COMPUTATIONAL FLUID DYNAMICS (CFD) SIMULATION OF HOT-AIR FLOW PROFILE AND TEMPERATURE DISTRIBUTION IN A CECH DRYER

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ABSTRACT

This paper presents the computational fluid dynamics simulation of air flow and temperature distribution in a CECH dryer. The CAD model of the dryer was done using Solidworks 2014 software The discretization process was done in ANSYS ICEM in order to cope-up with the thermal and velocity layers formation. ANSYS FLUENT 14.5, a Computational Fluid Dynamic (CFD) software in which flow fields and other physics are calculated in detail for various engineering applications, was used as the CFD solver. The analysis was done to characterize velocity vectors, temperature distribution, pressure, air flow pattern and turbulence intensity. Experimental data was used for the boundary conditions. Standard k-ε turbulence model was allowed to predict the three-dimensional flow and the conjugate various profiles of the air parameters. Simulation results revealed air temperature profile to be 365.56K, 368.93K, 376.14K, 373.53K and 383.12K on trays 1, 2, 3, 4 and 5 respectively. Taking tray 5 as a reference point, air temperature decreased from 383.12K at the reference point (0) along the distance of travel of heated air to 363.54K at the end point 0.65 m. Air density profile shows 9.74×10^{-1} kg/m^3, 9.65×10^{-1} kg/m^3, 9.46×10^{-1} kg/m^3, 9.53×10^{-1} kg/m^3 and 9.29×10^{-1} kg/m^3 on trays 1, 2, 3, 4 and 5 respectively. From the results, it is noted that the heated air was not flowing well to tray 1 and 2 and this is due to the configuration of the dryer. It is therefore suggested that during drying operation, the trays should be inter-changed intermittently in order to achieve uniform distribution of the heated air in the drying chamber. It can be inferred from the study that the drying rate of the product would be significantly influenced by the air velocity, the drying air temperatures and the arrangement of the trays.

Key words: *CECH dryer, CFD simulation, food processing, heat transfer, SWFS software*

1. INTRODUCTION

One of the easiest and oldest methods of food processing which can contribute to a reduction in postharvest losses and promote food security is drying. This operation is energy consuming, so there is need for an actual optimization based on dynamic mathematical models, analysis and numerical simulations. The system behaviour and performance of a dryer is directly influenced by the air flow pattern and temperature distribution in the drying chamber. A thorough understanding of the fundamental principles of this system behaviour is highly essential for the optimization of the drying process.

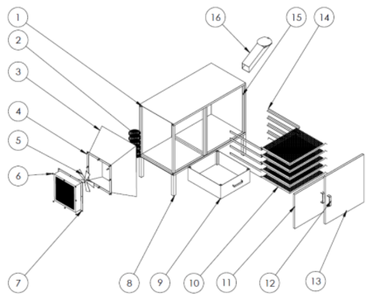
Olaniyan and Alabi (2014) designed and fabricated a prototype dryer for paddy rice using locally-available construction materials. A preliminary test carried out on the dryer revealed that it was able to dry paddy rice from a moisture content of 22.36% to 13.37% and this shows that the dryer performed satisfactorily. Olaniyan and Omoleyomi (2014) designed, built and tested a hot-air dryer for small scale drying of tomato taking into consideration the techno-economic status of small holder farmers and tomato processors. Testing the dryer with 840g samples of sliced tomato at 55^{0}C for 6h showed that it was able to dry the tomato samples from a moisture content of 89% (wb) to 21.8% (wb). Olaniyan et al (2017) conducted experiments to determine the effects of foaming agent, foam stabilizer and whipping time on the drying process of tomato paste under different drying equipment. Result showed that showed that an optimum drying rate of 11.36 g/h could be achieved using a mechanical dryer if tomato paste is pretreated with foaming agent, foam stabilizer and whipping time of 14.0 %EW, 0.48 %CMC and 9 min respectively.

An understanding of temperature distribution at any point in the drying chamber is important because spoilage can start from regions with poor temperature distribution and caking of the products can occur at the region with undesirable level of temperature. Therefore, the objective of this study is to investigate the air flow profile and temperature distribution in a CECH dryer using Solidworks 2014 SP4.0 software. The work presents the computational fluid dynamics simulation of air flow and temperature distribution in the CECH dryer.

2. MATERIALS AND METHODS

2.1. Description of the CECH Dryer

The CECH dryer was designed and constructed as part of a project on drying of agricultural products. As shown in Figure 1 below, the dryer has three major functioning units, which are the inlet air diverging unit, heating (plenum) chamber and the drying chamber (having five drying trays numbered upwards from the bottom). The major components of the dryer are the blower, heating elements, diverging unit to direct the flow of air, and drying trays which are stacked vertically in the drying unit. The mesh analysis of the geometry of the dryer is shown in Figure 2.



ITEM NO.	PART NUMBER	QTY.
1	EXTERNAL CHAMBER	1
2	Heating Element.ipt	5
3	DIVERGING UNIT	1
4	B18.2.3.1M - Hex cap screw, M8 x 1.25 x 25 --25N	9
5	BLOWER	1
6	B18.2.4.1M - Hex nut, Style 1, M8 x 1.25 --D-C	9
7	FAN UNIT	1
8	FRAME	4
9	COAL CHAMBER	1
10	DRYING TRAY	5
11	HEATING CHAMBER DOOR	1
12	HANDLE	2
13	DRYING CHAMBER DOOR	1
14	TRAY RACK	10
15	INNER CHAMBER	1
16	CHIMNEY	1

Figure 1: Exploded View of the CECH Dryer

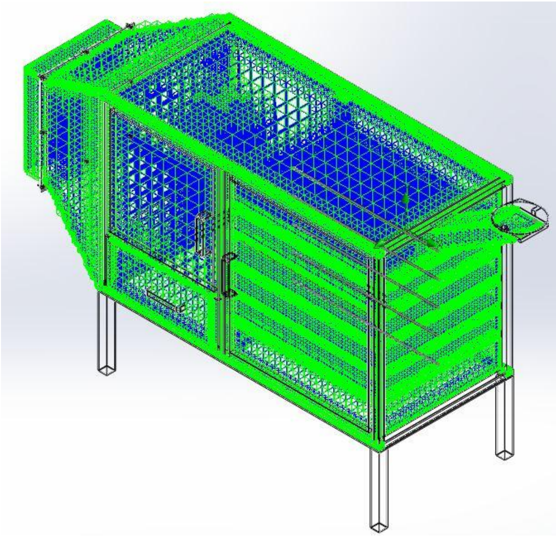


Figure 2: Mesh Analysis of the Geometry of the CECH Dryer

2.2. Simulation Model

The CAD model of the dryer was done using Solidworks 2014 software as used by Oyeniyi *et al.* (2016). The discretization process was done in ANSYS ICEM in order to cope-up with the thermal and velocity layers formation. Thereafter, ANSYS FLUENT 14.5, a Computational Fluid Dynamic (CFD) software in which flow fields and other physics are calculated in detail for various engineering applications, was used as the CFD solver. The analysis was done to characterize velocity vectors, temperature distribution, pressure, air flow pattern and turbulence intensity. The experimental data was used for the boundary conditions. Standard k-ε turbulence model was allowed to predict the three-dimensional flow and the conjugate various profiles of the air parameters.

2.3. Boundary Conditions

The boundary conditions considered are as shown in Tables 1 and 2 and illustrated by Figure 3 below. This takes into consideration x-axis as the reference axis with global coordinate system.

Table 1: Boundary Conditions for Inlet Velocity

Type	Boundary Conditions
Flow parameters	Flow vectors direction: Normal to face Velocity normal to face: 2.000 m/s Fully developed flow: Yes
Thermodynamic parameters	Approximate pressure: 101325.00 Pa Temperature: 363.20 K

Table 2: Boundary Conditions for Environment Pressure

Type	Boundary Conditions
Thermodynamic parameters	Environment pressure: 101325.00 Pa Temperature: 273.20 K
Turbulence parameters	Turbulence energy and dissipation Energy: 1.000 J/kg Dissipation: 1.00 W/kg
Boundary layer parameters	Boundary layer type: Turbulent

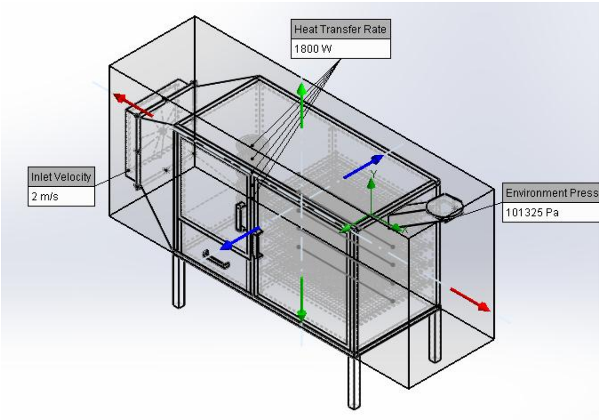


Figure 3: Boundary Conditions and the Computational Domain of the CECH Dryer

2.4. CFD Governing Equations

The basic governing equations of CFD analysis is the Navier-Stokes equations which is the conservation laws for mass, momentum and energy in the Cartesian coordinate (x,y,z) system rotating with angular velocity about an axis passing through the coordinate system's origin. These equations can be written as follows (Solidworks, 2012, Oyeniyi *et al.*, 2016):

Mass Equation:

$$\frac{\rho}{t} + \frac{}{x_i}(\rho u_i) = 0 \qquad (1)$$

Momentum Equation:

$$\frac{\partial(\rho u_i)}{t} + \frac{}{x_j}(\rho u_i u_j) + \frac{p}{x_i} = \frac{}{x_j}\left(\tau_{ij} + \tau_{ij}{}^{R}\right) + S_i \quad i = 1,2,3 \qquad (2)$$

Energy Equation:

$$\frac{\rho H}{t} + \frac{\rho u_i H}{x_i} = \frac{p}{x_i}\left(u_j\left(\tau_{ij} + \tau_{ij}{}^{R}\right) + q_i\right) + \frac{p}{t} - \tau_{ij}{}^{R}\frac{u_i}{x_j} + \rho\varepsilon + S_i u_i + Q_H \qquad (3)$$

Where: u is the fluid velocity (m/s), ρ is the fluid density (kg/m^3), S_i is a mass-distributed external force per unit mass (N), h is the thermal enthalpy, Q is a heat source per unit volume, τ_{ij} is the viscous shear stress tensor, q_i is the diffusive heat flux. The subscripts are used to denote summation over the three coordinate directions. P is pressure (Pa), $\frac{U_j}{x_i}$ is the body forces (N), and t is time (s), (i, j, k) depicts the three main coordinates which the mass force depends on, c_μ is the fourth-order tensor representing the constant of proportionality, λ is the viscosity tensor, μ the dynamic viscosity (Ns/m^3) and δ_{ij} is the Kronecker delta.

3. RESULTS AND DISCUSSION

3.1. CFD Post Process of the Air Flow Profile Cut Plots in the CECH Dryer

As shown in Figures 4 and 5 below, the temperature contours grew from the heating element to the drying chamber. It is also noted the heated air was not flowing well to trays 1 and 2 due to the configuration of the dryer. Hence, it is suggested that during drying operation, the trays should be inter-changed intermittently in order to achieve uniform distribution of the heated air in the drying chamber. In another sense, another fan to cause more turbulence in the drying chamber should be placed therein. It can also be suggested that the fan should be closer to the heating source. It is highly essential to note that the walls of the drying chamber are well insulated in order to minimize heat transfer through the dryer walls

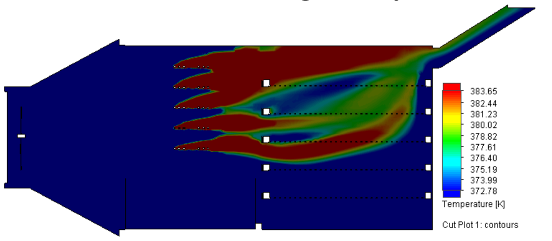


Figure 4: Temperature Field Pattern of the Hot Air in the CECH Dryer

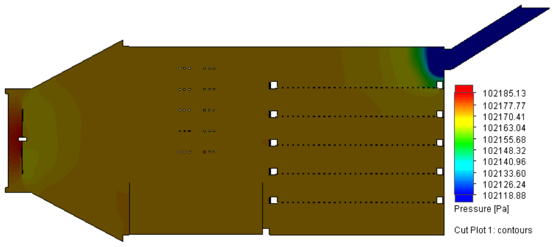


Figure 5: Pressure Profile of the Hot Air in the CECH Dryer

3.2. Variation of Drying Parameters in respect to the Arrangement of the Trays

As illustrated in Figures 6-12 below, simulation results revealed air temperature profile to be 365.56K, 368.93K, 376.14K, 373.53K and 383.12K on trays 1, 2, 3, 4 and 5 respectively. Considering tray 5 as a reference point, air temperature decreased from 383.12K at the reference point (0) along the distance of travel of heated air to 363.54K at the end point 0.65 m. Air density profile shows 9.74x10^{-1} kg/m^3, 9.65x10^{-1} kg/m^3, 9.46x10^{-1} kg/m^3, 9.53x10^{-1} kg/m^3 and 9.29x10^{-1} kg/m^3 on trays 1, 2, 3, 4 and 5 respectively. On tray 5, air density decreased 9.29 x10^{-1} kg/m^3 at the reference point to 9.78 x10^{-1} kg/m^3 at the end point 0.65 m. Air velocity profile indicates 5.08 x10^{-1} m/s, 7.79 x10^{-1} m/s, 4.75 x10^{-1} m/s, 2.14 x10^{-1} m/s and 1.36 x10^{-1} m/s on trays 1, 2, 3, 4, and 5 respectively. On tray 5, air velocity increased from 0.14 m/s at the reference point to 2.56 m/s at the end point. The total enthalpy were 371.00, 374.43kJ/kg, 381.71 kJ/kg, 379.07 kJ/kg and 388.78 kJ/kg on trays 1, 2, 3, 4 and 5 respectively. On tray 5, the total enthalpy388.78 kJ/kg at the reference point to 369.06 kJ/kg at the end point.

It is obvious from the results that the heated air was not flowing well to tray 1 and 2 and this can be adduced to the configuration of the dryer. It is therefore suggested that during drying operation, the trays should be inter-changed intermittently in order to achieve uniform distribution of the heated air in the drying chamber. Alternatively, another fan to cause more turbulence in the drying chamber should be placed installed closer to the heating chamber.

Tray 3 has the highest range of air temperature with the peak being at 0.4 m along distance of travel of the heated air on the drying tray while tray 1 has the least temperature profile due to its location in the drying chamber. This trend shows that the temperature of the fluid varies with the distance of travel best along tray 4 and the percentage of hot air it contributed to at this level is greater than others. It was observed that there are peak periods at the distance between 0.25-0.4 m along the trays and the temperature later drops towards the end of the trays due to the collision of a boundary (dryer door).

Turner and Jolly (1991) and Zhang and Mujumdar (1992) in microwave convective drying and Golestani *et al.* (2013) in convective drying simulations also reported a decreasing temperature profile near the wall of the drying chamber door due to the fact that in simulation, heat loss due to conduction is considered negligible. There was a surge in temperature level at a distance 0.3 m from the rare end of the dryer wall on tray 3 and this might be due to the flow trajectory of the hot air as a result of the upward direction of the flow.

It can be inferred from the study that the drying rate of the product would be significantly influenced by the air velocity, the drying air temperatures and the arrangement of the trays. The study revealed that it is possible to determine the effective length of the drying chamber and recirculation points which is in agreement with the study conducted by Karim and Hawlader, (2005).

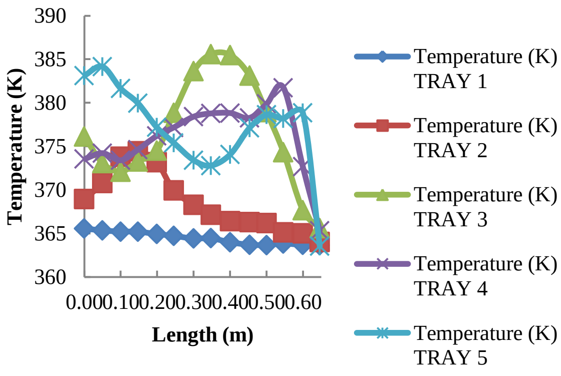


Figure 6: Temperature Profile at Various Points on the Tray with respect to Length

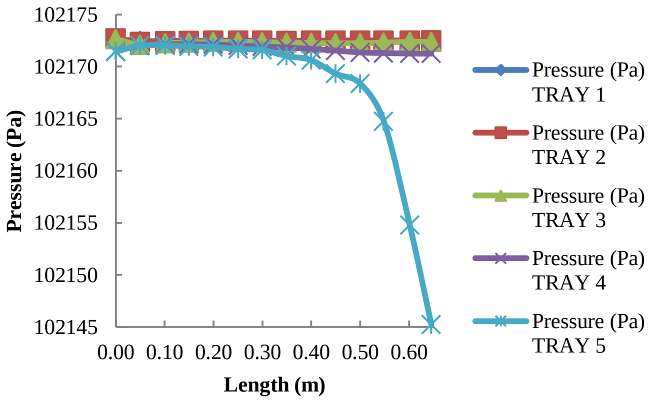


Figure 7: Air Pressure Profile at Various Points on the Tray with respect to Length

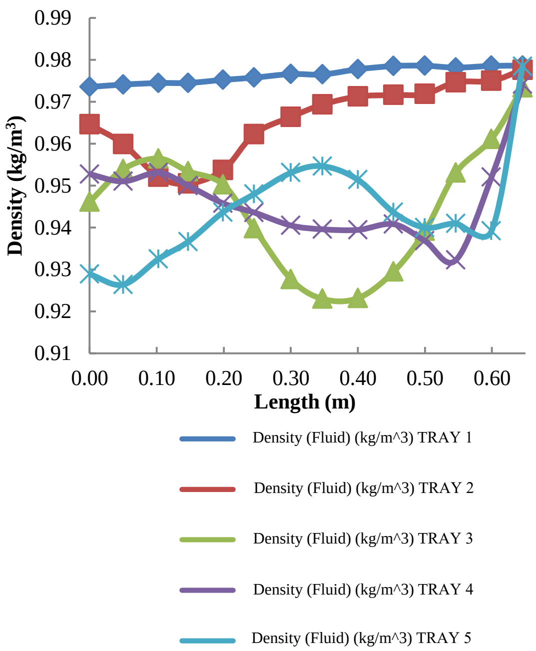


Figure 8: Fluid Density Profile at Various points on the tray with respect to length

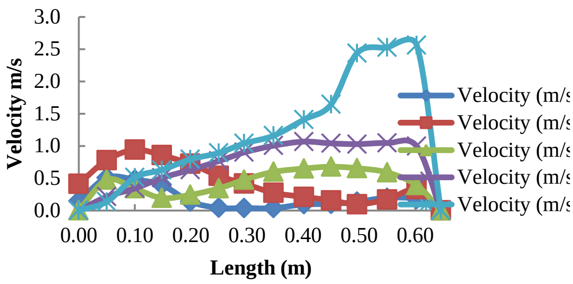


Figure 9: Air Velocity Profile at Various points on the tray with respect to length

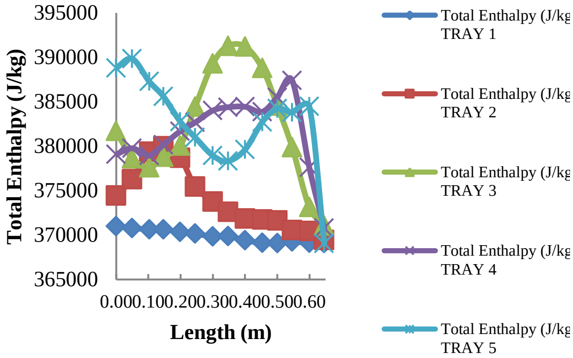


Figure 10: Total Enthalpy Profile at Various points on the tray with respect to length

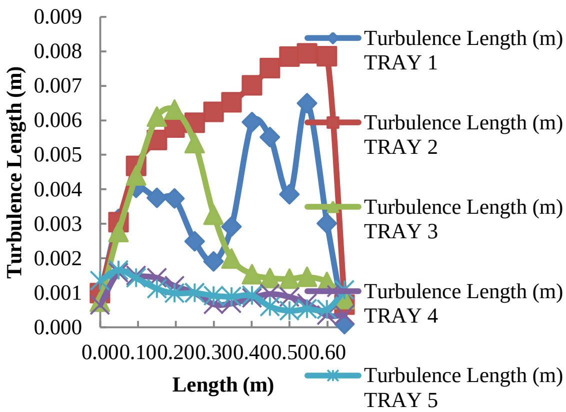


Figure 11: Turbulence Length with respect to the length of trays

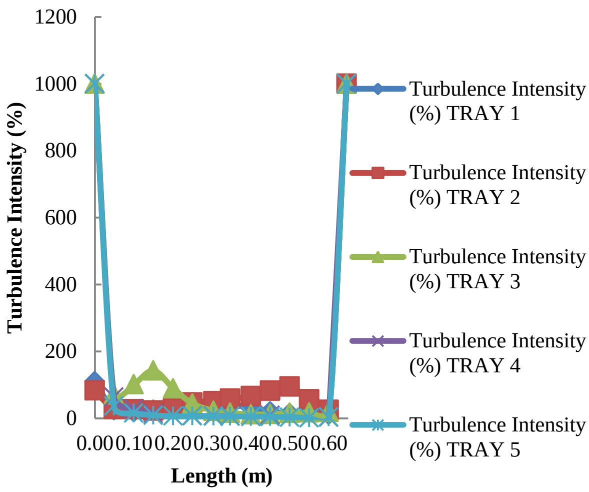


Figure 12: Variation of Turbulence Intensity along the Length of Trays

4. CONCLUSION

The computational fluid dynamic (CFD) simulation was used to predict the temperature distribution, velocity profile and pressure fields in the drying chamber of a CECH dryer. The air flow properties in terms of temperature distribution, velocity field profiles, pressure, fluid density, total enthalpy and turbulence effect of the air were also analyzed to predict the efficiency of the CECH dryer. From the study, it can be infered that the drying rate of the product would be significantly influenced by air velocity, air temperatures and the arrangement of the trays. It can be concluded that the turbulence model used for the CFD simulation is capable of predicting the dynamic behaviour of the dryer. Thus, CFD is highly efficient in predicting airflow pattern and analysis of drying parameters. Its application to dryer design is capable of solving the problems of uneven drying of products.

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1. Adesoji Matthew Olaniyan graduated with BEng, MEng and PhD in Agricultural Engineering from University of Ilorin, Nigeria in 1991, 1998 and 2006 respectively. Since 1998, he has been working on techniques, processes and equipment for processing agricultural and bioresources materials to food, fibre and industrial raw materials. Dr. Olaniyan's principal area of research is on Bioproduct Processing and Food Process Engineering, where he has carried out a number of projects and published a number of papers in local and international journals. He joined the service of the University of Ilorin in 1998 as an Assistant Lecturer in the Department of Agricultural and Biosystems Engineering and rose to the position of a Senior Lecturer in 2009. Currently, he is an Associate Professor at the Department of Agricultural and Bio-resources Engineering, Federal University Oye-Ekiti, Nigeria. Dr. Olaniyan has bagged several awards including the Award for the Best Paper (2007) in the Journal of Food Science and Technology, Mysore, India; Chinese Government Sponsorship (2008) for International Training Programme in Protected Agriculture at International Exchange Centre, Yangling, China; Netherlands Fellowship Programme (2009) for International Training Programme in Milk Processing at Practical Training Centre, Onkerk, the Netherlands; and Postdoctoral Fellowship (2011) of the Academy of Sciences of Developing Countries.

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3. Abraham Olusola Oloye bagged a National Diploma in Agricultural Engineering from the Federal Polytechnic, Ado-Ekiti and proceeded to the Federal University of Technology, Akure where he obtained his BEng and MEng degrees in Agricultural Engineering. He is a Corporate Member of the Nigerian Institution of Agricultural Engineers (MNIAE), Nigerian Society of Engineers (MNSE) and a Registered Engineer with the Council for the Regulation of Engineering in Nigeria (COREN). He joined the service of the Federal University, Oye-Ekiti as a Lecturer II in the Department of Agricultural and Bioresources Engineering specializing in Processing and Storage Engineering. He is a Member of the University COREN and NUC Accreditation Committee and has jointly published in a scientific research.

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