CFD simulation of fixed bed dryer by using porous media concepts: Unpeeled longan case

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Abstract: Quality of dried product depends on the temperature and velocity at each position in the dryer. Simultaneous microscopic and macroscopic simulation on Computational Fluid Dynamic (CFD) is a general problem of fixed bed dryer consisting of water transportation in porous media and dynamic flow of hot air in the dryer. Simplifying the dryer by assuming the packed bed as porous volume, viscous and inertial resistances ($1/\alpha$ and C_2) are necessary for calculating the pressure drop and velocity change in the bulk. Comparing the $\Delta P/L$ of the standard packing with experimental results, the porosity and resistance parameters can be estimated. Simulation of unmodified, adding false floor and invest mesh, and insulating the dryer wall are used for validation with previous results. Adding the round holed sieve as false floor and invert mesh can produce better profile but cannot obtain uniform distribution. Air velocity distribution shows similar but the calculating temperature is higher than that from the experiment. By analysis of thermal efficiency of dryer without insulator, the heat loss rates with flue gas and heat flux at wall are in the range 14%-17% and 5.5%-7.3%. Integrating with single fruit or thin layer drying kinetic in the future, the CFD simulation can be used for optimal design of fixed bed dryer.

Keywords: deep-bed dryer, longan, velocity and temperature distribution, Computational Fluid Dynamic (CFD), ANSYS

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1 Introduction

Computational Fluid Dynamic (CFD) is a powerful tool for calculating velocity profile of fluid flow and visualizing the air flow trajectory in the dryer for the purpose of obtaining the better quality and conserving the energy[1,2]. Dryer design for declining the temperature and velocity gradient in the bulk assures the moisture homogeneity of dried product or storage food. Heat and mass transfer with air flow in the bulk is necessary to calculate the rate of decline in water content from the product. Water can be transported through processes such as water sorption kinetic at surface, water evaporation, diffusing rate of inner liquid water and water vapor from inside through the structure barrier and convective water transfer from surface to bulk of air flow. CFD simulation is associated with transport phenomena calculation of complex geometry in both microscopic and macroscopic level. However, calculating in micron scale of food requires further information about geometry, material, and its properties which are inaccessible by experiment. Simulation of the air flowing through the fixed bed of food by using packing geometry in

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microscopic scale requires powerful computer to reduce the long data processing time. A Simple geometry by considering the bulk of particles as a porous zone volume lessens the calculation node and convergence time. Simulation of the velocity and temperature distribution of hot air in the dryer by assuming the food as porous zone has been studied by Molenda[3,4].

Unpeeled longan dryer has an advantage for CFD simulation and validation. This is due to the round shape of fruit which is related to the spherical particle packed in the column as explicated by Eugan[5]. The fruit contains large amount of water and is dried for 48 hours which is long enough to investigate the temperature and velocity contour. Water evaporation at the surface is not affected by the temperature distribution of air because the drying rate is very slow. The effect of hot air velocity on drying rate is less than the temperature therefore the drying kinetic is controlled by the inner diffusion of water in the fruit. Less changing of bulk porosity regarding the fruit has no shrinkage. It is necessary to improve the uniformity of the momentum, heat and mass transfer by redesign of CFD software, validation of hot air flow through the bulk by assuming as the porous volume.

1.1 Unpeeled longan dryer and its modification and experiment

Drying experiments were carried out at a farmer factory in the village of San Pa Tong, Chiang Mai, Thailand during 2004-2007 under collaboration project between Hohenhiem University (Germany), Mae Jo University, Chaing Mai University and Silpakorn University (Thailand) (see Table 1). About two tons of longan cultivar ‘E-Dor’ (or ‘Daw’) were dried in a fixed bed dryer, called ‘Taiwan’ type: Suncue SKS-480A, Taichung, Taiwan; mfd. 1996. The geometry of unmodified dryer and conventional drying procedure was described by Phaphuangwittayakul et al[6]. The air was supplied by axial fan blower (0.745 kW) and heated by liquefied petroleum gas (LPG) burner (48 kW/h). The air flows through round holed (8 mm) metal sieve which also uses for supporting the bulk of fruits presented in Figure 1. L. Henz[7] investigated the thermal efficiency by measuring ambient temperature, temperature of the air before and after burner, temperature inside the longan bed and longan fruit and air flow outlet and varying the air flow rate at inlet (after the burner) from 6.0 m/s to 3.45 m/s. Dryer was modified by inserting the wood wall to increase the bed height from 0.475 m to 0.600 m. The longan fruits were separated into three layers by enclosing them in a plastic net and later layers were shifted and rotated to 180 degree after every shifting procedure.

Table 1 Drying condition of all trial experiments

Experiment code	Bed height /m	Inlet velocity /m s^{-1}	Outlet velocity /m s^{-1}	Average ambient temperature/℃	Average temperature in bulk/℃	Pressure drop /Pa	Dryer
Henz (2005)[7]							
Exp05A	0.475	6.00	0.17 [1]	30.0	61.0	15.05	Unmodified
Exp05B	0.475	6.00	0.17 [1]	29.0	60.7	15.08	Unmodified
Exp05C	0.475	6.00	0.17 [1]	28.8	61.4	18.25	Unmodified
Exp05D	0.475	3.45	0.10 [1]	28.2	62.7	20.97	Unmodified
Azcárraga (2006)[8]							
Exp06A	0.60	5.15 [2]	0.15	28.5	56.7	15.29	Shifting A
Exp06B	0.60	4.88 [2]	0.14	29.8	57.0	16.03	Shifting B
Exp06C	0.60	3.93 [2]	0.11	29.5	55.8	16.22	Shifting C
Exp06D	0.60	na	na	na	na	na	Shifting D
Nagle et al. (2008)[9]							
Exp07A	0.60	2.17 [2]	0.06	29.4	55.3	na	Unmodified
Exp07B	0.60	3.06 [2]	0.09	29.5	57.0	na	Invertion
Exp07C	0.60	1.91 [2]	0.05	29.2	60.4	na	False
Exp07D	0.60	3.76 [2]	0.11	28.3	61.9	na	Insulation

Note: [1]estimated from inlet velocity; [2]estimated from outlet velocity; na: not available data.

This method improved the uniformity of the drying rate and gained better product homogeneity which developed by local farmer in 2005. Four applied methods of shifting procedures (Figure 2) were investigated in term of product uniformity and thermal efficiency improvement by Azcárraga[8]. In 2008, Nagle and Azcárraga[9] modified the dryer with (a) perforated sheet metal inside the plenum, inverted against the air entrance, (b) false plywood floor inside the plenum, inclined toward the air entrance, and (c) insulation of the plenum floor and dryer walls with fiber glass wool for improving the thermal efficient and air distribution. The dryer performance and product quality was reported by Nagle et al[9-10].

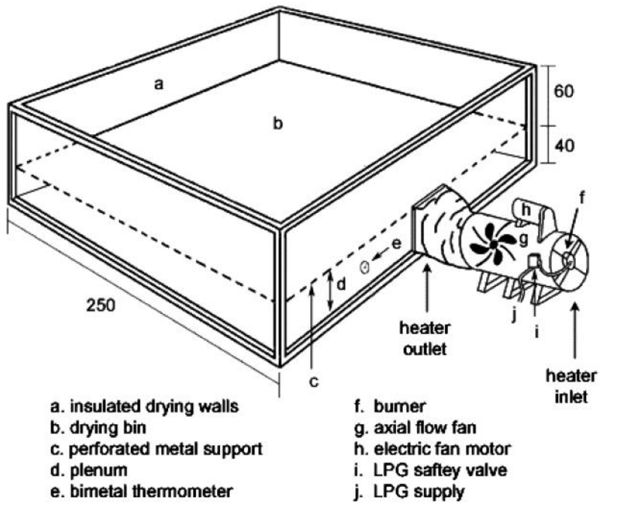


Figure 1 Longan dryer ('Taiwan' type) illustrated by Azcárraga[8]

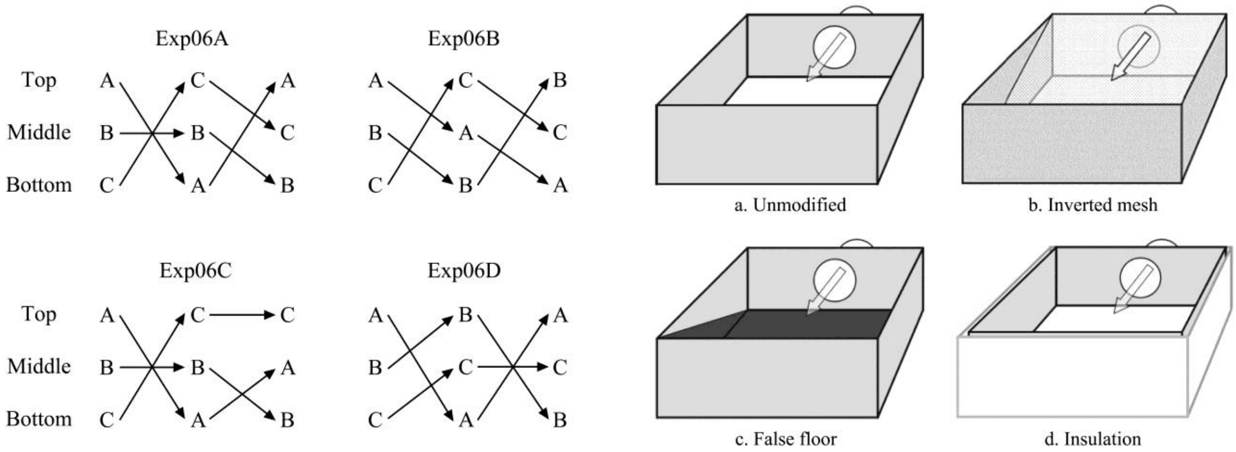


Figure 2 Longan drying experiment for investigating the effect of shifting method by Azcárraga[8] (left) and the efficiency of three modified dryers compared with original dryer by Nagle et al.[10] (right)

1.2 Fluid flow in porous media

Fluid flowing through the bulk of spherical particles, and the pressure drop across the fixed bed are related to the particle size, particle shape, particle alignment and void fraction (or bulk porosity). The correlation between fluid velocity and the pressure drop per the length/height of bed ($\Delta P/L$) was described by Ergun[5] in 1952. Ergun equation is shown in Equation (1) resulting of the Blake–Kozeny equation and Burke–Plummer equation. The Blake–Kozeny–Carman constant (A) and Burke–Plummer constant (B) are 150 and 1.75, respectively. Forchheimer presents this equation as Equation (2) for high flow rate in porous media which contains two specific coefficients for the particle bed named permeability tensor (K) and the inertial drag or form tensor (C).

Ergun
$$\frac{\Delta P}{L} = A\frac{\mu(1-\varepsilon)^2}{d^2\varepsilon^3}v_s + B\frac{\mu(1-\varepsilon)}{d\varepsilon^3}v_s^2 \quad (1)$$

Forchheimer
$$\frac{\Delta P}{L} = \frac{\mu}{K}v_s + \rho C v_s^2 \quad (2)$$

ANSYS
$$\frac{\Delta P}{L} = \frac{\mu}{\alpha}v + \frac{\rho C_2}{2}v^2 \quad (3)$$

These equations are comparable with the pressure drop equation in the porous volume (porous zone) and porous wall (porous jump) on ANSYS software presented in Equation (3). The viscous resistance ($1/\alpha$) and inertial resistance (C_2) are two important coefficients which are assessable by using Ergun equation with diameter of particle (d) and bulk porosity (ε) which is depended on the particle packing in the bulk[11].

1.3 Effect of particle packing on the bulk porosity

Both parameters depend on the grain porosity in a specific volume inside the bin during drying or storage, which is influenced by the type of grain, non-uniformity of bulk density, coefficient of friction between the grain and wall, moisture content, and filling method[12,13]. Figure 3 presents the model of three standard packing patterns which are primitive, body center cubic (BCC) and face center cubic (FCC) with their porosity value. Comparing the pressure drop value with these standard packing forms, the equivalent porosity of longan bed is possible to estimate which is necessary for calculating two resistance coefficients of longan bulk using ANSYS.

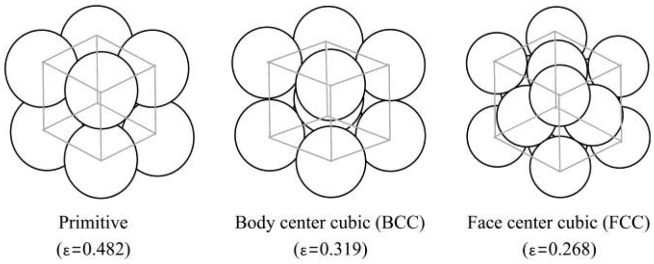


Figure 3 Illustration of bulk porosity of primitive, BCC and FCC packing

To unravel these problems for CFD simulation in this research, the number of calculating node were reduced by considering the fixed longan bed as the porous volume. The holed sieve is considered as the porous wall. Important factors (viscous and inertia loss coefficient) and equivalent porosity of longan bulk are estimated from the pressure drop and air velocity of previous drying results. The overall objective of this study is to conduct simulation of the temperature and air velocity profiles in the dryer by using ANSYS (FLUENT) software and to validate the results with the previous experiment. Finally, a simple dryer model will be developed for redesign the dryer in the future.

2 Materials and methods

2.1 Viscous and inertia loss coefficients of holed sieve and packed longan

Microscopic simulation of hot air flowing through the sieve with 8 mm diameter round holed and flowing through three types of longan packing are running on ANSYS (FLUENT) V14 (ANSYS, Inc. Pennsylvania, US). Simulation of hot air flow through the sieve (50×50 mm) placed at one-third of air volume height as shown in Figure 4a. Air flows from the bottom to the top of box. Determine the pressure drop across the sieve by varying the temperature of air flow from 40 to 100℃ at 0.1 m/s and varying the air velocity from 0.01 to 100 m/s every ten time magnitude while the temperature was fixed at 80℃. Similarly, the air flow through the longan packed sizes 75×75×75 mm^3, the bed height is kept constant at 50.2 mm. The diameter of each longan fruit (d_p) is 25 mm and packed in primitive, BBC and FCC patterns are shown in Figures 4b-4d. Correlation between air velocity and pressure drop per length was described in Ergun equation. The $1/\alpha$ and C_2 coefficient were determined from curve fitting as a second order polynomial function on Microsoft Excel.

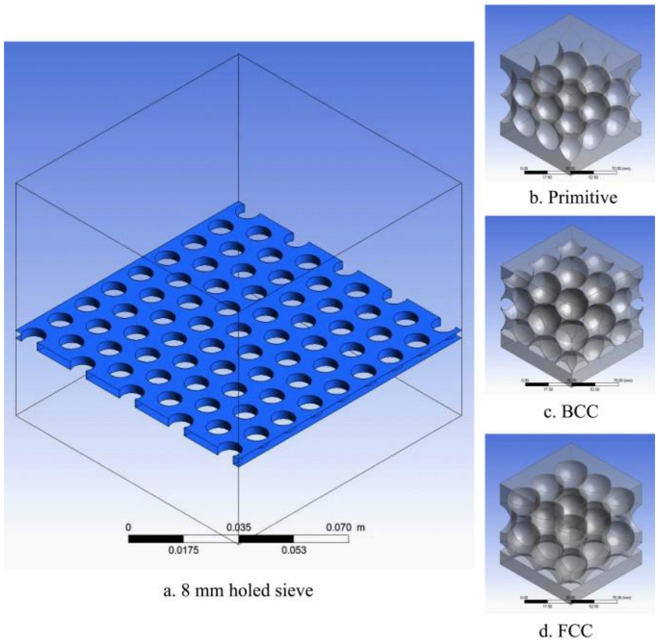


Figure 4 Geometry of simulation volume of (a) 8 mm holed sieve and longan fruit packed as (b) primitive (c) BCC and (d) FCC

2.2 Simulation of the dryer with porous zone and porous jump

Geometry of the unmodified longan dryer for CFD simulation is shown in Figure 5. The horizontal cross section area is 2.5×2.5 m^2 with 0.875 m height for all experiments by Henz[7] and 1.0 m. Volume of air is simplified into two volumes of fluid. The first volume is the part with 0.4 m height called the plenum, the empty space for homogenizing the hot air temperature and velocity before flowing through sieve. Sieve is considered as the porous jump. The second volume is air volume with the bulk of longan fruit and it is assumed as a porous zone. The porosity and two resistance coefficients of the sieve and longan bed is estimated from the previous section. The size of hot air inlet is 0.40×0.40 m^2 and was placed at the front of dryer in the x-direction. The side wall of the dryer was made from steel with wall thickness of 3 mm.

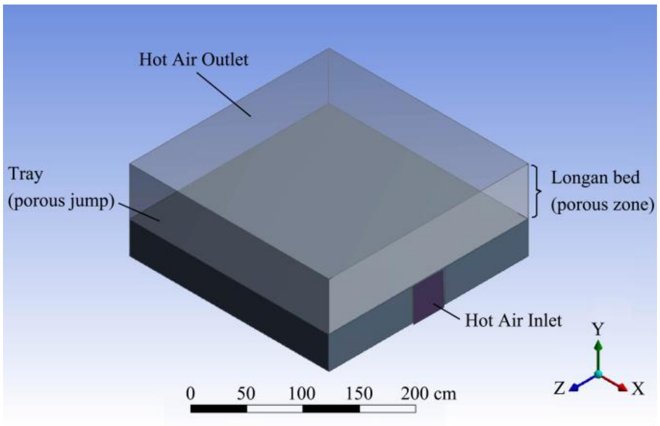


Figure 5 Geometry of longan dryer after simplify the longan bulk to porous zone

The results of the pressure drop for the first two years of the experiment were used to estimate the equivalent porosity of longan bulk by comparing the pressure drop value with the three packing structures. Hence, this porosity will be used to simulate the hot air flow of three modified dryers which was investigated by Nagle et al[10]. The ambient temperature is an average value at 25℃; the inlet air velocity is 6 m/s. Enthalpy of inlet flow and flue gas, and heat loss at wall of dryer is estimated and used for thermal efficiency analysis.

A low velocity of drying air resulted in a Mach number less than 0.1. Therefore, fluid can be considered as incompressible flow. Dried air contained small amount of vapor water while the viscosity remains constant therefore, fluid can be assumed as a Newtonian fluid. With constant density and low velocity, simulation with laminar model still validate for simulation in this study. Simulations were conducted until continuity residue reaches a stable value and lower than 6.3×10^{-5} for default convergence criterion of ANSYS (Fluent)[14]. The simulated results of air velocity and temperature distribution were compared with velocity contour which was estimated by using MATLAB 7.0 and the temperature contour taken by thermal camera which was reported by Nagle et al[10].

3 Results and discussion

3.1 Resistance coefficients of round holed sieve

The average Reynold number (Re) at inlet and outflow of unmodified dryer running at 6.0 m/s air velocity is lower than 1.0×10^5 which is in laminar region[15]. The hot air flows through the sieve at 0.1 m/s and variation of the temperature from 40℃ up to 100℃ were simulated when the pressure drop across the sieve is constant. The pressure drop per bed height ($\Delta P/L$) is a function of velocity only. The momentum resistance coefficients play an important role with the size of particle and porosity of bulk, which can be described by Ergun relation. Fitting the curve between $\Delta P/L$ and velocity using the second order polynomial with zero intercept, the viscous and inertia loss coefficients ($1/\alpha$ and C_2) of the sieve are determined and presented in Table 2.

3.2 Resistance coefficient and equivalent porosity of packed of longan

The results represent that the simulation of drying air flowing through 75×75×75 mm^3 consisting longan packed with primitive, BCC and FCC patterns, show no differences between $\Delta P/L$ simulated on ANSYS and calculated from Ergun equation. This confirms the Blake-Kozeny-Carman constant (A) and Burke-Plummer constant (B) of Ergun equation are 150 and 1.75, respectively. The $1/\alpha$ and C_2 of packed longan bulk estimated from curve fitting are presented in Table 2. The $\Delta P/L$ simulation of whole dryer (longan bed and sieve) for all experiments is presented in Figure 6. The correlation of regression

longan dryer with real porosity of packed longan is a power function ($R^2 = 0.8879$). The equivalent porosity of longan bed is 0.365 which is necessary for estimating the $1/\alpha$ and C_2 of longan bed by using the Ergun equation. This porosity value was explained as a random packing of spherical particle which the porosity value is in the range of 0.35-0.41[16]. The experimental pressure drop (ΔP, Pa) value was measured by Henz[7] and Azcárraga[8]. The value is in the range of 15.2-20.9 Pa, depending on the air velocity.

Table 2 Resistance coefficients ($1/\alpha$ and C_2) of Ergun Equation of each dryer part and the porosity of each part of dryer

Dryer parts	Viscous resistance ($1/\alpha$)	Inertial resistance (C_2)	Theoretical porosity (ε)	Equivalent porosity (ε)
Tray	5.1544×10^6	2511.67	-	-
Pack bed				
- Primitive	1.1175×10^7	460.64	0.482	0.356
- BCC	3.2418×10^7	1799.80	0.319	0.260
- FCC	1.7994×10^8	1535.12	0.268	0.167
- Longan	4.3853×10^6*	4003.29*	-	0.365

Note: * calculated by Ergun equation with porosity of 0.365.

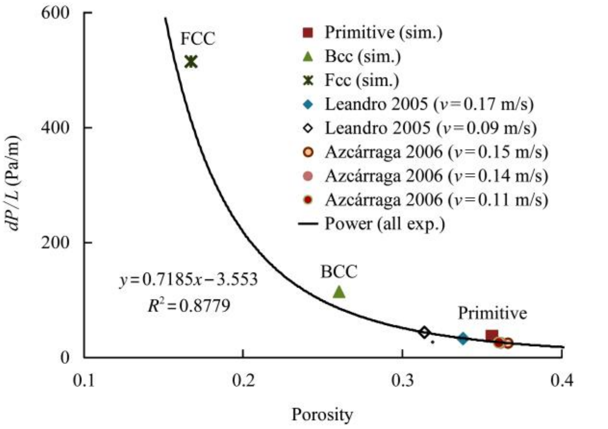


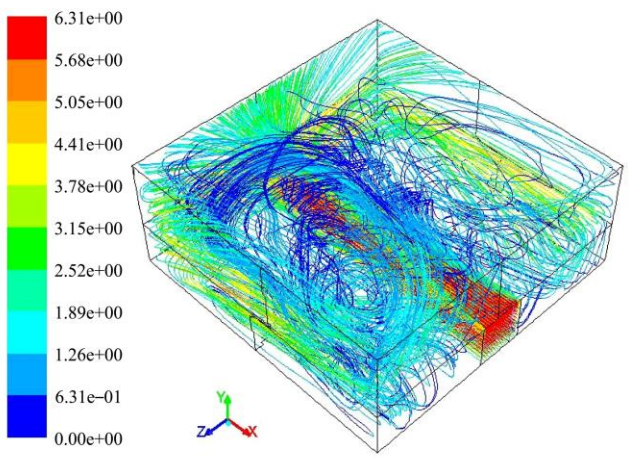
Figure 6 Correlation between $\Delta P/L$ and porosity of longan bulk

3.3 Air velocity contour

The path line by velocity magnitude (m/s) of air flow through (a) the empty dryer and (b) longan bulk height of 0.475 m with porosity of 0.365 are presented in Figures 7A and 7D. Empty dryer with low momentum resist, the effect of sieve on trajectory of air circulation is very small. Non-uniform and no directional trajectory of air flow in empty dryer is shown in Figure 7A. Simulation presents the low efficient in distributing the hot air of metal sieve. The Re of fluid flow in the plenum under the sieve is in the range of 85.79- 4116.34. The area weight average value of Re is 1880.77 with very high deviation (SD=1113.55) which represents high non-uniformity of velocity.

According to CFD simulation of the dryer with longan bulk, the pack of spherical fruit does not only have low flow resistance but also distributes the hot air to get the uniform velocity, presents in Figure 7B. The average Re values of fluid flow inner the packed bed after the sieve and at the outlet are 293.49 and 339.08, respectively. The standard deviation value decreases from 66.15 at sieve to 2.77 at outlet position. Packing of longan fruit improves the air velocity distribution in the dryer.

Measured velocity distribution generated from 25 points on a cross section area is presented in Figure 7C. The contour plot of velocity from CFD simulation presents that the air velocity nearby the dryer wall is zero regarding the viscous effect. Measuring the air velocity at this point is not possible therefore this effect is not shown on contour plot from experimental results. The air velocity near the burner measured from the dryer is the negative value. This might come from the air flowing reverse from above the dryer due to the air temperature difference between the sieve and ambient which are not able to be found in simulation results.



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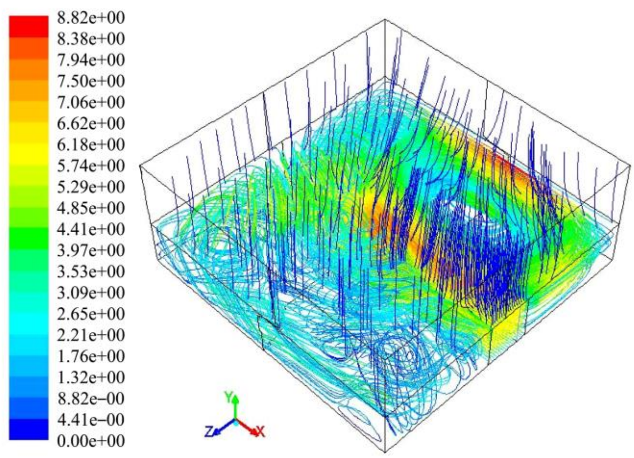

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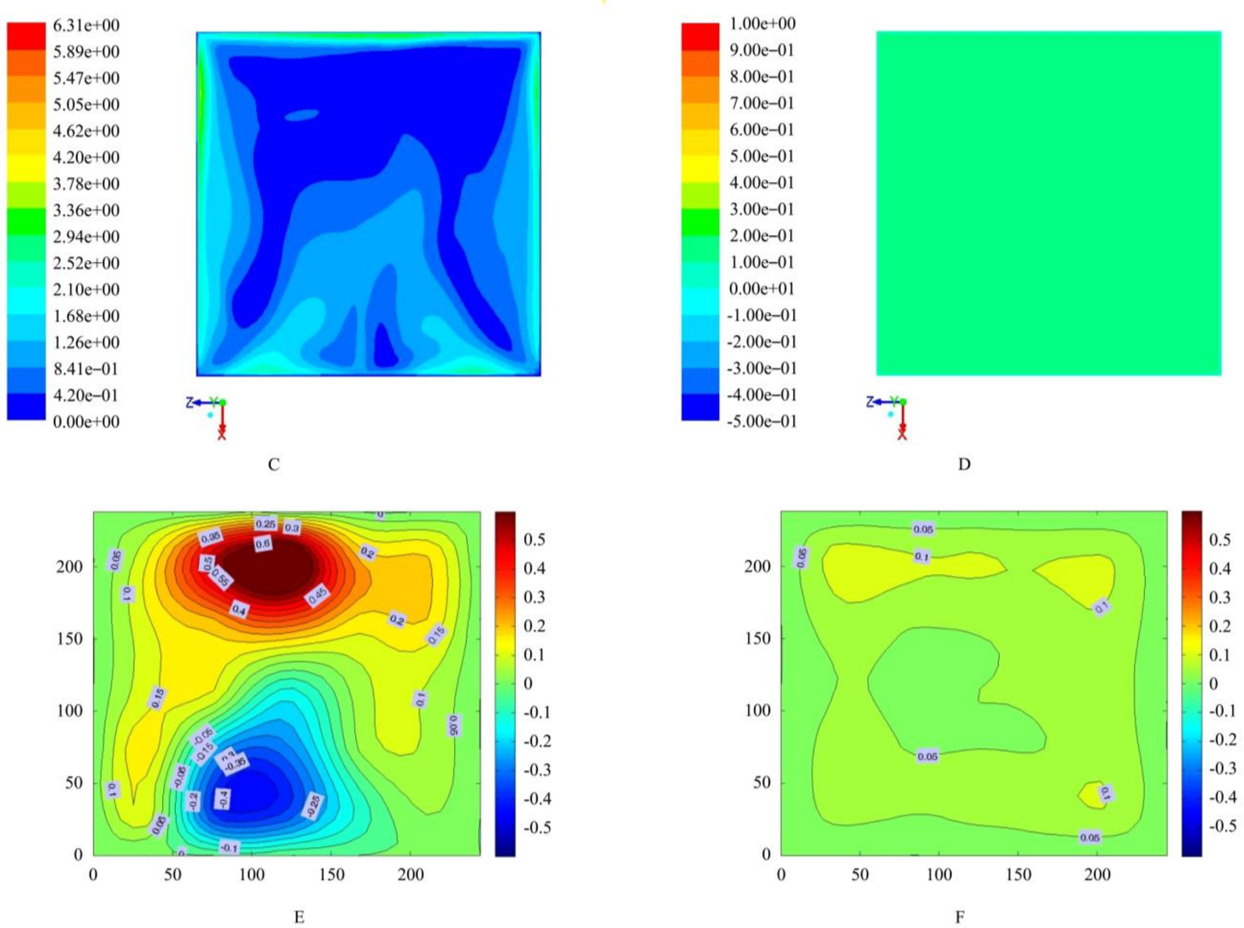

Figure 7 CFD post processing of empty dryer (A-C) and dryer with packed bed with porosity equal 0.365 (D-F) as the pathlines of velocity magnitude (A and C), the velocity distribution at the top layer of dryer (B and E), comparing with the velocity distribution from experiment (C and F) by Nagle et al.[9]

3.4 Air temperature contour

Temperature contour in horizontal cross section near the wall of dryer simulated by ANSYS (FLENT) and measured with thermal camera, is shown in Figure 8. The high temperature in plenum region of unmodified dryer and modified dryer (false floor) is also seen in the simulation results. The temperature simulation of drying air near the outlet is higher than that in the real dryer which might be caused by no evaporative cooling effect at the longan surface during drying. Concerning this, the heat consumption according to water evaporation can be calculated through each node by adding user define function (UDF) of the single fruit drying model or thin layer model.

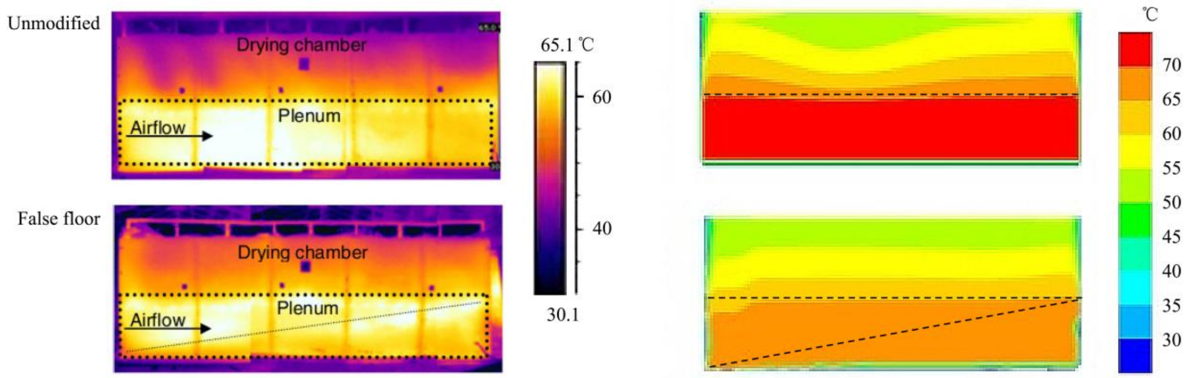

Figure 8 CFD post processing of temperature distribution in unmodified and false floor comparing with thermo picture investigated by Nagle et al.[10]

The thermal picture and the contour plot of simulated air temperature of unmodified dryer, modified dryer with additional false floor are presented in Figure 9. The wall temperature opposite the inlet is always higher than that of wall near the inlet. Therefore the farmer has to rotate the longan layers 180 degree every shifting time for obtaining uniform drying rate. Additional sieve for improving the air distribution purpose gets the better

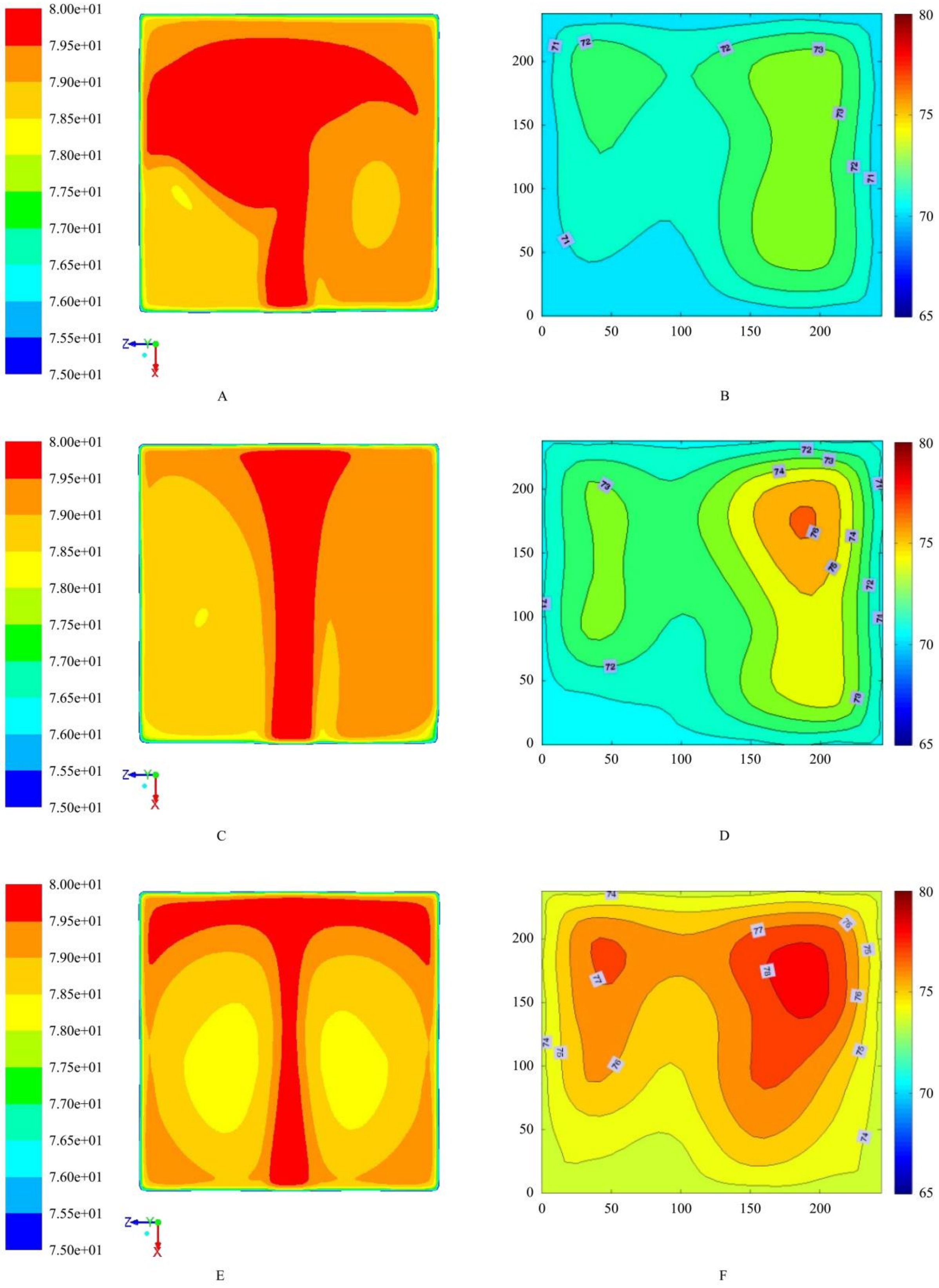

Figure 9 CFD post processing of temperature distribution in (A) unmodified, (B) false floor and (C) invert mesh, comparing with experimental results (D-F) measured by Nagle et al.[9]

trajectory in the plenum, however this still inefficient in term of distribution. Figures 9A to 9C presents the temperature distribution of air in vertical cross section area in the longan bulk. Temperature contour rendering from 25 point of measured value is shown in Figures 9D-9E. CFD simulation shows similar temperature contour as experimental results. The temperature contour shows better distribution but still not uniform after modified by adding sieve in invert and false direction. Invert floor result presents the highest flow resistance. With lower air velocity, the momentum transfer is small and less convective heat transfer, therefore the temperature of this case is higher than others.

Table 3 Thermal analysis of trial longan experiment

Information	Henz (2005)[7]				Azcárraga (2006)[8]				Nagle et al. (2008)[9]			
Drying experiments	Investigate efficiency of dryer				Investigate shifting method				Modified dryer			
Modified drying method	Exp05A	Exp05B	Exp05C	Exp05D	Exp06A	Exp06B	Exp06C	Exp06D	Exp07A	Exp07B	Exp07C	Exp07D
Dryer	Original	Original	Original	Original	Bed hight	Bed hight	Bed hight	Bed hight	Unmodified	Invertion	False	Insulation
Bed depth (m)	0.475	0.475	0.475	0.475	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Material information												
Initial moisture content (%)	69.56				73.50*				70.41	70.75	73.80	72.60
Final moisture content (%)	13.34				19.43*	18.48*	16.83*	9.85*	23.07	19.23	21.04	16.30
Mass of fresh fruit (kg)	2187	2107	2325	2220	1289	1944	1927	1990	1960	1806	1947	1987
Mass of dried fruit (kg)	706	1191	851	690	424	632	614	585	898	822	841	876
Mass of evaporated water (kg)	1481	916	1474	1530	865	1312	1313	1405	1062	984	1106	1111
Drying conditions												
Drying time (hr)	51.3	51.6	47.5	47.8	51.6	56.3	58.0	53.8	54.8*	57.0*	54.8*	53.3*
Air flow rate (m^3/hr)	3600	3600	3600	2070	3091	2930	2360	na	1301	1834	1147	2258
Drying experiment data												
Fuel consumption (kg of LPG)	179	174	na	171	186	194	203	181	194	171	196	187
Electrical consumption (MJ)	137	138	127	128	138	151	156	144	147	153	147	143
air velocity at inlet channel (m/s)	6.00	6.00	6.00	3.45	5.15*	4.88*	3.93*	na	2.17*	3.06*	1.91*	3.76*
air velocity at outlet channel (m/s)	0.17*	0.17*	0.17*	0.10*	0.15	0.14	0.11	na	0.06	0.09	0.05	0.11
Enthalpy of inlet air (MJ/kg)	130.79	126.56	125.69	70.57	106.73	105.57	84.34	na	46.30	65.60	40.56	77.39
Enthalpy of outlet air (MJ/kg)	236.54	235.14	237.82	139.66	188.64	179.76	141.74	na	77.51	112.48	74.51	150.53
Energy consumption and loss												
Heat from LPG combustion (MJ)	8917	8668	na	8529	9293	9695	10119	9016	9681	8539	9783	9333
Heat consumption from water evaporation (MJ)	-3343	-2067	-3327	-3453	-1952	-2961	-2963	-3171	-2397	-2221	-2496	-2508
Heat loss with flue gas (MJ)	-5420	-5600	na	-3299	-4223	-4178	-3329	na	-1711	-2674	-1861	-3900
Heat loss at wall of dryer (MJ)	-498	-501	na	-464	-501	-547	-564	-522	-533	-628	-571	0
Others heat loss (MJ)	-344	500	na	1312	2617	2008	3263	na	5041	3016	4855	2925
Others heat loss (%)	-4$^+$	6	na	15	28	21	32	na	52	35	50	31
Economical calculations												
Specific Energy for water evaporation (MJ/kg)	6.11	9.61	na	5.66	10.90	7.50	7.83	na	9.25	8.83	8.98	8.53
Specific Energy for product weight (MJ/kg)	12.82	7.39	na	12.55	22.24	15.58	16.73	na	10.94	10.57	11.81	10.82
Energy cost for product weight (THB/kg)	5.56	3.20	na	5.44	9.64	6.75	7.25	na	4.74	4.57	5.12	4.69

Remarks: na: no data available; * estimated from data, + unreal data.

Thermal parameters of the dryers were determined of twelve experiments from 2005 to 2007 is presented in Table 3. The standard heating value of LPG in Thailand is 49.88 MJ/kg with the cost of 0.44 THB/MJ. Total heat requirement was estimated from the combustion heat and electrical consumption which is the results of the fuel consumption and drying time. Observation of air velocity and temperature from trial experiments, the average value of them can be used for estimating the enthalpy of inlet flow and outlet flow. Nagle et al.[10].

have concluded that concerning the energy consumption and thermal efficiency, the modified dryer with insulation is the best alternative.. Additional holed sieves (invested and false floor) increased the drying rate but only in the bottom level[10]. Consistent with the simulation results, heat loss is zero based on no heat flux at the wall. Total heat loss of insulated wall dryer is minimized (31%) when compared with that of other modified dryer (35%-52%). Simulation of modified dryer with sieve results in higher velocity and temperature in the bottom layer. Especially higher air velocity at the wall opposite the inlet channel causes higher drying rate by convection.

Without insulation material covering, the invert mesh trial represents the higher thermal efficiency in term of specific energy for water evaporation, specific energy for product weight and energy cost for product weight. The fourth experiment in 2005 (EXP05D) gave the lowest specific energy for water evaporation. In terms of slow drying rate of longan fruit, lower air velocity is still high enough to remove the water at the surface. Analogy of this phenomenon was also found in the trail experiment in 2007. From CFD simulation, the enthalpy loss with flue gas (17%-40%) and convective heat transfer at wall (5.5%-7.3%) are important thermal energy loss of the dryer. Covering the wall with insulation can save energy about 5%. The air inlet velocity of 6 m/s is too high. Additional sieve as false floor and invert mesh is not a good air distributor. Calculation of water evaporation inner the bulk improved the CFD simulation but required the single fruit or thin layer drying model as UDF. Furthermore, simulation of the new modified dryer concerning optimal air velocity, heat loss reduction and modern distributor design can be possible with CFD software.

4 Conclusions

The unpeeled longan bulk drying is a good sample for fixing bed dryer. Transport phenomena of hot air flow through the packed bed and hold sieve can be simplified by assuming this volume as the porous media (porous zone and porous jump). Viscous and inertial resistances ($1/\alpha$ and C_2) are important coefficients for simulating with CFD software. This can be estimated from the pressure drop per length and air velocity by using Ergun equation. From simulation results, packing of spherical fruit improves the air distribution. Since the optimal air velocity covers the wall with insulator, more efficient air distributor does not improve the non-uniform temperature and velocity distribution and both shifting and rotating the layers at 180℃ are necessary for homogenizing the dried product. Integrating the water evaporation by applying the drying kinetic of single fruit or thin layer is important for temperature distribution and moisture distribution during drying.

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Nomenclatures

A The Blake–Kozeny–Carman constant

B Burke–Plummer constant

$\Delta P/L$ Pressure drop per unit length (Pa/m)

μ Viscosity of fluid

ρ Density of fluid (kg/m^3)

v_s Average velocity of fluid flow through a cross section area (m/s)

ε Porosity

d Diameter of bed particle (m)

K Permeability tensor

C Inertial drag or form tensor

C_2 Inertial Resistance

$1/\alpha$ Viscous Resistance

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