NUMERICAL INVESTIGATION HEAT TRANSFER OF ROTARY DRYER OLIVE LEAF DRYING USING COMPUTATIONAL FLUID DYNAMICS METHOD

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Abstract-- The conventional drying process of olive leaves is carried out in the sun. The drying capacity is relatively small over a long period. The use of rotary dryers with heating from solar energy is expected to increase the drying process and capacity. Tests using computational fluid dynamics simulations can determine the optimal temperature from heating temperature variations of 30, 40, 50, and 60 [ºC]. The total heat energy transferred from the heater to the olive leaves by convection is 366.252 [kJ/s] and 21.371 [kJ/s] by conduction with a rotational speed of the rotary dryer of 75 [rpm]. The drying temperatures resulting from these four variations are 25.65, 26.85, 29.55, and 31.35 [ºC] with a heat flux of 2.542 x 10^{-6} [W/m2]. The heating temperature of the rotary drying machine set at 60 [ºC] can distribute the heat of 1.8 [M.J.], resulting in an optimal olive leaf drying temperature of 31.35 [ºC].

Keywords: Rotary dryer; Heat transfer; Computational fluid dynamics; Drying process; Numerical analysis

1. INTRODUCTION

Olive leaves can be used as a herbal medicine, which is consumed in the form of tea by changing it into small pieces which are dried to reduce the water content in the leaves [1]. One of the olive leaf plantations in Bogor still uses the conventional process of drying the leaves in the sun. The weakness of this process is that sunlight can only be used during the day with fluctuating intensity due to uncertain weather factors. Apart from that, the plantation area in Bogor has relatively high rainfall compared to several surrounding cities [2]. As a result, the production process is not optimal, so it cannot dry at a large capacity.

The basic principle of the drying process is that heat and mass transfer co-occur. The process consists of two stages: heat is transferred from the heating medium to the material. After evaporation, water vapor formed is transferred through the structure of the material to the surrounding medium. This process includes liquid fluid flow that is transferred through the structure of the material during the drying process. The heat available to evaporate water must be diffused through various types of resistance so that the water vapor can freely escape from the formed material.

The length of the drying process depends on the material being dried and the heating method used [3]. The drying method for olive leaves can be done with the help of a drying machine to speed up the time and capacity of the drying process. A drying machine with a rotating concept, such as a rotary dryer, uses a heater, a heating device that utilizes energy from sunlight through solar panels. This tool can be an economical, energy-efficient, and environmentally friendly alternative solution for farmers to speed up and improve the quality of the olive leaf drying process [4]. Irfansah researched the use of solar energy in a heating system with a heater as an energy source to operate a tubular heater dryer to dry chili [4]. Solar panels installed outside the drying room capture and absorb the sun's heat, convert it into electrical energy, and charge the battery using a solar control charger. The electrical energy stored in the battery is channeled through the inverter to turn on the tubular heater to heat the drying chamber.

A rotary dryer is a type of drying device that consists of a cylinder that rotates on a bearing with a slight inclination along the horizontal axis [5]. Drying occurs in the cylinder that rotates on the bearing and is usually slightly inclined to the horizontal. Material enters from the top end of the rotating drying cylinder, and the cylinder's tilt causes the dry product to move toward the bottom end [6]. The drying process in the rotary dryer is carried out several times so that all top and bottom surfaces are exposed to heat to evenly dry product in the rotary dryer drum [7]. Dryer type Rotary have several advantages: they can be operated quickly and safely, provide better-drying results in a short time, are easy to operate, have flexibility, and have large drying capacity [8].

Drying in a rotary dryer occurs in two types of heat transfer, conduction, and convection processes. Conduction heat transfer occurs between objects or particles that are in direct contact attached, and there is no relative movement between these objects [9]. Heat transfer in the system is assumed to be in a steady state where temperature does not change with time. Convection heat transfer occurs between the surface of a solid object and liquid fluid or gas, which flows and touches the surface of the solid object [9].

To produce an optimal drying process, the heat transfer in the rotary dryer is ensured to be distributed evenly so that it does not cause energy losses. Even drying olive leaves at the desired water content level is the goal of the drying process using computational fluid dynamics methods. With computer technology and software development, CFD applications provide many great benefits because they can support several findings [10], especially in heat transfer studies CFD is a branch of fluid mechanics that analyzes fluid elements to create a simulation. Simulations using CFD processes can be completed quickly and accurately. CFD can analyze fluid flow systems, heat, and other phenomena, such as chemical reactions, using computer-based simulations by solving mathematical equations that can explain the laws of mass, momentum, and energy conversion [11].

CFD has also been widely used in the rotary dryer design process because it can quickly and accurately identify the heat transfer process, flow pattern, air velocity, and heat distribution in the rotary dryer machine process [11]. CFD application is used to determine the best type of dryer in the design process before the manufacturing stage. Using CFD applications, a cabinet drying machine with internal fins and without fins was designed, resulting in a more uniform temperature distribution in the dryer with fins [12].

Designing a rotary dryer machine to use CFD application can numerically investigate the distribution of heat transfer that occurs in the drying chamber. Variations in several modeling simulations can determine the optimal temperature for drying olive leaves faster and with better product efficiency.

2. METHODO

The data in this research was obtained using the Mixed-Method Research (MMR) method, which combines qualitative and quantitative data collection techniques. The MRR method tests results and processes that combine quantitative and qualitative methods [13].

In qualitative methods, secondary data is collected from existing and ongoing research. The quantitative method is carried out using simulation, starting from collecting secondary data to presenting the results. Simulation results are displayed in the form of numerical data, contours, and graphs of the heat distribution in the drying chamber of the rotary dryer.

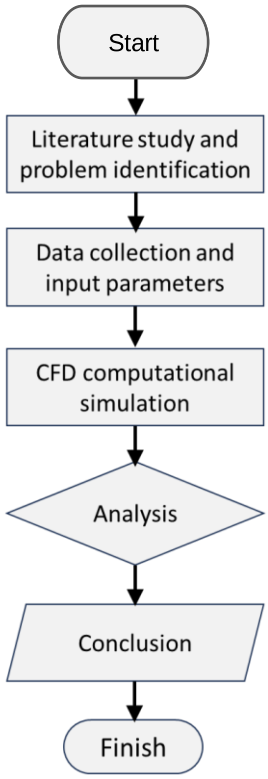

Figure 1. Research Flow Diagram.

The rotary dryer's shape geometry was designed using the SolidWorks 2022 software application. ANSYS Workbench 2022 R1 was used for the CFD software application to simulate heat transfer and movement in the drying chamber based on the geometric design. This research tested for each drying temperature variation of 30, 40, 50, and 60 [ºC] using the computational simulation method. Ansys Fluent fluid dynamics computational software was chosen to identify the optimal temperature in the drying process using sunlight energy. The CFD simulation process is carried out sequentially according to stages, from checking fluid and boundary conditions to entering data, determining settings, running the simulation, and reading the results. Table 1 displays the secondary data parameters used in the CFD simulation process's geometric design and boundary conditions.

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Table 1. Design Parameter Data and CFD Simulation Boundary Conditions [14]

Description	Value	Remark
Plate thickness	3 mm	Rolling process
Plate type	Stainless Steel	Grade 316 L
Outer drum diameter	500 mm	Place heater
Inner drum diameter	300 mm	Warming room
Number of fins	30 pcs	Flow breaker
Drum rotation speed	75 rpm	Constant
Motor rotation speed	2.800 rpm	Helical Gears
Heating direction	Horizontal on all sides	Heater tube
Power source	Output 100 W	Solar cell flashfish
Load of olive leaves	2 kg	0,002105 m^3
Water content of olive leaves	2.5 – 8%	SNI 01-1902-2000
Temperature conditions	30 – 45 ºC	Olive leaves
Duration of drying time	0.5 – 1 jam	-

The simulation data will be configured in several model variations to obtain results according to the objectives as shown in Table 2.

Table 2. Configuration of CFD Simulation Data Variations

Configuration	Heater Temperature [ºC]	Environmental temperature [ºC]	Rotary Dryer Rotation [rpm]
A1	30	25	75
A2	40	25	75
A3	50	25	75
A4	60	25	75

The geometric design of the model consists of the main parts of the dryer frame, drive shaft, base motor, gear reducer, electrical motor, base cover, stator drum, rotor drum, and control box. Heat transfer occurs between the drum stator and drum rotor in the rotary dryer chamber.

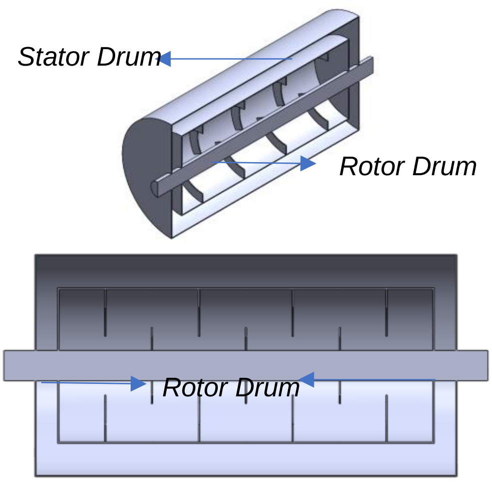


Figure 2. Rotary Drum Design

The stator drum is the outermost tube part of the rotary dryer, with dimensions of diameter Ø500 [mm] and length 950 [mm]. This tool functions as a place for placing the drum rotor heating component, and when the rotary dryer is operating, the drum stator is in a static position, as shown in Figure 3.

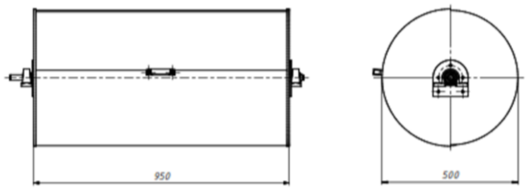


Figure 3. Drum Stator Dimensions

The drum rotor is a tube placed inside the drum stator. It functions as a container for the olive leaves, which rotate during the drying process. The dimensions of the rotor drum are Ø350 [mm] in diameter and 850 [mm] in length, as shown in Figure 4. This research focuses on both parts of the drum stator and drum rotor geometry, which are inputted into CFD software for simulation and analysis.

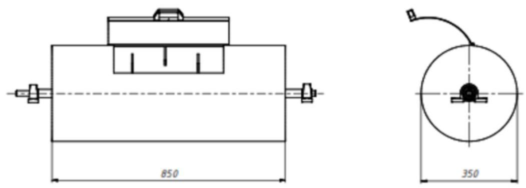
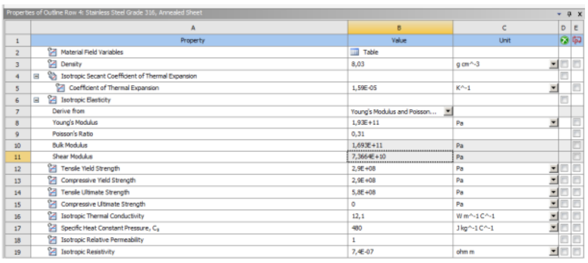


Figure 4. Drum Rotor Dimensions

The two main components of the rotary dryer use stainless steel with grade SS 316 because it is suitable for applications on food ingredients. The consideration for choosing this material is because it is resistant to corrosion, to use of high temperatures and the influence of acidic liquids on chemical processes.


Properties of Outline Row 4: Stainless Steel Grade 316, Annealed Sheet

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	8,03	g cm^-3
4	Isotropic Secant Coefficient of Thermal Expansion		
5	Coefficient of Thermal Expansion	1,59E-05	K^-1
6	Isotropic Elasticity		
7	Derive from	Young's Modulus and Poisson...	
8	Young's Modulus	1,93E+11	Pa
9	Poisson's Ratio	0,31	
10	Bulk Modulus	1,693E+11	Pa
11	Shear Modulus	7,3664E+10	Pa
12	Tensile Yield Strength	2,9E+08	Pa
13	Compressive Yield Strength	2,9E+08	Pa
14	Tensile Ultimate Strength	5,8E+08	Pa
15	Compressive Ultimate Strength	0	Pa
16	Isotropic Thermal Conductivity	12,1	W m^-1 C^-1
17	Specific Heat Constant Pressure, C_p	480	J kg^-1 C^-1
18	Isotropic Relative Permeability	1	
19	Isotropic Resistivity	7,4E-07	ohm m

Figure 5. Determining the property settings for SS 316 Stainless Steel in the CFD system

Hot airflow in the rotary dryer comes from an electric heater, which uses energy from solar panels. Table 3 displays heater specifications as a reference for simulation data and calculations.

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Table 3. Heater Heating Media Specifications [14]

Category	Specification
Heating type	Straight tubular heater
Brand/Type	Tempco THF00558
Temperature capacity	70 – 275 ºF
Power	1000 Watt
Rated voltage	240 VAC
Phase	1 phase
Dimensions	⌀ 0.315 inci x 500 mm
Minimum air flow	700 FPM

The rotary dryer design is a tube made of thin plate material with several fins on the inside. Because it has an irregular shape and many complicated curves, it requires a higher aspect ratio. The mesh creation process is classified into two categories based on the topology of elements that fill the domain, namely structured and unstructured mesh [15]. The pre-processing stage for CFD simulations performs desired domain discretization and mesh generation. The type of mesh used for rotary dryer simulations is tetrahedral because it can estimate surface contours more accurately than hexahedral meshes. The limited condition of the computer hardware used and the simulation time are special considerations. Parameters in the pre-processing step and mesh quality specifications are shown in Table 4.

Table 4. Data Parameters and Mesh Quality

Characteristics	value
Mesh type	Tetrahedral
Element size	10 mm
Span angle center	Fine
Target skewness	0.8
Number of dividers	100
Average area size	6.1089 x 10^5 mm²
Mesh method	Sweep Axisymmetric

The meshing results obtained from pre-processing are shown in Figure 6.

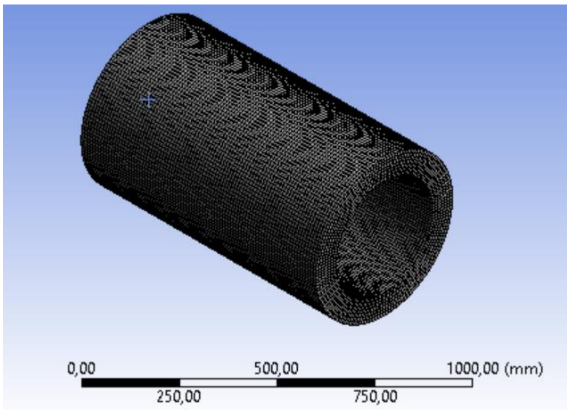

Figure 6. Mesh Generation Results for Rotary Dryer

3. RESULTS AND DISCUSSION

The heat transfer that occurs when olive leaves are dried in a rotary drying machine is calculated mathematically using the heat transfer formula and then compared with the results of computational simulations using the CFD method.

3.1. Analysis of Thermal Energy Sources

From the heater specifications in Table 3, it can be calculated that the resistance value of the heater used is:

$$R = \frac{(240\ [V])^2}{1000\ [Watt]} \tag{1}$$

$$R = 57.6\ [\Omega]$$

The amount of electric current flowing in the heater is obtained as follows:

$$I = \frac{240\ [V]}{57.6\ [\Omega]} \tag{2}$$

$$I = 4.167\ [A]$$

The amount of heat energy converted from electrical energy by the heater is:

$$Q = (4.167\ [A])^2\ x\ 57.6\ [\Omega]\ x\ 1.800\ [s] \tag{3}$$

$$Q = 1800288.012\ [J] \text{ or approx. } 1.8\ [\text{MJ}]$$

3.2. Analysis Convection Heat Transfer in the Stator

The thermal convection coefficient h value is obtained by calculating the Reynolds number from the airflow in the stator:

$$R_e = \frac{1.145\ [kg/m^3]\ x\ 33.929\ [m/s]\ x\ ((494-350)x10^{-3})\ [m]}{1.895\ x\ 10^{-5}\ [kg/ms]} \tag{4}$$

$$R_e = 295209.1567$$

The value is > 4000, indicating that the fluid flow that occurs in the stator is turbulent.
The value of the Prandtl number that applies to airflow in the stator can be calculated as follows:

$$P_r = \frac{1.007\ [J/kgK]\ x\ 1.895\ x\ 10^{-5}\ [kg/ms]}{0.02625\ [W/mK]} \tag{5}$$

$$P_r = 0.727$$

After obtaining the Reynolds and Prandtl numbers, the magnitude of the Nusselt number can be determined by calculating as follows:

$$N_u = 0.023\ x\ (295209.1567)^{0.8}\ x\ (0.727)^{0.33}\ x \left(\frac{1,.895\ x\ 10^{-5}\ [kg/ms]}{1.849\ x\ 10^{-5}\ [kg/ms]}\right)^{0.14} \quad (6)$$

$$N_u = 493.892$$

So, the thermal convection coefficient h value can be calculated as follows:

$$h = \frac{493.892\ x\ 0.02625\ [W/mK]}{((494-350)x10^{-3})\ [m]} \quad (7)$$

$$h = 90.032\ [W/m^2K]$$

After obtaining an h value of 90.032 [W/m2K] or 90.032 [W/m2ºC], the convection heat transfer rate in the stator drum can be estimated as follows:

$$Q = 90.032\ [W/m^2{}^\circ C]\ x\ 0.113\ [m^2]\ x\ 20\ [^\circ C]\ x\ 1.800\ [s] \quad (8)$$

$Q = 366251.786$ [J/s] or approx. 366.252 [kJ/s].

3.3. Analysis of Conduction Heat Transfer in Stator

To determine the conduction heat transfer rate of the stator drum made of SS 316 stainless steel, a mathematical calculation was carried out. It is assumed that the temperature on the inner surface of the stator is the same as the temperature of the hot air flowing into the stator drum space, which is 35 [ºC].

$$\frac{Q}{L} = \left[\frac{2\ x\ \pi\ x\ 12.9\ [W/mK]x\ (308-298)[K]}{\ln\left(\frac{0.247\ [m]}{0.250\ [m]}\right)}\right] \quad (9)$$

$\frac{Q}{L} = 21.370{,}741$ [J/s] or approx. 21.371 [kJ/s].

3.4. Air Movement Conditions

The simulation results identify air movement in the stator drum. When the drum rotor rotation speed is 75 rmp or around 7854 [rad/s] with the drum rotor not moving, the air flow movement pattern is shown in Figure 7.

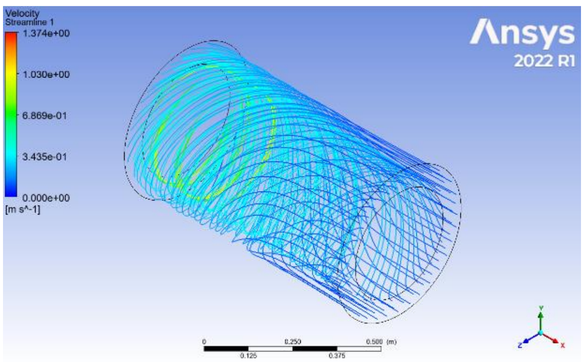

Figure 7. Streamline of Air Speed Flow Movement in Rotary Dryer

3.5. Rotor Outer Surface Temperature

The simulation results obtain the temperature distribution of heat transfer in the rotary dryer drying chamber. The result data is used on the outflow side because the flow has undergone perfect rotation due to the influence of the drum rotor's rotation. Table 5 shows that the highest temperature value in the rotor drum obtained when using a heater with a temperature of 60 [ºC] is 31.35 [ºC], while the lowest temperature when using a heater with a temperature of 30 [ºC] is 25.65 [ºC], as shown in Figures 8, 9, 10, and 11.

Table 5. Rotor Surface Temperature Data from Simulation Results

No.	Boundary Conditions	Rotor Internal Temperature
1.	30 [ºC]	25.65 [ºC]
2.	40 [ºC]	26.85 [ºC]
3.	50 [ºC]	29.55 [ºC]
4.	60 [ºC]	31.35 [ºC]

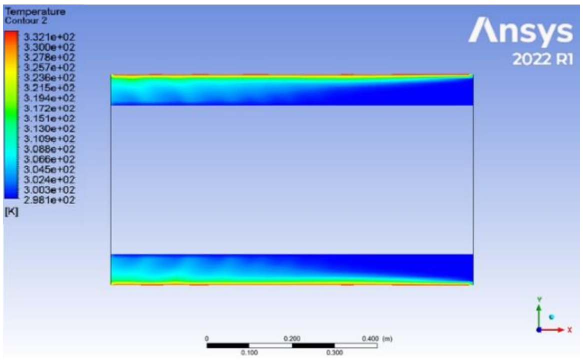

Figure 8. Air Domain Temperature Contour at Boundary Conditions of 30 [ºC]

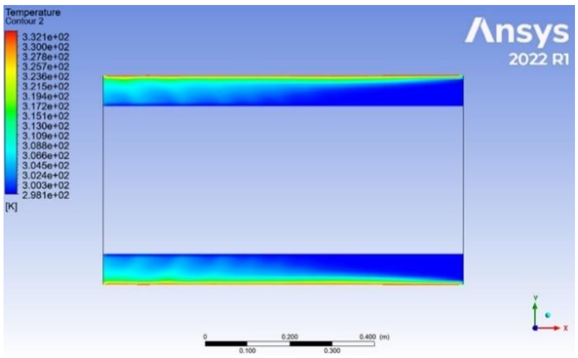

Figure 9. Air Domain Temperature Contour at Boundary Conditions of 40 [ºC]

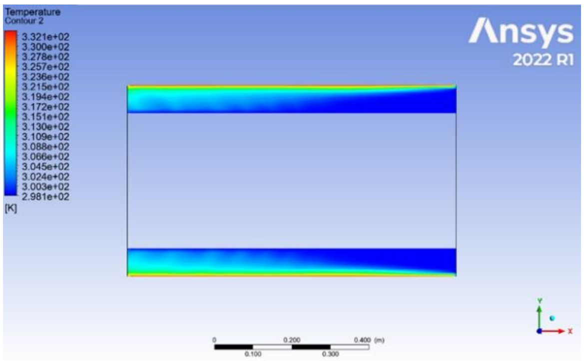

Figure 10. Air Domain Temperature Contour at Boundary Conditions of 50 [ºC]

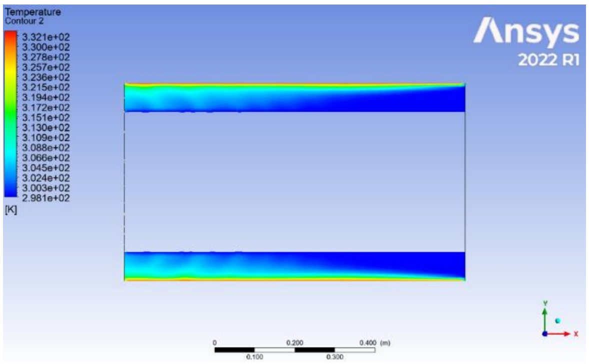

Figure 11. Air Domain Temperature Contour at Boundary Conditions of 60 [ºC]

3.6. Heat Flux Spread

From the simulation data, it can be seen that the distribution of heat flux on the side of the air flowing out of the heating chamber, which rotates, is relatively perfect.

Table 6. Heat Flux Data from Simulation Results

No.	Boundary Conditions	Heat Flux
1.	30 [ºC]	0.037 x 10^{-6} [W/m^2]
2.	40 [ºC]	1.089 x 10^{-6} [W/m^2]
3.	50 [ºC]	1.762 x 10^{-6} [W/m^2]
4.	60 [ºC]	2.542 x 10^{-6} [W/m^2]

Table 6 shows that the highest heat flux value in the rotor drum was obtained when the heater was set at a temperature of 60 [ºC], producing a heat flux of 2.542 x 10^{-6} [W/m^2]. Meanwhile, the lowest heat flux was obtained when using a heater temperature of 30 [ºC], namely 0.037 x 10^{-6} [W/m^2], as shown in Figures 12, 13, 14, and 15). The higher the heating temperature, the greater the spread of heat flux in the rotating heating chamber.

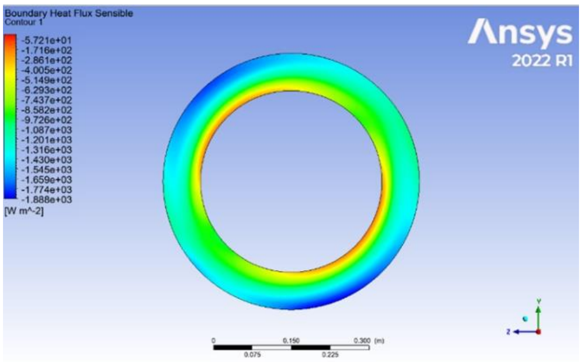

Figure 12. Heat Flux Contour at Outflow with Boundary Conditions of 30 [ºC]

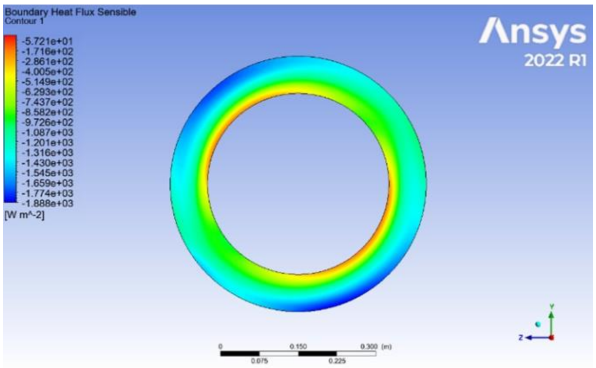

Figure 13. Heat Flux Contour at Outflow with Boundary Conditions of 40 [ºC]

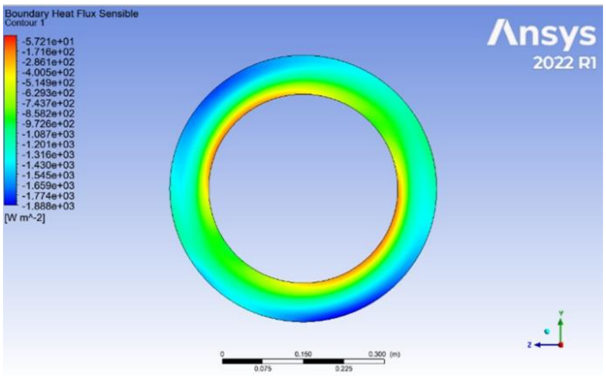

Figure 14. Heat Flux Contour at Outflow with Boundary Conditions of 50 [ºC]

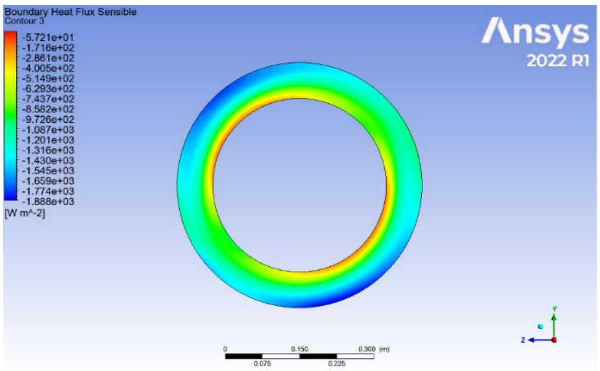

Figure 15. Heat Flux Contour at Outflow with Boundary Conditions of 60 [ºC]

3.7. Interpretation of Temperature, Heat Flux, and Air Domain Relationships

From the overall simulation results, the distribution of temperature and heat flux in the rotary dryer was identified for each varied condition. Figure 16 shows the magnitude of the temperature change in the rotor drum; the higher the heater temperature, the more the heat flux distribution tends to increase, approaching a linear function.

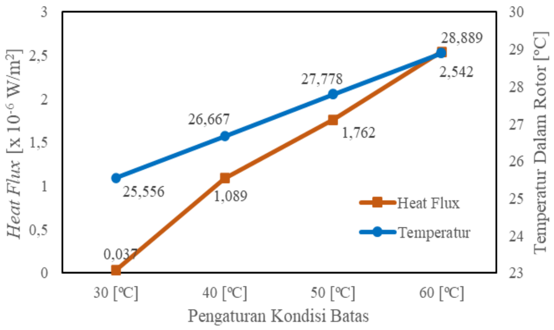

Figure 16. Effect of Boundary Conditions on Temperature and Heat Flux

The highest temperature is achieved at a boundary condition of 60 [ºC]. This shows that the higher the boundary condition's temperature value, the higher the temperature inside the rotor drum. The same is true for heat flux: the heat flux value increases if the boundary condition's temperature value increases.

4. CONCLUSION

Results of research and discussion of simulations using computational fluid dynamics for rotary dryers using solar panels can be concluded:

1. The total heat energy distributed by conduction and convection from the heater to the stator and rotor drum is 1.8 [MJ]. The amount of convection heat transfer in rotating air media at the temperature of 25 ºC is 366.252 [kJ/s], while the conduction heat transfer through SS 316 stainless steel media is 21.371 [kJ/s].
2. The optimal temperature in the rotary dryer drying room is 30-45 [ºC] sourced from the heater for a minimum temperature of 60 [ºC], which will produce an olive leaf drying temperature of 31.35 [ºC] with a heat flux of 2.542 x 10^{-6} [W /m^2].

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