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Computational Fluid Dynamic Analysis on Double-Type Drying Machine Design

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Abstract

The design of a double-type dryer with tray and rotary will be designed to be able to dry chips and grains commodities in one time process for energy and time-saving. In the designing process, Computational Fluid Dynamic (CFD) simulation is used to analyze the distribution of hot air and minimize failures in the design. The purpose of this study was to determine the pattern of hot air flow distribution and determine the best design of the drying machine. The parameters used in the CFD input have a temperature of 60 ºC, air velocity 1 m/s, and a pressure 1.01325 bar with a constant time. This study used 2 treatments, namely the outlet position parameter (A) with dimension 60 mm x 60 mm and the number of holes in the bulkhead between the tray and rotary have the gap type (L) with dimension 540 mm x 70 mm with a total of 21 treatments. This research begins with pre-processing for made geometry and boundary condition input, next is solver process with average iterations 298 with 36 s interval, and the last is post-processing for having air contour. The results showed that the best treatment based on temperature pattern is the A2L1L2 treatment, with the output A2 and 2 limiting gaps, on gaps 1 and 2. This treatment had an average temperature distribution of 56.69 ºC, deviation 3.55 ºC, air velocity 1.57 m/s, and turbulence 0.021 m/s.

Keywords: CFD; drying; rotary; tray

1. Introduction

Post-harvest processes in agricultural products that play an important role in maintaining product shelf life by reducing mositure content through the drying process. Highest moisture content in the products will cause the products to be susceptible to microorganisms and spoilage [1]. The farmers usually use manual drying with the open sun drying and mechanical drying using a dryer machine.

Drying machines commonly used are trays for drying chips and rotary types for grain. Tray dryer usually have a disadvantage, the process of distributing hot air that is not evenly distributed just tray near with the heater and caused change the tray position. The rotary dryer can only dry certain types of products, but the distribution of hot air produced is evenly distributed over the entire surface of the dried material.

Based on these problems, a dryer is designed that has a dual system that can dry materials with different characteristics in one machine to save time and save energy in the process. The dryer is design have two parts, the top is a rotary and the bottom is a tray. The process of the flow of hot air that is exhaled will flow to thectray and then be directed to the top for the rotarydryer and then exit at the outlet.

The drying machine design process consists of design, simulation, and manufacturing stages. The simulation process plays an important role in the drying machine design process, because the simulation aims to optimize the work and distribution of airflow in the drying chamber which spreads to all parts of the machine to be more efficient and effective and minimize failures in the process [2]. The analysis used to determine the distribution of hot air and fluid distribution is Computational Fluid Dynamics (CFD) analysis because the visualization results can be easily interpreted by researchers [3]. CFD simulation on the drying machine is very necessary to know the environmental conditions and the contours of the hot air in the design of the drying machine, especially for drying food [4]. Airflow distribution simulation has been carried out on a tray-type drying machine using CFD and the analysis is very helpful in the drying machine design process because adjusting the tray position and adjusting the air distribution flow will affect the drying rate [5].

The development of drying technology must continue to be carried out in order to obtain an efficient and effective machine, one of the developments carried out is the development of two types of dryers in one machine. The design of this double-type dryer has a partition that

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functions to separate the tray and rotary positions. To optimize the temperature distribution from the tray to the rotary, it is necessary to have the right number, position of the gap on the bulkhead and the outlet holes so that hot air is locked for a long time in the chamber before it finally comes out. The purpose of this study was to determine the distribution of hot airflow and the best design for a double-type dryer.

2. Material and Methods

2.1. Experimental set up

This research used SolidWorks 2021 flow simulation software. The machine design have length 1950 mm x 600 mm x 1030 mm (Fig. 1), with silinder diameter 400 mm and length 1120 mm (Fig. 2), and tray length 500 mm x 490 mm x 270 mm (Fig. 3).

The designed process is divided into 3 outlets and 3 gaps positions consists of outlet positions (A) and bulkhead gap (L) (Table 1).

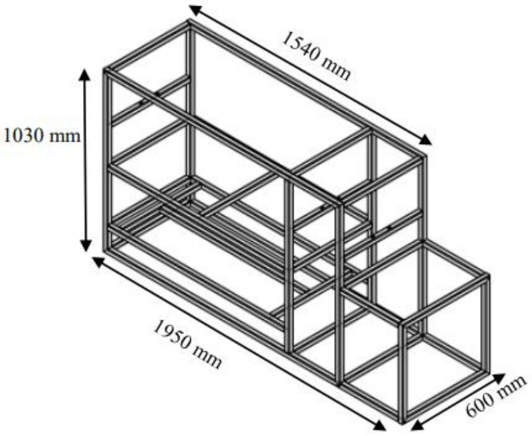


Figure 1. Isometric view machine framework

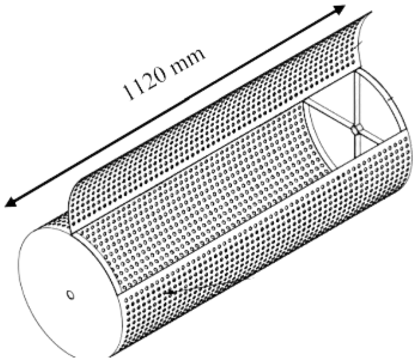


Figure 2. Isometric view silinder

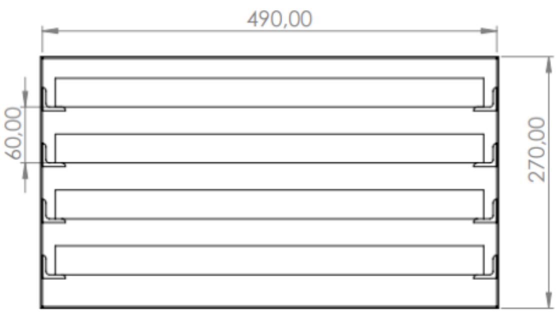


Figure 3. Isometric view tray

Table 1. The process division

Notation	Description
A1	Outlet in the right side
A2	Outlet in the left side
A3	Outlet in the top side
L1	Gap 1
L2	Gap 2
L3	Gap 3

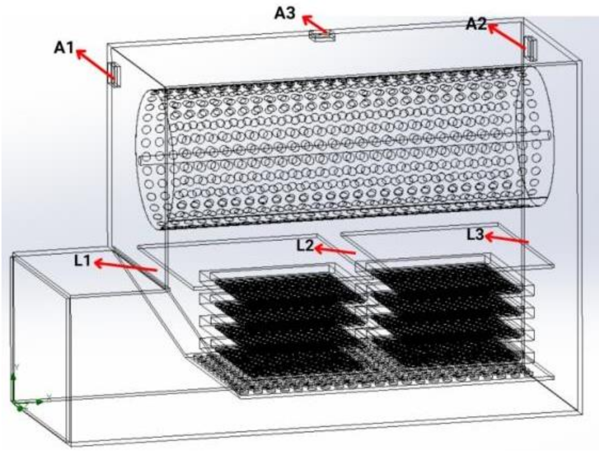


Figure 4. Isometric view machine

The size made with a outlet hole's size 60 mm x 60 mm and with a gap's size 540 mm x 70 mm. The treatment was made as many 21 geometries, according to the treatment made placement outlet is on the side and top of the machine, while the position of the hole is on the side and center of the partition (Fig. 4).

2.2. Mathematical model

Mathematical equation used a navier-stokes equation which consisting of mass, momentum, and energy conservation on fluid flows is [6]:

$$\frac{\partial \rho}{\partial t} + \nabla(\rho \vec{v}) = 0 \quad (1)$$

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla(\rho \vec{v}\vec{v}) = -\nabla \rho + \nabla(\vec{\tau}) + \rho \vec{g} + \vec{F} \quad (2)$$

$$\frac{\partial}{\partial t}(\rho E) + \nabla(\vec{v}(\rho E + \rho)) = \nabla\left(k_{eff} \nabla T\right) + S_h \quad (3)$$

2.3. Boundary condition

The initial temperature input data is 60 °C with an inlet velocity 1 m/s, and environmental temperature is made with an average temperature of 27 °C and a pressure of 1,01325 bar. The use of an input temperature of 60 °C is adjusted to the commodity to be dried simplicia products that contain high volatiles, so that the use of temperatures below 60 °C is the optimum temperature that can be used [7]. Boundary conditions made consist of 4 parts, namely the inlet velocity on the inlet hot air environmental pressure on the outlet, real wall 1 on the rotary, and real wall 2 on the tray.

2.4. Analysis process

2.4.1. Pre-processing

The first process is the process of making machine geometries, 21 geometries are made according to the geometries made. The next process is to enter data for simulation in the boundary conditions in the form of temperature, pressure, and air velocity. The most important things in the design of the dryer is the initial input conditions in the form of temperature, pressure and fluid velocity which are the keys in a simulation process [8]. The stages after data input are the desired input goals, temperature, velocity, pressure and turbulence. The last stage in preprocessing is meshing and what is used is global mesh.

2.4.2. Solver

The solver or processing stage is the analysis stage of the input data in the process with the equation used until a convergent value or value with the smallest error rate is found, which is called the iteration process. The iteration of the 21 treatments made has an average iteration value of 298 iterations, with the time required for $\pm$ 3 hours with iterations per travel for 36 seconds.

2.4.3. Post-processing

The last stage in the simulation process is to interpret the analysis results into certain images and graphs. The result obtained is in the form of numerical data from variables of fluid properties such as temperature, velocity, and turbulence. The data from the simulation results that have been carried out on the machine produces an image of hot air contours throughout the engine surface, velocity, air contours on the tray, hot air contours on the rotary, and the level of air turbulence when the airflows.

2.5. Simulation condition

The simulation settings parametric are temperature, air velocity, and air turbulence. The parametric of the study in this research is to design the outlet to maximize the temperature inside the drying chamber. The use of air flow velocity and temperature in research using CFD will show the temperature distribution in the drying chamber and it can be used in design improvements [9].

3. Result and Discussion

3.1. Simulation results on the position of the outlet and the gap

The position outlet and the number of gaps will affect the value of temperature distribution, air velocity, and the level of turbulence that occurs in the drying process. The temperature and speed of the inlet and outlet will affect the material being dried from a physical and chemical properties [10]. The average pressure is same because the geometric shape is almost the same, which is 1.06 bar.

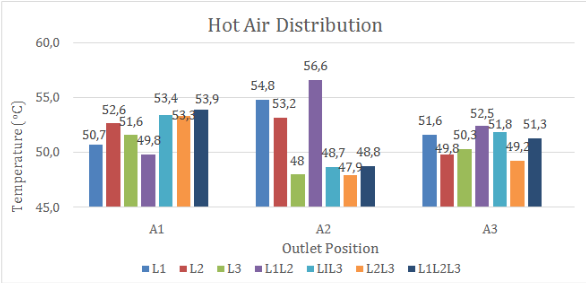


Figure 5. Hot air distribution 21 treatments

3.1.1. Temperature

The results obtained the farther the position of the hole from the outlet, the greater the average value of the temperature distribution in the drying chamber because the hot air will circulate first in the chamber. The distribution of the highest temperature values is in the A2L1L2 sample, namely the disposal of A2 with two gaps opened, namely hole 1 and hole 2 with a value of 56.69 ºC (Fig. 5). Position outlet with the placement of the gap also affects the level of flatness in the drying tray system because the hot air will pass through the tray first and then enter the rotary and then exit at the outlet. The treatment that has the lowest value is the A2L2L3 treatment which produces an average temperature of 47.92 ºC, there is a much different decrease in temperature due to the cold temperature trapped in the dryer (Fig. 5).

The results of the temperature distribution are the key to having the best design for the machine, the distribution of the hot air temperature contour from the simulation results can interpret the plan to have the design (Fig. 6). Based on research [11] in simulations on the design of the dryer, the best result is a design that produces a low-pressure drop, high drying rate, and uniformity of hot air in the dryer.

3.1.2. Velocity

The results show fewer the number of gaps given, the faster the air velocity. This is because the air is not divided and passes through many gaps. The highest air velocity will affect the drying process because hot air will quickly exit the outlet. Increasing the speed of the drying process will cause a decrease in temperature that occurs faster towards the outlet because it is caused by an increase in the rate of evaporation of water [10]. The highest velocity value is shown by the A3L1 treatment with a speed of 2.15 m/s and the treatment with the lowest value is A2L2L3 with a speed of 1.18 m/s. The position of the open hole and its distance from the outlet are factors that influence because it causes the speed value to decrease rapidly.

3.1.3. Turbulence

The results obtained the level of turbulence is directly proportional to the air velocity. The higher air velocity value, the faster the turbulence that occurs. This turbulence occurs because the velocity of the air experiences friction with the inside of the dryer quickly and then goes to the outlet. The highest velocity value was shown by the A3L1 treatment with the turbulence of 0.024 m/s and the treatment with the lowest value was A2L2L3 with the turbulence of 0.014 m/s. The stability of the

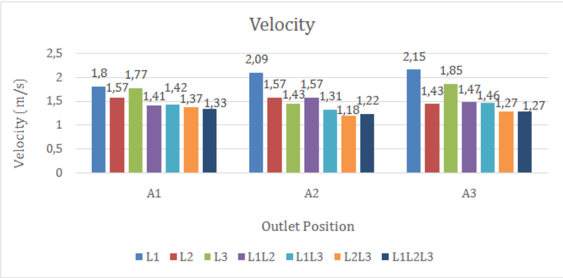


Figure 6. Velocity 21 treatments

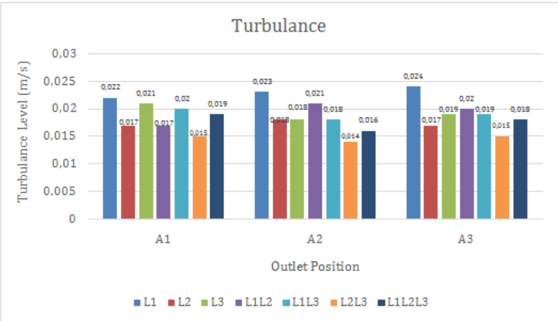


Figure 7. Air turbulance 21 treatments

turbulence level will affect the mass transfer and heat transfer in the dried material [12].

3.2. Hot air distribution process

Airflow scheme blown as shown in Fig. 8 by a fan throughout the drying chamber passes through the bottom of the machine, continues to the drying tray through the gaps and gap of the perforated plate, followed by a distribution to the top of the machine where there is a rotating drying. The rotating rotary is made so that the hot air evenly touches the dried product and the cold air will come out through the air funnel on the right side of the machine.

3.2.1. All Parts

All parts of the machine in 21 treatments, which was taken the treatment that had the highest temperature distribution value, namely the A2L1L2 treatment (Fig. 9). The most uniformity of the red color is the best result because the red color represents the maximum temperature obtained in the design. The average velocity produced in the A2L1L2 treatment was 1.57 m/s, the resulting average was smaller than the one-hole treatment and larger than the three-gaps treatment.

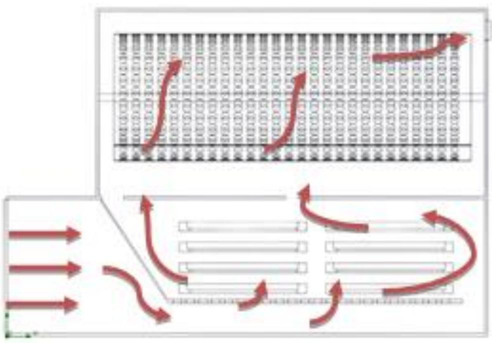


Figure 8. Distribution flow

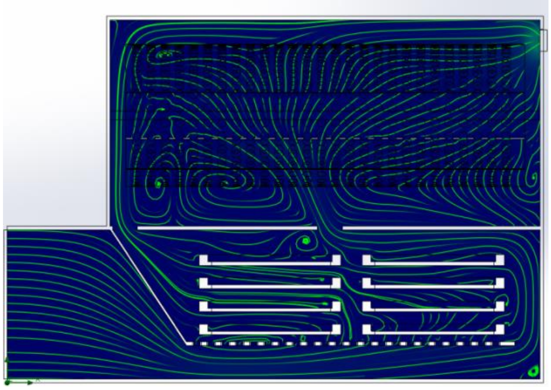


Figure 9. Velocity A2L1L2

These results are because the fewer the number of gaps made the faster the airflow rate and the more gaps the lower the airflow rate. Study in [13] simulated the drying chamber and produced an average speed of 1.51 m/s this was due to a large amount of space so there was not much turbulence. The level of turbulence that occurs is 0.021 m/s, the more gap made the more turbulence that occurs because hot air will touch the end of the hole (Fig. 7). The occurrence of differences in the decrease in water content in different samples is due to differences in turbulence which directly affect the moisture of the dried material [13].

3.2.2. Tray

The simulation results of the A2L1L2 treatment on the tray produce uniform results where the average temperature of the shelf section is 57.52 ºC. This is because the tray is the section that is first fed by hot air (Fig. 10).

The tray dryer that is running usually only the part that is close to the hot air and the hot air is not evenly distributed throughout the shelf [14]. The simulation results show that the average temperature value is not much different from the input temperature and the temperature of each shelf (Fig. 11). The temperature distribution of the dryer in the tray has a standard deviation of 2 ºC, with a maximum and minimum air difference of 5.12 ºC.

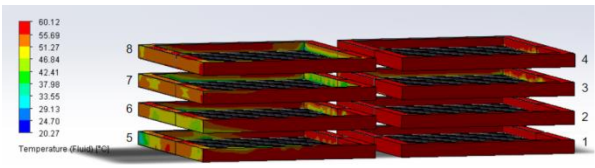


Figure 10. Tray contour A2L1L2

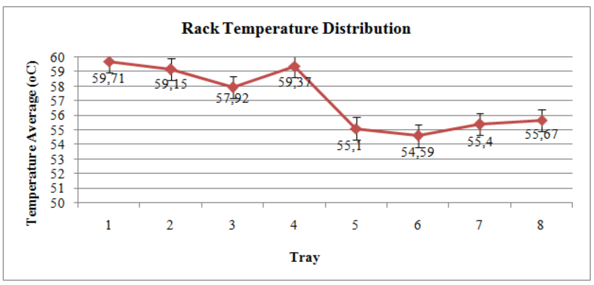
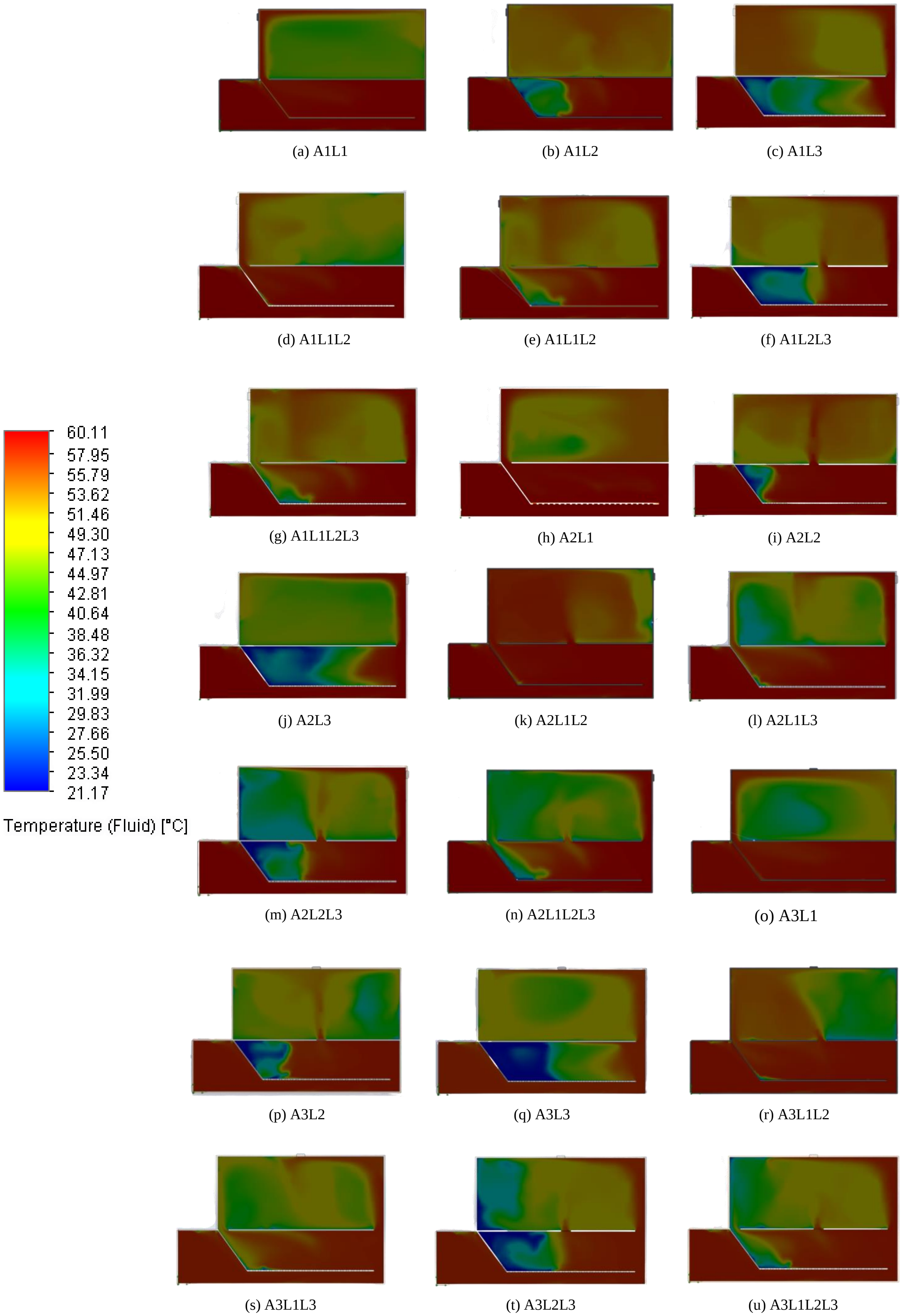


Figure 11. Tray temperature distribution A2L1L2



(a) A1L1 (b) A1L2 (c) A1L3

(d) A1L1L2 (e) A1L1L2 (f) A1L2L3

(g) A1L1L2L3 (h) A2L1 (i) A2L2

(j) A2L3 (k) A2L1L2 (l) A2L1L3

(m) A2L2L3 (n) A2L1L2L3 (o) A3L1

(p) A3L2 (q) A3L3 (r) A3L1L2

(s) A3L1L3 (t) A3L2L3 (u) A3L1L2L3

Figure 12. Simulation results

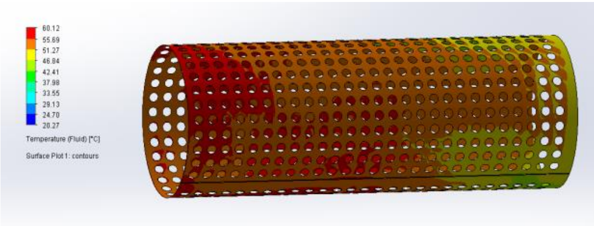


Figure 13. Hot air contours A2L1L2

The highest temperature is still owned by the first tray exposed to airflow, but there is a difference in the 3rd tray. This can be seen in Fig. 13 that the temperature distribution based on color shows more yellow color than tray 1,2, and 4, and tray 3 is in the temperature range 46-51 ºC.

3.2.3. Rotary section

The simulation results of A2L1L2 treatment on the rotary section produce fewer uniform results (Fig. 10) where the average temperature of the rotating part is 53.52 ºC. This is because the rotating part is the part that is flowed with hot air after the tray, the air drops due to convection and conduction heat transfer in the tray. The air temperature in the left rotary is lower than the left, based on the temperature distribution on the left side of 46-51 ºC and on the right a range of 51-60 ºC.

4. Conclusion

The distribution of hot air in the design of this double-type dryer have an average temperature 56.59 ºC, standard deviation 3.55 ºC, velocity 1.57 m/s, pressure 1.06 bar, and turbulence of 0.021 m/s. The average temperature on the tray is 57.52 ºC which is higher than the average rotary temperature of 53.52 ºC. The treatment that gives the most optimal hot air distribution value is the A2L1L2 treatment with the outlet on the right and with 2 gaps opened, gap 1 and gap 2.

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