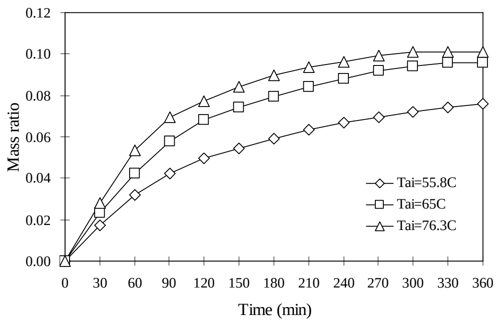


**Figure 13** Regeneration performance of desiccant unit with difference air inlet temperature.
($m_a$ = 0.28 kg/s, $W_{ai}$ = 0.00973 kg water/kg dry air).

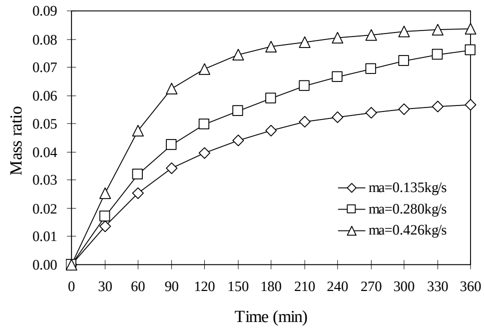


**Figure 14** Regeneration performance of desiccant unit with difference mass flow rate of air.
($T_{ai}$ = 55.8 °C, $W_{ai}$ = 0.00973 kg water/kg dry air).

In the adsorption process, the desiccant is not only reduced the humidity in the air stream but it can also increases the temperature of air. This result comes from the exothermic reaction of adsorption process. Figures 10-12 show the heat transfer rate released from the desiccant. For higher humidity ratio, or higher air mass flow rate or lower inlet air temperature, the heat transfer rate is increased correspondingly.

Regarding the regeneration process, the effects of inlet air temperature and mass flow rate are shown in figures 13-14 respectively. It is apparent from figures 13-14 that there is an increase of mass ratio (the mass of water rejected from the desiccant divides by the mass of dry desiccant) with the inlet temperature and mass flow rate. These results can be explained by using the mass transfer equation of the regeneration process as follows:

$$R = h_m A_s \left( \rho_{ms} - \rho_{ma} \right) \tag{2}$$

In case of regeneration process, the density of moisture in the desiccant is higher than that of the air stream. Thus, the moisture is transferred from desiccant to air. Regeneration temperature and mass flow rate of air play important roles as the driving force of the mass transfer. When increasing the inlet temperature, higher temperature of desiccant and the increasing of moisture density in the air are obtained. Hence, the mass transfer or the mass ratio is increased. While the mass flow rate of air is increased, the mass transfer coefficient is increased correspondingly and equation 2 shows the raising of mass transfer.

The models for predicting the mass ratio in case of adsorption and regeneration processes are also developed in this work. These models are as follows:

Adsorption process

$$Mass\ ratio = 16.172 t^{0.53099} m_a^{0.36622} T_{ai}^{-1.0204} W_{ai}^{0.94668} \tag{3}$$

Regeneration process

$$Mass\ ratio = 4.4989 \times 10^{-5} t^{0.52085} m_a^{0.41316} T_{ai}^{1.2412} \tag{4}$$

Figures 15-16 describe the comparisons of mass ratio calculated from the experimental data and model in the adsorption and regeneration processes respectively. These results show the models can be predicted the experimental value quite well.

In case of the heat gain from adsorption process, the model for predicting the outlet temperature of air from desiccant unit is also developed. The detail of this model is

$$Q = 1.3272 \times 10^{5} t^{-0.37257} m_a^{0.38378} T_{ai}^{-1.1783} W_{ai}^{0.10140} \tag{5}$$

Figure 17 show the comparisons of heat transfer rate calculated from the experimental data and the model. This model can be predicted the experimental values quite well.

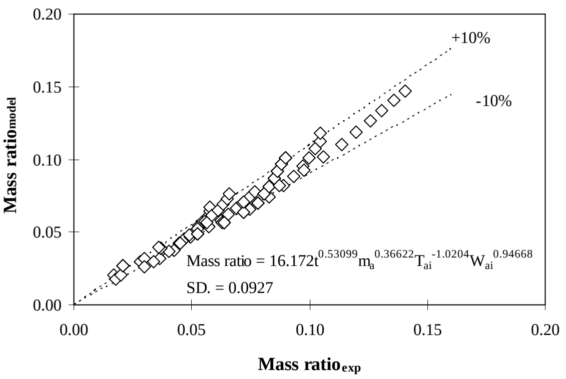


**Figure 15** Comparisons of mass ratio calculated from the experimental data and model in case of adsorption process.

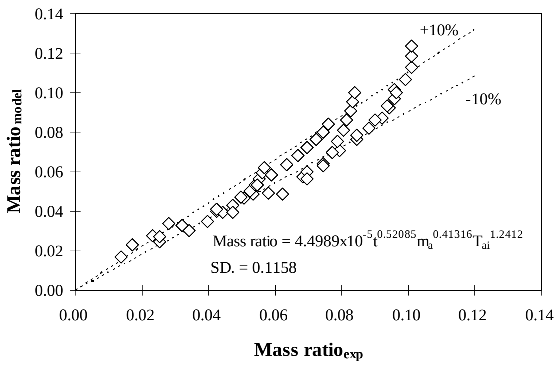


**Figure 16** Comparisons of mass ratio calculated from the experimental data and model in case of regeneration process.

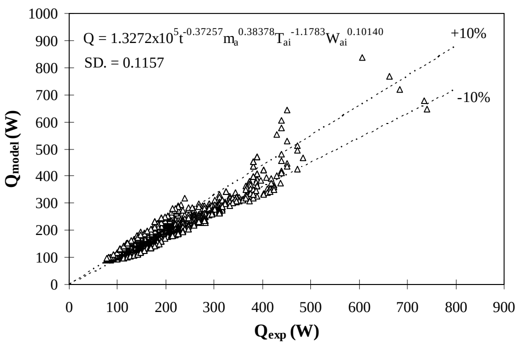


**Figure 17** Comparisons of heat transfer rate calculated from the experimental data and model.

2 Performance of longan dryer having desiccant tray

In this part, a simulation program is developed for predicting the energy saving of longan dryer using desiccant unit and is compared with that of conventional one. The flow chart of the simulation program is shown in figure 4 and the input parameters for longan dryer are presented in table 2.

**Table 2** Input data of simulation program

| Item | Data |
|---|---|
| Mass of desiccant in each tray | 3,628 g |
| Number of tray | 2-20 |
| Inlet temperature of air | 30 °C |
| Inlet relative humidity of air | 70% |
| Mass flow rate of air | 0.65 kg/s |
| Drying temperature | 80 °C |

Figures 18-19 illustrates accumulated mass of water inside the desiccant and heat releasing from desiccant at various times. In this program, it is assumed that the effective mass flow rate of each tray is the same and it may be calculated by divided the total mass flow rate with the number of tray. As can be seen from these figures, increase the number of trays, higher performance is obtained. However, it leads to high investment cost and use more time for replacing. Thus, the economic analysis should be considered for future. The results from the simulation agree well with the experiments.

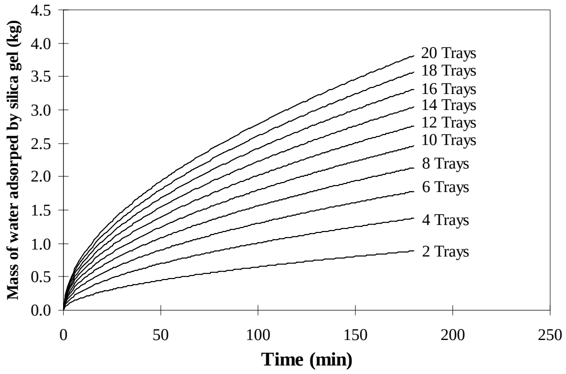


**Figure 18** Mass of water adsorbed by silica gel at various times.

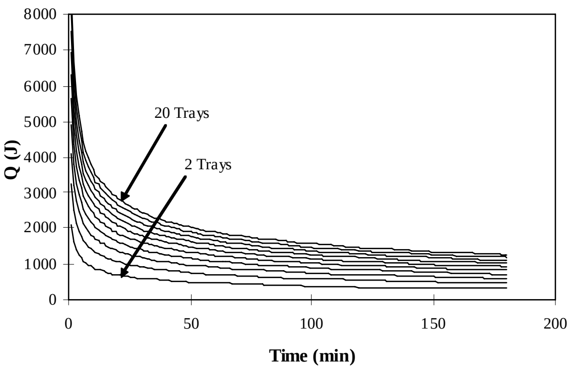


**Figure 19** Heat transfer rate from adsorption process by silica gel at various times.

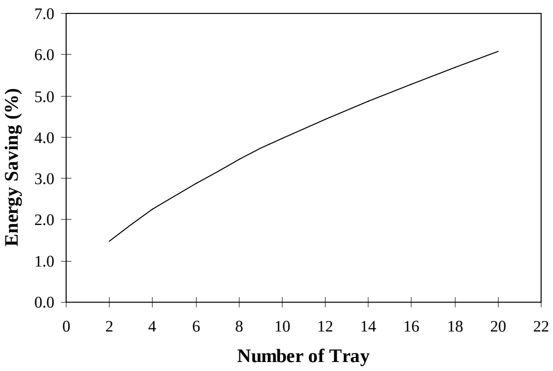


**Figure 20** Energy saving at various numbers of trays.

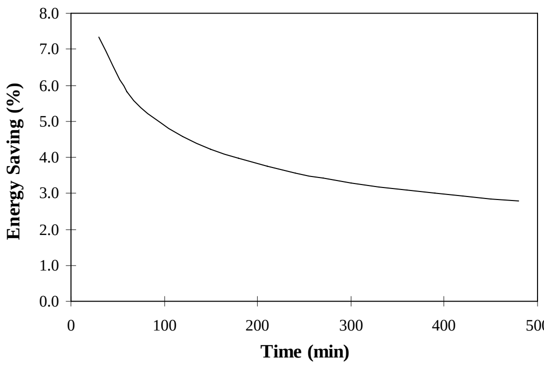


**Figure 21** Energy saving at various replacement periods.

The energy saving of the longan dryer with desiccant trays are also compared its performance with the conventional dryer. As shown in figure 20, the developed dryer has higher efficiency or more energy saving than that of original one. Moreover, it is also found that the energy saving increases with the number of tray. It should be noted that, this result calculates from the assumption of replaceable time for new desiccant tray every 3 hrs and the used tray is regenerated by external heat source.

Figure 21 provides the case of various replaceable time of desiccant tray. The result shows that shorter replaceable time, higher energy saving is obtained undoubtedly. However, the suitable number of tray and replaceable time should be optimized with the economic analysis. This part also will be the subject of a future coming study.

## Conclusions

The present study was designed to determine the effect of different tray thickness which is 2.5, 5.0 and 7.5 cm in the adsorption and regeneration processes. Each size of the desiccant tray is tested the adsorption/regeneration performances in a wind tunnel. The parameters related such as the tray thickness, the air velocity and the air moisture content including the air temperature are also examined for both adsorption and desorption modes of operation. The experimental models are developed to design a desiccant unit of bed-type longan dryer. The following conclusions can be drawn as follows:

The adsorption and regeneration rate are highly effected by the tray thickness

The performance of adsorption and regeneration processes are depended on the inlet temperature, mass flow rate and inlet humidity of air stream.

The energy saving of longan dryer using desiccant tray depends on the number of tray and replacement period. Increase the number of trays or reduce the replacement period leads to increase the energy saving.

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### Nomenclature

| | |
|---|---|
| $A_s$ | surface area of desiccant ($m^2$) |
| $h_m$ | mass transfer coefficient (m/s) |
| $m_a$ | mass flow rate of air (kg/s) |
| $Q$ | heat transfer rate (W), heat transfer (J) |
| $R$ | mass transfer rate (kg/s) |
| $T_{ai}$ | inlet temperature of air (°C) |
| $t$ | time (min) |
| $W_{ai}$ | humidity ratio in air ($kg_{water}/kg_{dry\ air}$) |
| $\rho_{ma}$ | density of moisture in the air ($kg/m^3$) |