EVALUATION OF THE EFFECT OF AIR BLADE ANGLE ON AIR DISTRIBUTION IN CHAMBER DRYING EQUIPMENT VIA CFD METHOD

ĐÁNH GIÁ ẢNH HƯỞNG GÓC NGHIÊNG CỦA CÁNH CHIA GIÓ ĐẾN PHÂN BỐ TÁC NHÂN SẤY TRONG THIẾT BỊ SẤY BẰNG PHƯƠNG PHÁP CFD

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ABSTRACT

The non-uniform air distribution in the drying chamber causes the uneven moisture content reduction of material. The solution for more air uniformity in this study is tuning air blade angle, and the CFD simulation method in COMSOL Multiphysics® is applied to reduce the time and cost of solving this. After the test with several values of air blade angle (15, 30, 40, 45, 50, 60 degrees), the appropriately found result is 60 degrees.

Keywords: *CFD, drying process, uniform drying, tray dryer, COMSOL Multiphysics.*

TÓM TẮT

Sự phân bố không khí không đồng đều trong buồng sấy dẫn đến việc vật liệu trên các khay có độ giảm độ ẩm cũng không đều. Trong nghiên cứu này, giải pháp cải thiện sấy giúp cho không khí phân bố đồng đều hơn đó là điều chỉnh góc nghiêng của các cánh chia gió, và phương pháp mô phỏng CFD trong phần mềm COMSOL Multiphysics® được áp dụng để giảm thời gian và chi phí cho việc thực hiện giải pháp trên. Sau khi thử nghiệm với nhiều giá trị góc nghiêng khác nhau (15°, 30°, 40°, 45°, 50°, 60°), giá trị phù hợp nhất là 60°.

Từ khóa: *CFD, quá trình sấy, sấy đồng đều, thiết bị sấy dạng khay, COMSOL Multiphysics.*

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1. INTRODUCTION

Tray dryers are widely used because of their simple design and versatility, but uneven air distribution can cause variation in the final moisture content of dried products on different trays. Generally, the drying rate is heavily affected by air temperature and velocity [1]. This defect reduces the quality of the final product and increases both time and energy consumption per unit of dehydrated water mass from the material [2]. The drying experiment in one day illustrates the inhomogeneity of the drying product on each tray, and the air distribution in the chamber is not always absolutely uniform [3].

CFD simulation is applied to improve drying efficiency by simulating the air velocity and the air distribution in different types of drying equipment: drying cabinets [4] and drying kilns [5]. However, none of the above achieved the design of air uniformity in the dryer without swapping the trays. Applying CFD simulation to tune the dryer improves air uniformity, reduces time and cost [6], and has proven to be a highly accurate and essential tool for optimizing the designs of drying equipment [7]. CFD simulation can be combined with methods like genetic algorithms and machine learning to optimize equipment design and improve air uniformity [8].

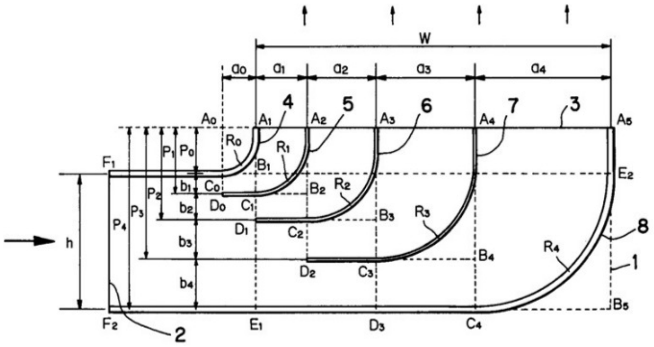


Fig. 1. Elbow-type air blade

The structure for dividing the airflow to increase the dryer's air uniformity is necessary; the patent [9] introduced the elbow-type air blade for the drying equipment, but less effective with numerous trays. This study used the straight-type air blade, which is more common than the elbow-type, to evaluate the effect of blade angle on air uniformity in small industrial drying equipment. CFD method is used to predict the air distribution in the chamber, which has a strong influence on the drying rate efficiency and the product quality [10].

2. MATERIALS AND METHODS

2.1. Governing equations

The Navier-Stokes equation is used to govern the fluid motion. The k-ε model is the most appropriate to simulate turbulent flow mode [11]. The Finite Element Method (FEM) divides the domain of a partial differential equation into elements and approximates solutions using a set of functions. The FEM applies to Navier-Stokes equations [12]. COMSOL Multiphysics® is a multi-platform Finite Element Analysis (FEA) software that allows users to solve systems of PDEs based on conventional physics. It offers a wide range of features for solving PDEs, including adaptive meshing, multiphysics coupling, and uncertainty quantification [13].

Boundary conditions are constraints that must be satisfied at the boundary of the area where a PDE is defined. There are two types: Dirichlet (temperature, concentration, etc.) and Neumann (velocity, flux, etc.). In drying process simulation, setting boundary conditions is based on measured or assumed parameters, such as velocity at the inlet and pressure at the outlet. These need to be set appropriately to reduce simulation time and improve the accuracy of the results.

$$u = -nU_0 \quad (1)$$

$$p = p_{abs} \quad (2)$$

$$u \cdot n = 0 \quad (3)$$

$$j \cdot n = 0 \quad (4)$$

Equations (3) and (4) define Slip conditions for Wall and Interior Wall conditions. The notations u, n, and j are the vector variables difference between fluid velocity and wall velocity, the tangential velocity component, and the mixture velocity through the interior boundaries (trays, air blades, etc.), respectively. The symbols p and pabs corresponding are the scalar variables that illustrate the air pressure at specific points on the bounds and absolute pressure.

2.2. Description of drying equipment

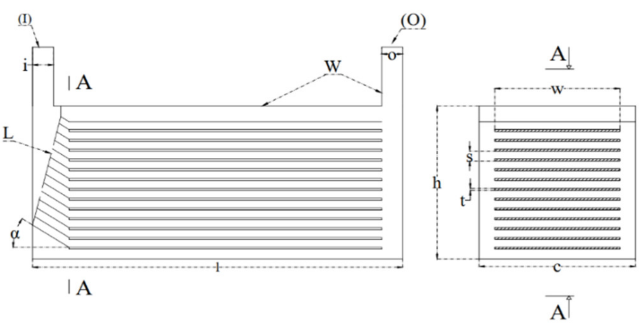


Fig. 2. Equipment cross-sections

Table 1. Equipment cross-sections dimensions and details

Symbol	Description	Value (mm)
i	Inlet width	300
o	Outlet width	200
h	Chamber height	1560
l	Chamber length	3550
c	Chamber width	1600
d	Distance between the trays and the inlet	0
s	Tray spacing	100
t	Tray height	20

Fig. 2 and Table 1 show the main parameters and components of the two-dimensional simplified model of the drying chamber used in the simulation. The equipment consists of multiple tray trolleys with multiple drying trays on each one. The simplified two-dimensional model has only one big tray on each row and one tray trolley, making it easier and faster to simulate than the original one and still accurate. Assuming that the porous material fills the drying trays and the block in the model represents the tray with the material filled. The air blades in the equipment are modeled as a straight line from the top corner of the tray to the lines labeled "L" in Fig. 1. On top of the model, the air blade and the air shield prevent airflow directly from the inlet to the outlet.

Different values of air blade angle α (15, 30, 40, 45, 50, 60 degrees) are simulated. The cases of air blade angle values greater than 60 degrees (depending on the equipment height) are not simulated due to the practical limitations of manufacturing technology, which require small tolerances and are difficult to manufacture accurately.

2.3. Simulations settings

COMSOL Multiphysics 6.0® is used to simulate the air distribution in the drying chamber, assuming steady-state conditions for the drying process. The equipment and the trapezoid-shaped wind duct are symmetrical, so it can be simulated in 2D, giving approximate results with 3D simulation, and the velocity profile is also the same [14]. The trapezoid-shaped duct ensures even distribution, making inlet air the uniform velocity source.

Turbulent flow mode and k-ε physical interface are selected for all simulations with air as material for stationary analysis. The Navier-Stokes equation is a fully differential equation with velocity, so the pressure node is set for outlet boundary conditions. If there is only the velocity boundary condition, the simulation does not converge. Free triangular and extremely fine element sizes for the inlet, outlet, and tray bounds to mesh the model.

Table 2. Simulation settings

Boundary	Boundary Conditions	Value
Inlet (I)	Inlet velocity	3 (m/s)
Outlet (0)	Outlet pressure - Suppress backflow	1 (atm)
Wall (W)	Slip condition – Stationary wall	-
Material surface	Slip condition - Interior wall - Stationary wall	-

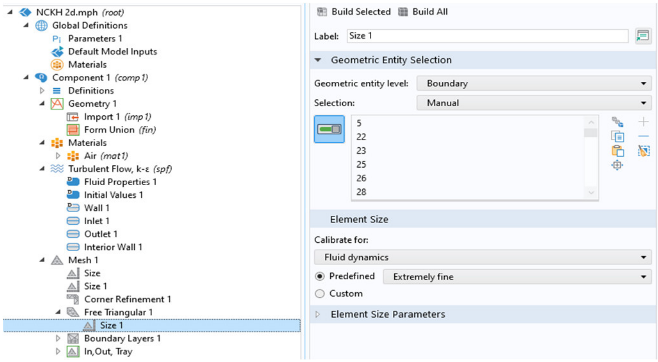


Fig. 3. Meshing in COMSOL

Fig. 4. Meshing for velocity distribution computation

2.4. Evaluation criterion

The average air velocity of the material surface on each tray is analyzed. The air velocity is proportional to the drying rate. This study uses the following criteria to estimate the amount of air going through the material surface and the air distribution in the drying equipment when all the studies mentioned are not used.

$$v_a = \frac{\sum v_i}{N} \quad (5)$$

$$S_v = \sqrt{\frac{\sum (v_i - v_a)^2}{N}} \quad (6)$$

$$S_{\%} = \frac{S_v}{v_a} \times 100(\%) \quad (7)$$

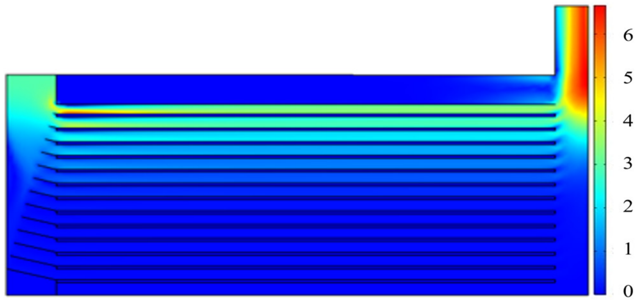
$$\Delta_v = \frac{v_{i_{max}} - v_{i_{min}}}{v_a} \quad (8)$$

Table 3. Notations description

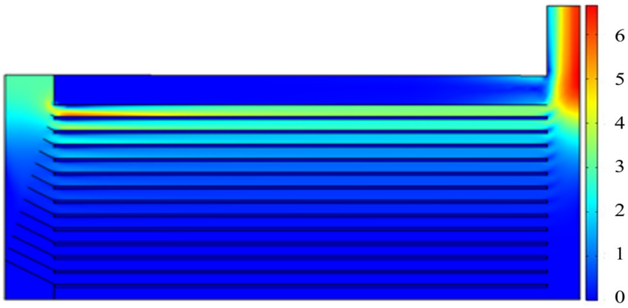
Notation	Description	Definition
v_i	The effective velocity of the material surface on i^{th} tray	The average velocity value of finite points on the evaluated surfaces.
v_a	The pretension velocity	Evaluate the amount of air going through the material surface.
n	Number of trays	-
Sv	The standard deviation of the v_i value of the case	Measure the amount of variation or dispersion of the v_i set.
$S_{\%}$	Coefficient of velocity variation	The coefficient to evaluate the correlation between the velocity dispersion and the pretension velocity achieved.
Δ_v	The coefficient of the actual difference velocity.	The relative variability of the v_i set.

3. RESULT AND DISCUSSION

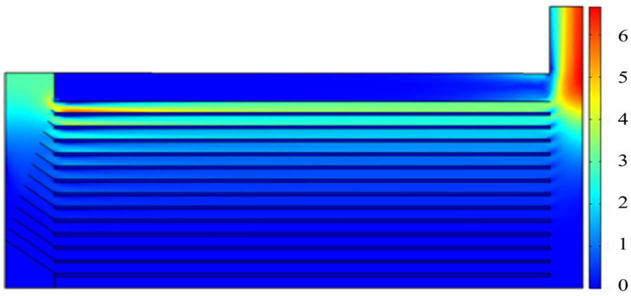
Table 3 shows the simulation results. The value of α varies from 15 degrees to 50 degrees; the value of v_1, v_2, and v_3 increases and decreases when α equals 60 degrees. On the other trays, v_i values increases when α increases, meaning that more air is in these trays when the air blade angle increases.



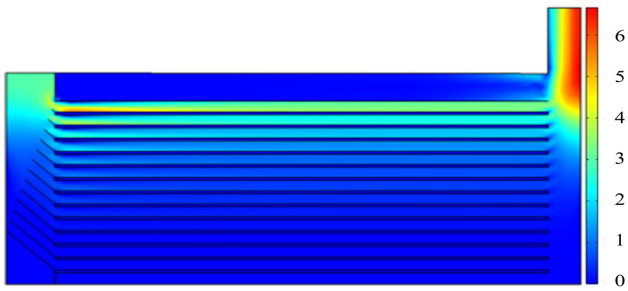
a) α = 15°



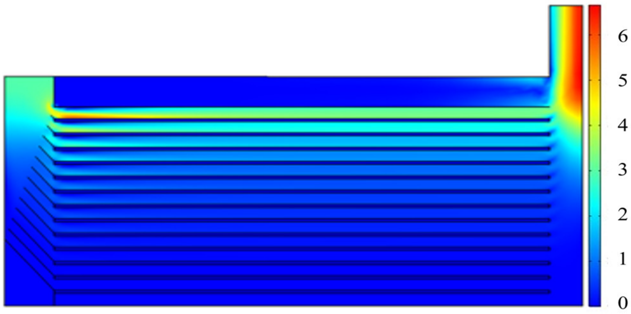
b) α = 30°



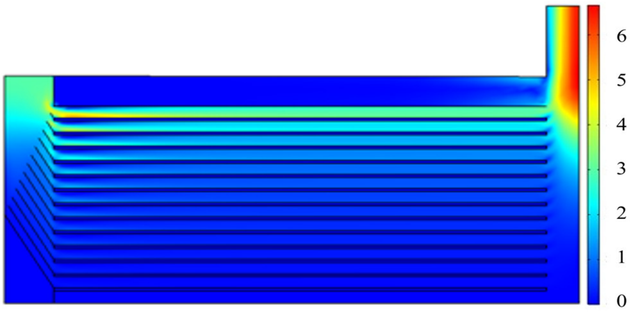
c) α = 40°



d) α = 45°



e) α = 50°



f) α = 60°

Fig. 5. Air velocity contour in the drying chamber

Table 4. Simulations results of average velocity on the material surface (AAVOMS, m/s)

Tray \ α (°)	15	30	40	45	50	60
1	1.1961	1.7505	1.7081	1.6763	1.6429	1.5109
2	0.9396	1.2676	1.2200	1.2159	1.1849	1.0776
3	0.6817	0.8461	0.8427	0.8520	0.8362	0.8224
4	0.5129	0.5740	0.5876	0.6197	0.6112	0.6230
5	0.3873	0.3992	0.4148	0.4394	0.4562	0.4899
6	0.2695	0.2842	0.3053	0.3310	0.3384	0.3800
7	0.1435	0.2048	0.2254	0.2472	0.2539	0.2982
8	0.0581	0.1230	0.1555	0.1796	0.1951	0.2363
9	0.0284	0.0417	0.0760	0.1121	0.1397	0.1871
10	0.0313	0.0076	0.0188	0.0473	0.0819	0.1451
11	0.0312	0.0029	0.0028	0.0080	0.0302	0.1038
12	0.0296	0.0024	0.0007	0.0004	0.0036	0.0627
13	0.0249	0.0025	0.0010	0.0006	0.0001	0.0310

Table 5. Criterion calculated for different angle values

Criterion \ α (°)	15	30	40	45	50	60
v_a	0.3334	0.4236	0.4276	0.4407	0.4442	0.4591
$S_{\%}$ (%)	117.68	130.79	125.05	118.7	113.75	96.80
Δ_v	3.5130	4.1270	3.9931	3.8025	3.6985	3.2236

While α and v_a increase, $S_{\%}$ and Δ_v change nonlinearly, increase when α increases from 15 to 30 degrees, and decrease when *α* increases from 30 degrees onward. The average air velocity difference on the material surface on each tray changes and reaches its minimum value when α equals 60 degrees ($S_{\%}$, Δ_v also reach their minimum values), which means the air uniformity, in this case, is the best among the others.

4. CONCLUSION

COMSOL Multiphysics® is one of many useful software for applying CFD methods to predict the air distribution of the chamber drying equipment, which saves plenty of time and cost. The efficiency and quality of drying are greatly influenced by air velocity and flow rate across the material surface. While most of the equipment's air distribution is poor, installing and tuning air blades to overcome this defect is recommended. This study shows the change in the air blade angle affects the air uniformity, and 60 degrees is the most appropriate value. Based on the simulation results, depending on the equipment height, the larger the air blade angle (less than 60 degrees because angle values greater than 60 degrees cause difficulties in the manufacturing process), the more air goes through the lower trays.

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