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Development of Rotating Tray Dryer and Study of the Hot Air Flow Pattern with Computational Fluid Dynamics

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Rotating tray dryer has the advantages over Cabinet dryer when we compare them, which is the end product from drying procedure has more regularity of moistness after the procedure. A new tray dryer with three rotating trays was designed, constructed and evaluated to find the optimal pattern for inputting hot air into the chamber. Three experiments to supply hot air were investigated. First, hot air flows in lower inlet tube with and without tray rotation. The comparison on hot air ratio with tray rotation was made by varying the ratio of air flow rate though three wall-side tubes at 0:0:100, 20:20:60 and 30:30:40 (upper: middle: lower). The optimal ratio was found to be 30:30:40. Next, this optimal ratio was used to compare the drying efficiency between entering hot air through one-way inlet with tray rotation (rotating tray) and entering hot air through two-way inlets without tray rotation (stationary trays). The optimal pattern for entering hot air is two-way inlets of hot air with stationary trays at the ratio of 30:30:40. This setting was used for drying of mulberry and measuring total phenolic compound (TPC) in dried mulberry. After drying process, the quantities of TPC in each tray were not significantly different. Furthermore, the optimal condition is used to study the temperature profile with simulation program (Computational Fluid Dynamics, CFD) and the results from CFD are correlated with the experiments.

1. Introduction

Advancement in technologies affects the trend of increasing productivities in agriculture, thus, it is important for farmers to be able to store their product for a prolong period of time. Products that have gone through transformation process will prevent the overload fresh market, which stabilize the price of these products and increase their own value at the same time. Drying process is one of the many processes in food conservation. Normally it utilizes the principle of transferring heat into the product to vaporize the moistness within the product. The result depends on the natural characteristic of each product. Drying process is one of the most popular methods used by farmers because it is easy to perform and low cost. Good drying process should take suitable condition, such as correct temperature usage, the method used in the procedure and characteristic of material that will undergo the process, into consideration (Mujumdar, 2007). There are many types of dryer unit at this moment. The most common use for cabinet dryer is to decrease moistness level in agricultural product. However, there is a problem in heat distribution which leads to lower quality in final product (Amanlou and Zomorodian, 2010). Rotating tray dryer is another way to transform product that can maintain the nutritional value as well. Moreover, building this equipment is low-cost which is ideal for use in small industry. When we compare the quality of the product such as anti-oxidant quantities, color and rehydration ratio in dryer unit with and without tray rotation after drying process, dryer with tray rotation yields better quality result (Sánchez et al., 2012).
Mulberry is one of the fruits that has caught many attentions in the past few years due to its high vitamin and mineral contents such as Folic acid, Antioxidant substances (flavonoids, anthocyanins and carotenoids), which

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help reduce risk of cancer. Mulberries are rich in phenolic (Ercisli and Orhan, 2007). Although fresh mulberries are perishable, they can be kept at room temperature for a few days. If there are a lot of mulberries produced and they could not be consumed or sold in time, they will become a waste.In this present study, researchers has studied the drying process of rotating tray dryer by design and develop a suitable way allowing hot air to flow in the dryer unit, in order to study suitable drying condition. Afterward, the experiment involving putting a mulberry through the drying process was carried out, to find the amount of essential substances remained in the mulberry after the process. Utilizing CFD technique to calculate the characteristic of air flow inside the dryer unit and compare with the outcome of the experiment (Ryu et al., 2013). This paper aims to utilize the result from CFD calculation technique as a guideline in designing dryer unit for industrial usages in the future.

2. Materials and methods

2.1 Experimental apparatus

The rotating tray dryer was designed and constructed as shown in figure 1. The drying chamber was a cylindrical shape. Its wall was made of steel and covered with insulation to minimize heat transfer through the chamber wall. Six tubes which were tangentially attached to the wall, used as an entrance for hot air to go inside the unit. The hot air will come out at the top. Three circular stainless plates with a hole arrange in vertical stack. The stack will be connected to a shaft, which spins at the speed of 6 rounds per minute. Drying process was conducted using thermal energy obtained from 1 kW electronic heater. The drying temperature and velocity of air in the chamber were controlled at 60 °C and 0.5 m/s respectively. Three butterfly values were used to control a ratio of air flow rate through wall-side tubes.

2.2 Drying curves

The material which will be used in drying process for testing the result of air flow characteristic inside the drying unit with rotating trays is a damped towel with dimension of 10 x 10 cm^2 and initial moisture content at 300 % dry basis, then tied every towel into the same knots and place 4 of them on each drying tray then start the drying process using 60 °C temperature .The samples were weighed in an analytical balance every 15 minutes. The drying was continued until a final moisture content of 20 % dry basis, taking about 2 hours of drying time. The procedure can be divided into 3 steps.
Step 1 Hot air flows in lower inlet tube with and without tray rotation
Step 2 Hot air was separated through three wall-side tubes (upper : middle : lower) at different ratios with tray rotation.
Step 3 Comparing the drying efficiency between inputting hot air through one-way inlet with tray rotation (rotating trays) and inputting hot air through two-way inlets without tray rotation (stationary trays).

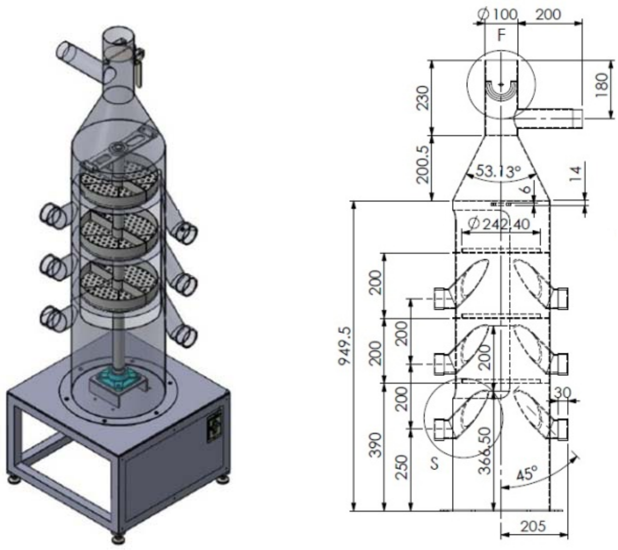


Figure 1: Configuration of rotating tray dryer used in this work.

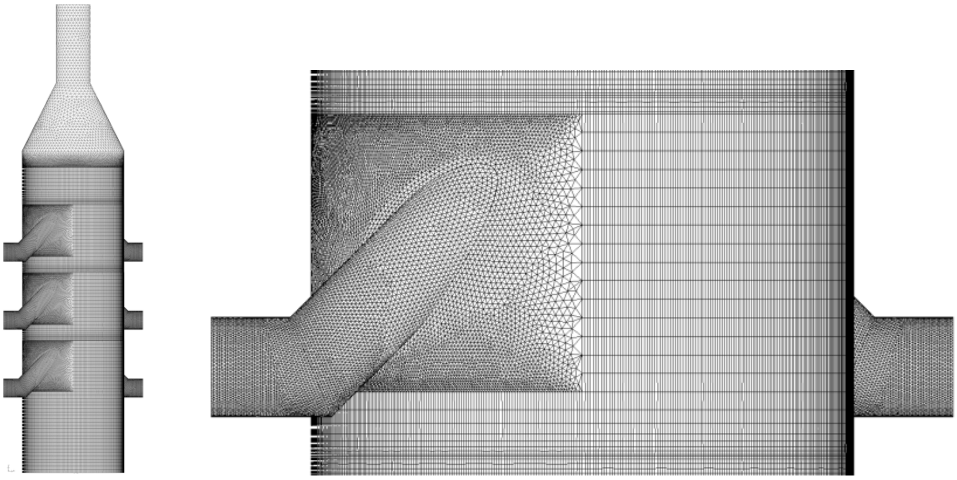


Figure 2: Surface mesh generation and its enlargement of surface mesh at inlet section.

2.3 Total phenolic compounds (TPC)

Dry the reaped mulberries with rotating tray dryer until the mulberry is 30 % dry basis (water activity = 0.7) at the optimal condition that gives the highest working potential of the dryer unit. Then extract and determine the quantities of TPC in dried mulberry using a modified method of Kim et al. (2003). Briefly, Phenolics of the mulberry were extracted from 0.2 g ground freeze-dried samples using 10 ml of ethanolic solution (98:2 by volume of 95% ethanol containing 1% hydrochloric acid). Shake it until the mixtures are well mixed together and let it set for 24 hours. Put the mixture into centrifuge at the speed of 10000 rpm for 5 minutes. Seperate the clear fluid extract for further analysis .0.5 ml of extracts or standard solutions of gallic acid (50, 100, 150, 200 and 250 mg/l) was added to 0.5 ml of Folin & Ciocalteu's phenol reagent and shaken. After 5 min, 3 ml of 10% Na_2CO_3 solution was added with mixing. The solution was then immediately diluted to volume (10 ml) with ddH_2O and mixed thoroughly. After incubation for 30 min at 25 °C, the absorbance versus prepared blank was read at 765 nm. Total phenolic contents of mulberry were expressed as ppm as gallic acid equivalents (GAE).

2.4 Study of hot air flow characteristic inside stationary tray dryer by using CFD method

In this section, the preliminary CFD simulation was conducted to support the experimental data, meaning that the model without drying materials was simulated. The three-dimensional dryer model with non-conformal mesh was generated by using GAMBIT as shown in Figure 2. In drying chamber, the hexahedral cells were generated. While, for inlet and outlet sections, the tetrahedral cells were adopted due to the complexity of the geometry. The properties of materials for this simulation can be expressed as shown in Table 1. At inlet section, the uniform velocity profile of the hot air with temperature of 340 K was adopted. For two-way inlet hot air, the normal velocity magnitude for upper, middle and lower inlets were 1.475, 1.515, and 2.225 m/s, respectively. Furthermore, for one-way hot air inlet, the velocity magnitude of 9.46 m/s was only specified at the bottom. At the wall, no-slip boundary condition was used. Further, the temperature profile at the wall was specified by using UDF, which was written in C language. The temperature profile can be expressed as shown in equation (1).

$$T = -79.04X^6 + 206.88X^5 - 69.96X^4 - 169.99X^3 + 98.55X^2 + 26.89X + 308.69 \quad (1)$$

where T is temperature (K), X is the height from dryer base (m)

Table 1: Properties of materials.

Properties	Air	Iron	Stainless steel
Density ($kg \cdot m^{-3}$)	Ideal gas	7,080	7,800
Specific heat ($J \cdot kg^{-1} \cdot K^{-1}$)	1009.2	461.4609	487.5575
Thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$)	0.0264	79.0268	15.1425
Viscosity ($kg \cdot m^{-1} \cdot s^{-1}$)	Kinetic theory	-	-
L-J Characteristic length (Å)	3.711	-	-
L-J Energy parameter (K)	78.6	-	-

Table 2: The predicted temperature and measured temperature at the height of 0.5 m above the drying base

	Experiment	CFD	% Error
Temperature (K)	333	332.11	0.27

For this simulation, the energy equation and renormalization group k-epsilon turbulence model with enhanced wall treatment were employed to simulate the temperature distribution and turbulence field, respectively. These equations were iteratively solved by using FLUENT, which base on Finite Volume Method (FVM). For numerical methods, the SIMPLE algorithm was used to solve the pressure-velocity coupling. The discretisation schemes of pressure and momentum were standard and first order upwind, respectively. Moreover, the interpolation scheme of turbulence quantities were first order upwind.

In order to obtain the correct simulated results, 7,504,684 mesh cells were used. Further, the simulated temperature at the height of 0.5 m above the drying base was validated by comparing with the measured temperature as depicted in Table 2. In Table 2, the measured and predicted temperatures are 333.15 K and 332.11 K, respectively. Moreover, the percent error of these temperatures is 0.27. According to these results, it can be concluded that this model is in a good agreement with experiment. In other words, the model can be adopted to analyze the phenomena inside the drying.

3. Results and discussion

3.1 Effect of inlet hot air flow pattern

After gone through experimental process by placing experimental material inside dryer unit and using results gathered from this test to create a graph. The created graph demonstrates relationship between moisture content of the experimental material and time the dryer used to eliminate the moistness. The results are as shown in figure 3 to figure 5.

Referring to the figure 3, this experiment was conducted by letting hot air enter the dyer unit from lower inlet tube only. Result shows that moistness in materials used in the experiment was at its peak at the lower tray of the dryer and at its lowest at the upper tray of the dryer. These were the result of utilization of energy within the hot air to cause evaporation of moisture within these experimental materials. Furthermore, the increasing of moisture level in the hot air due to the evaporation of moisture causes the drying rate in middle and lower tray of the dryer to decrease. In the case of when these trays are not moving, the evaporation of moisture within experimental materials on the same tray is varied due to uneven distribution of heat. However, in the case of trays are spinning properly the evaporation rate of moisture within these materials are less fluctuate. When compare the results between these two experiments, it is recommended to keep trays spinning when in drying process for best result.

Referring to figure 4, this experiment allowed the hot air to enter from only one-way inlet with rotating tray dryer. The result demonstrated that by letting hot air flow into different entrance, including upper, middle and lower entries. The heat is distributed evenly inside the dryer. This result is illustrated by even evaporation of moisture within experimental materials. In addition, from the research, it is advisable that the hot air should be divide into ratio of 30: 30: 40 (upper: middle: lower) to maximize the outcome.

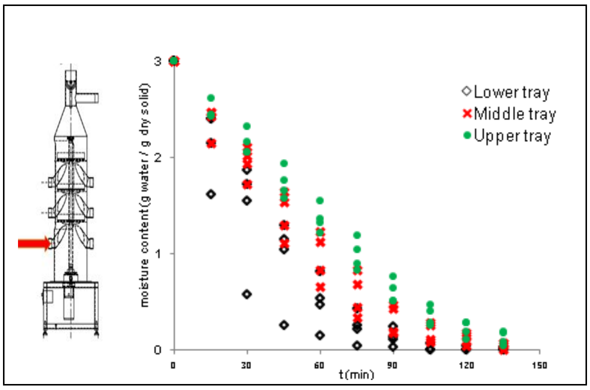
When compare the effectiveness of drying process between the "one-way inlet with rotating tray" method shown in figure 4 and "two-way inlets with stationary trays" shown in figure 5. The results indicated that both methods provide similar result in drying results. The reasons for this outcome was that by letting hot air flow into the dryer from two directions and redirect the air flow to travel along the wall of the dryer. The movement of hot air within the dryer will show characteristic of spiral flow, similar to cyclone, and cause even distribution of heat. As result, as aforementioned, this was the reason why the "two-way inlets with stationary tray" method yielded similar result as "one-way inlet with rotating tray" method.

3.2 Total phenolic compounds (TPC)

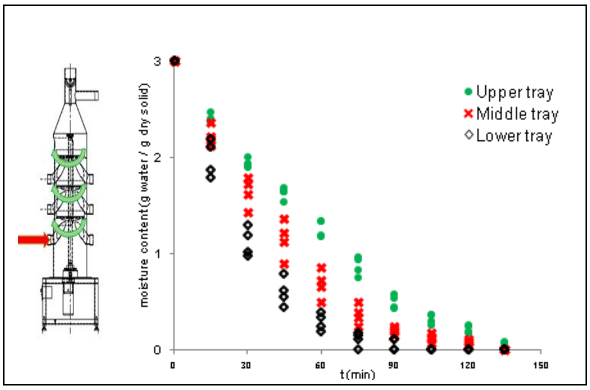
When put mulberries through maximum potential drying procedure of rotating tray dryer, which is two-way inlets hot air flow at ratio 30:30:40 (upper : middle : lower) with stationary tray dryer. The outcome indicated that moisture level in mulberries decreased overtime and amount of TPC from the mulberry from different area inside the dryer are similar to each other. The TPC was approximately 1953 ppm as garlic acid equivalents (GAE).

3.3 Hot air flow characteristic inside stationary tray dryer by using CFD method

From the simulation of hot air flow characteristic inside the dryer in case of two-way inlets hot air flow at ratio 30:30:40 (upper : middle : lower) with stationary tray dryer and case of hot air entering the dryer at the bottom entrance only, result demonstrate the distribution of heat as shown in figure 6.

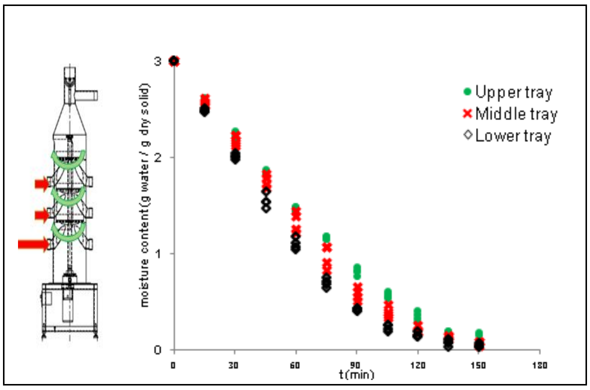


(a) Stationary tray dryer

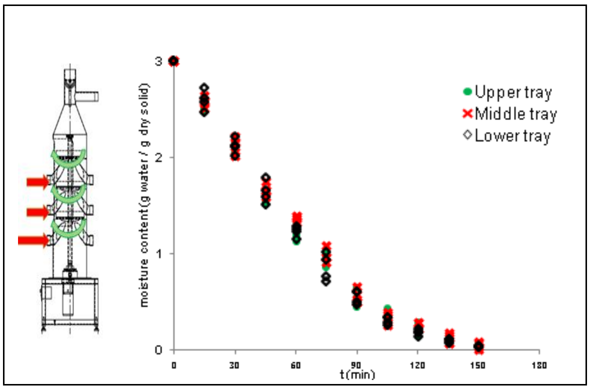


(b) Rotating tray dryer

Figure 3: Moisture content vs time for inlet hot air flow ratio 0: 0: 100 (upper : middle : lower)



(a) Inlet hot air flow ratio 20: 20: 60 (upper: middle: lower)



(b) Inlet hot air flow ratio 30: 30: 40 (upper: middle: lower)

Figure 4: Moisture content vs time for vary inlet hot air flow ratio with rotating tray dryer

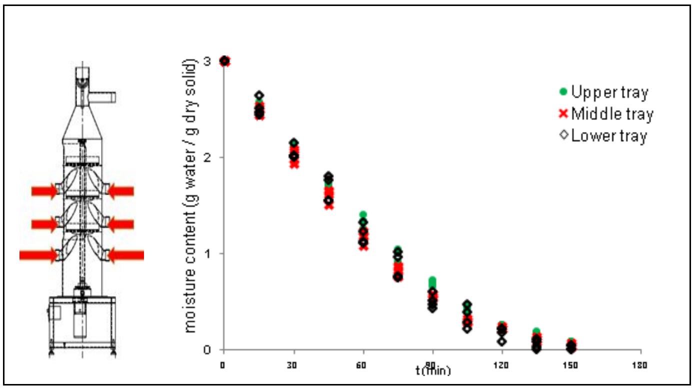
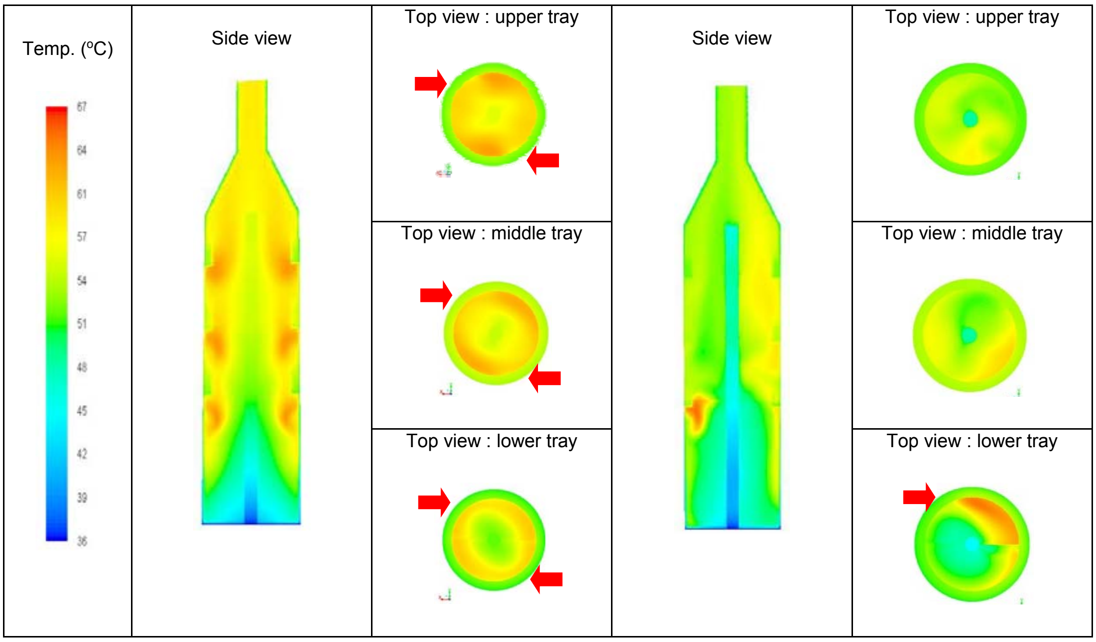


Figure 5: Moisture content vs time for two-way inlets hot air flow at ratio 30:30:40 (upper : middle : lower) with stationary tray dryer



(a) Two-way inlets hot air flow at ratio 30:30:40 (upper : middle : lower) with stationary tray dryer

(b) One-way inlet at lower inlet tube only with stationary tray dryer

Figure 6: Hot air flow characteristic inside stationary tray dryer by using CFD method

4. Conclusions

From the study of the design and suitable development for controlling air flow into the dryer unit at 0.5 m/s and the temperature set at 60 °C, we can conclude that dividing the air flow into the ratio of 30: 30: 40 in "one-way inlet with rotating tray" method yielded better result than ratio of 0: 0: 100 and 20: 20: 60. These numbers represent flow rate of the entering air to the top: middle: bottom of dryer, respectively. The comparison of using 30: 30: 40 divided air flow ratio and two-way inlets with stationary tray method showed that these two methods yielded very similar result in drying rate. This result suggested that, design of dryer unit for small industrial business is recommended to be a combination of both methods, by installing inlet on every level of the unit with stationary trays. This is because it is easier to design and has more power efficiency. By utilizing CFD technique to study the characteristic of the air flow inside the unit, the temperature characteristic inside the unit can be predicted precisely. From this research, the results demonstrate that stable temperature inside the dryer unit will maximize the outcome shown through evenly evaporated moisture. Therefore, utilizing CFD technique in designing the dryer unit is an idea worth trying.

Acknowledgements

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References

Amanlou Y., Zomorodian A., 2010, Applying CFD for designing a new fruit cabinet dryer, Journal of Food Engineering, 101, 8-15.

Ercisli S., Orhan E., 2007, Chemical composition of white (Morus alba) red (Morus rubra) and black (Morus nigra) mulberry fruits, Food Chemistry 103, 1380-1384.

Kim D.O., Jeong S.W., Lee C.Y., 2003, Antioxidant capacity of phenolic phytochemicals from various cultivars of plums, Food Chemistry, 81, 321–326.

Mujumdar A.S., Ed., 2007, Handbook of Industrial Drying, 3rd edition. CRC Press, Boca Raton.

Ryu J.B., Jung C.Y., Yi S.C., 2013, Three-dimensional simulation of humid-air dryer using computational fluid dynamics, Journal of Industrial and Engineering Chemistry, 19, 1092–1098.

Sánchez N.F. Blanco R., Gómez M.S., Herrera A., Coronado R., 2012, Effect of rotating tray drying on antioxidant components color and rehydration ratio of tomato saladette slices, LWT-Food Science and Technology, 46, 298-304.