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Research Article

Temperature Distribution Simulation and the Analysis of Cyclones Performance on Sago Starch Pneumatic Conveying Recirculated Dryers

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Abstract

Background and Objective: Recirculating cyclones and cyclones of the material output are some of the vital parts of the drying machine known as Pneumatic Conveying Recirculated Dryer (PCRD) for sago starch drying. This research was intended to undertake simulation of air temperature distributions in dryers and analyze performance of recirculating cyclones and cyclones of the material output. **Materials and Methods:** The analytical and simulation methods used are Computational Fluid Dynamics (CFD), as well as mathematical and statistical analyses. Computational Fluid Dynamics simulation was using the software Fluid Flow (Fluent) available in the Ansys Workbench package (ver. 15). The variable variations are the air temperature and velocity of dryers and the dimensions of recirculating cyclones. **Results:** The temperature distributions inside the recirculating cyclones and cyclones of the material output were well distributed with low error values, namely by 2.044 and 4.594%. The mathematical and statistical analyses showed that the means of changes in the moisture content and effectiveness of the recirculating cyclones and cyclones of the material output were equal to 8.93% wb and 89.61%, respectively. Almost all the variables of variation significantly affected the value of the moisture content and the effectiveness, except the temperature variable (T_{u3}). **Conclusion:** This study indicates that the simulation results are close to observed values or the real condition of the PCRD machine. Thus the designs of the recirculating cyclones and cyclones of the material output are feasible to be implemented for sago starch drying.

Key words: Ansys fluent, computational fluid dynamics, pneumatic conveying recirculated dryer, simulation, temperature distribution, sago starch

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Pneumatic Conveying Dryer (PCD) is one of the most popular artificial drying machines used in the food processing industry, especially for flour-based products. One of the developments in the PCD machine is the addition of material recirculation processes to reduce the high use of vertical pipes. Material recirculation aims to increase the recirculation time of materials containing a high moisture content[1]. Therefore, in this research, a cyclone-shaped recirculation process has been designed which was connected in series with the cyclones of material output on the Pneumatic Conveying Recirculated Dryer (PCRD). Recirculating cyclones were equipped with centrifugal blowers and material flow regulators. The function of the recirculating cyclones was to separate dry materials from wet materials during the drying process using the PCRD machine. However, temperature distributions within the recirculating cyclones and cyclones of the material output could not be observed directly in the course of the drying process. Temperature distributions within recirculating cyclones greatly affect the drying process, i.e., the contact between hot air and materials[2,3].

The study on temperature distribution on PCD machines had been developed by several previous studies. Mezhericher *et al*.[4] developed a three-dimensional model of a pneumatic drying process using CFD. El-Behery *et al*.[5] performed simulation and validation of PCD machines using CFD. Jamaleddine and Ray[6] used a CFD analysis on PCD machines for sludge drying. Bhattarai *et al*.[7] had performed simulation of a sawdust drying process on PCD machines to produce pellets using CFD.

Computational Fluid Dynamics (CFD) application on separating cyclones has also been done by Caroko and Suyitno[8] by comparing the Spalart-Allmaras Turbulence Model to the Reynolds Stress Model to analyze efficiency and cyclone pressure loss. Sylvia *et al*.[9] analyzed efficiency and drop pressure in a gas-solid square cyclone separator with CFD. Wasilewski and Duda[10] used the CFD analysis to optimize the cyclone of dust separators used in cement plants. Jadhav[11] designed and studied performance cyclone parameters using CFD.

The purpose of this research was to perform simulation of air temperature distributions and analyze performance of recirculating cyclones and cyclones of the material output. Variable variations are the air temperature and velocity of dryers as well as the dimensions of recirculating cyclones. Variation in the dimensions of recirculating cyclones consisted of the height of the cylinder, the length and diameter of the upper outlet pipe and the air velocity of the centrifugal blower.

MATERIALS AND METHODS

This study had been conducted from January-May, 2017, in laboratory of Energy and Agricultural Machinery (EMP) and laboratory of Food and Post-harvest Engineering and Department of Agricultural Engineering and Biosystems, Faculty of Agricultural Technology, Gadjah Mada University, Yogyakarta.

Materials and tools: The materials used in this research were wet sago starch. While the main tool used was the Liquid Petroleum Gas (LPG)-fueled PCRD machine[12]. The main focuses of this research were recirculating cyclones and cyclones of the material output. Recirculating cyclones and cyclones of the material output are some of the parts installed in series on a PCRD machine. They are made of stainless steel and consist of several parts, namely the inlet, cylinder, cone, upper outlet, lower outlet and centrifugal blower. The shapes of recirculating cyclones and cyclones of the material output can be seen in the schematic drawing of a PCRD machine shown in Fig. 1.

In this research, variation was made to the dimensions of recirculating cyclones, namely the height of the cylinder, the length and diameter of the upper outlet pipe and the air velocity of the centrifugal blower. The temperature measurement points, geometric shapes, recirculating cyclone mesh and cyclones of the material output of PCRD machines can be seen in Fig. 1. Measurement of the air temperature and velocity of dryers was performed on the recirculating cyclone inlet and the upper outlet of cyclones of the material output of PCRD machines. Temperatures were measured when dryers were under the condition of containing no drying materials (empty loads) by simply turning on the heating stove. To measure the air temperature and velocity of dryers within recirculating cyclones, a digital thermometer with a K-type thermocouple (4 channel TM 946 LUTRON) and an air flow meter (flexible thermo-anemometer KW06-562 KRISBOW) were used.

CFD simulation: The analysis of the air temperature within recirculating cyclones and cyclones of the material output using the CFD method in this research was carried out based on variation in the air temperature and velocity of dryers and by changing the dimensions of recirculating cyclones. The variation in the dimensions of the recirculating cyclones included the height of the cylinder, the diameter and length of the upper outlet pipe and the air velocity of the centrifugal blower. Data on the air temperature and velocity of dryers used for simulation were obtained from observation within

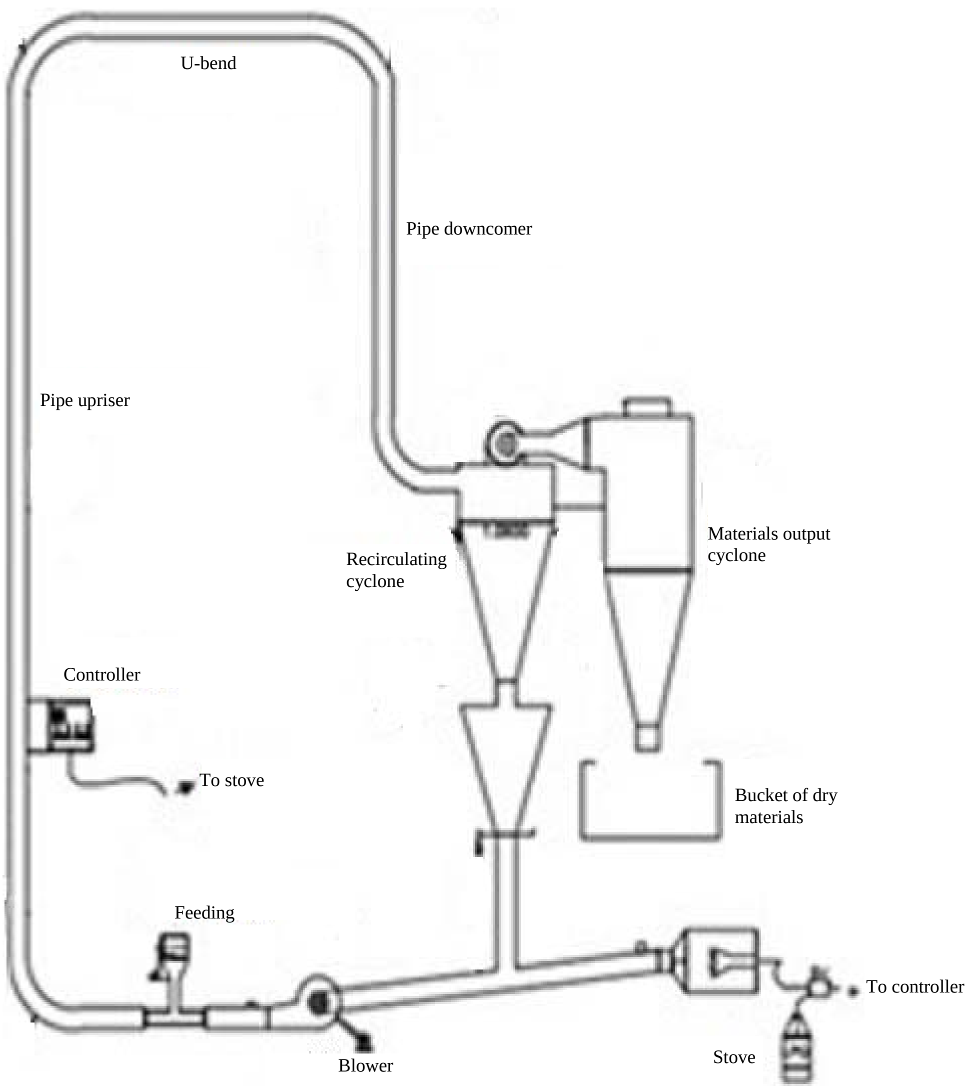


Fig. 1: Drawing of schematic of PCRD machine

recirculating cyclones and cyclones of the material output of PCRD machines. Perform simulation of air temperature distributions of dryers within recirculating cyclones and cyclones of the material output of PCRD machines using the software Fluid Flow (Fluent) available in the Ansys Workbench package (Ver. 15). The software Ansys Workbench (Ver. 15) with the system analysis Fluid Flow (Fluent) consists of Ansys Design Modeler (geometry), Ansys ICEM CFD (meshing), Fluent Launcher (setup), Fluent or Ansys CFD (solution) and CFD-POST (result)[13]. According to Bhattarai *et al.*[7], the software Ansys Fluent has been widely used to analyze fluid flow systems and heat transfer based on the finite volume method. The geometric shapes of recirculating cyclones and cyclones of the material output based on variation in the dimensions of the cylinder length (L_{scrb}), the diameter of the upper outlet pipe (D_{Acrb}), the length of the upper outlet pipe (L_{Acrb}) and air velocity of the blower on recirculating cyclones (v_{ucrb}) was made using the software Autodesk Autocad (Ver. 2016). The resulting geometry was then exported to the software Ansys Design Modeler for editing, allowing it to be read by the software Fluent or Ansys CFD. The geometry and mesh of recirculating cyclones and cyclones of the material output can be seen in Fig. 2. All those pieces of software have been installed in a set of laptops with Intel Corei3-4030u CPU, 1.9 GHz, 4 GB of memory and a 500 GB hard disk.

Boundary conditions were used to determine the inlet, outlet, wall and so on by entering information or data to the pre-determined limits[13-14]. In this research, boundary conditions were determined based on the properties of dryers' air flow inside recirculating cyclones and cyclones of the material output and thus the velocity inlet was selected as the inlet while the pressure outlet was selected as the outlet.

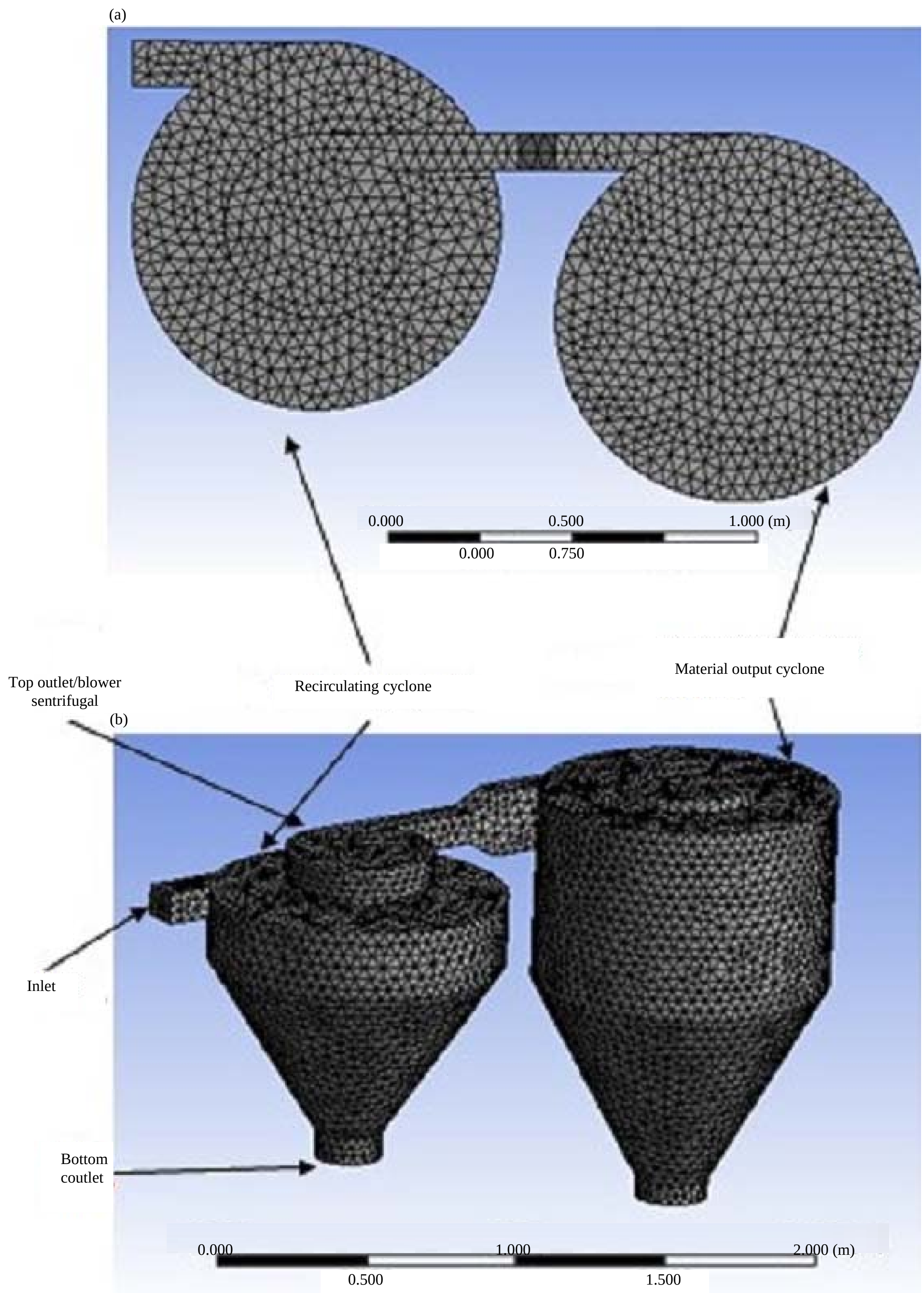


Fig. 2: Shape geometry and mesh of cyclone recirculation and materials output

Recirculating cyclones and cyclones of the material output made of stainless steel served as the wall. The inlet values used consisted of the air temperature and velocity of dryers. The values of the physical properties of the dryers' air (fluid) as the

Table 1: Fluids and material properties as inlet and wall

Fluids temperature (°C)	Density (ρ) (kg m^{-3})	Thermal capacity (c) (J kg^{-1} K^{-1})	Viscosity (μ) (kg m^{-1} sec^{-1})	Thermal conductivity (K) (W m^{-1} K^{-1})
75	0.982	1048.50	2.0594×10^{-5}	0.0289
100	0.916	1022.00	2.1673×10^{-5}	0.0307
125	0.8485	1026.00	2.2948×10^{-5}	0.0325
Stainless steel	8030	50.48	8330000	16.270

Table 2: Variable of variation of dimension of cyclone recirculation

Variable of variation	Value of variation
v_u (m sec^{-1})	15, 28, 31
T_{u3} (°C)	75, 100, 125
L_{scrb} (m)	0.27, 0.54, 0.81
$_{Dascrb}$ (m)	0.1016, 0.17, 0.22
$_{Lacrb}$ (m)	0.2, 0.37, 0.65
v_{ucrb} (m sec^{-1})	10.75, 12.75, 15.75

inlet and stainless steel or the material as the wall used in the simulation process constituted secondary data[15]. Those inlet and wall values were used in each variation in the dimensions of recirculating cyclones (L_{scrb}, D_{Acrb}, L_{Acrb} and v_{ucrb}). The values of inlet and wall variations can be seen in Table 1. While the values of variation in the dimensions of recirculating cyclones used in the simulation can be seen in Table 2.

The assumptions used for the simulation of temperature distributions within recirculating cyclones and cyclones of the material output of PCRD machines were the air flow model is turbulent; air flows under steady, adiabatic conditions; physical properties of dryers' air (density, specific heat, conductivity and viscosity) are constant; environmental temperature is constant and air flows at the same velocity. Based on those assumptions, the model used to analyze air temperature distributions of dryers was the Reynold Stress Model (RSM)[8,13].

The RSM is the most meticulous model of fluent and approaches the Navier-Stokes equation by solving the transport equation for Reynolds voltages together with the dissipation rate equation. This model is suitable for flows in pipes and cyclones passing through a rotating or recirculating trajectory. It can accommodate the presence of anisotropy arising from turbulence which has a significant effect on the main flow[8,14]. This RSM model is derived from the Navier-Stokes equation. The RSM model equations are presented in Eq. 1-5 by Kornev[16]:

$$\frac{\partial}{\partial t}\left(\overline{u_i' u_k'}\right) + \bar{u}_j \frac{\partial}{\partial x_j}(\overline{u_i' u_k'}) = \frac{\partial}{\partial x_j} D_{ik} + R_{ik} + P_{ik} - \varepsilon_{ik} \quad (1)$$

where, u' refers to fluctuating random parts, D_{ik} refers to the diffusion process which can be calculated using Eq. 2:

$$D_{ik} = \nu \frac{\partial\left(\overline{u_i' u_k'}\right)}{\partial x_j} - \overline{u_i' u_j' u_k'} + \frac{1}{\rho}\overline{(\delta_{jk} u_i' + \delta_{ij} u_k')p'} \quad (2)$$

The R_{ik} value is R_e distribution or energy exchange, the P_{ik} value is generation and the e_{ik} value is dissipation. Those values can be calculated using Eq. 3-5:

$$R_{ik} = \overline{\frac{1}{\rho}\left(\frac{\partial u_i'}{\partial x_k} + \frac{\partial u_k'}{\partial x_i}\right)p'} \quad (3)$$

$$P_{ik} = -\overline{u_j' u_k'}\frac{\partial \bar{u}_i}{\partial x_j} - \overline{u_j' u_i'}\frac{\partial \bar{u}_k}{\partial x_j} \quad (4)$$

$$\varepsilon_{ik} = 2\nu \overline{\frac{\partial u_i'}{\partial x_j}\frac{\partial u_k'}{\partial x_j}} \quad (5)$$

where, D refers to diffusion, R refers to resistance, u refers to turbulent flow velocity component, u' refers to random parts fluctuate, e refers to dissipation rate, r refers to density, v refers to viscosity, p refers to pressure and I, j, k refers to direction of fluid flow.

Validation: To determine the level of accuracy of CFD simulation results with that of observation results in terms of temperature distributions within recirculating cyclones and cyclones of the material output of PCRD machines, validation was done using the method employed by Yani *et al.*[17] and Anisum *et al.*[18]. The method was undertaken by comparing the output of CFD simulation with that of the observation by calculating the error value. In this research, the error value between CFD simulation results with that of observation results was calculated using Eq. 6:

$$e = \frac{T_{u-sim} - T_{u-obsv}}{T_{u-sim}} \times 100 \quad (6)$$

where, e refers to the differential (error) between CFD simulation results with observation results (%), $T_{u\text{-}sim}$ refers to the air temperature of dryers resulting from CFD simulation (°C) and $T_{u\text{-}obsv}$ refers to the air temperature of dryers resulting from into PCRD machines (°C).

Mathematical analysis: The mathematical analysis was used to calculate the performance of recirculating cyclones and cyclones of the material output based on the values of the final moisture content of the material (M_{ob}) and effectiveness. The final moisture content or the output of a material in the drying process is one of the most important parameters to determine the extent to which a drying process will be successful. In this research, the value of the moisture content of the material output (M_{ob}) was determined based on the oven method[19] using Eq. 7:

$$M_{ob} = \frac{W_1 - W_2}{W_1} \times 100 \quad (7)$$

where, M_{ob} refers to the final moisture content of the material (% wb), W_1 refers to the wet weight of the material (g) and W_2 refers to the dry weight of the material (g). As for the effectiveness value, it refers to the ratio between the mass of the material output to the dry weight of the material, expressed in percentage[12]. In this research, the effectiveness value was calculated using Eq. 8:

$$\eta_{ef} = \frac{m_{ob}}{bk_b} \times 100\% \quad (8)$$

where, h_{ef} refers to the effectiveness value (%), m_{ob} refers to the mass of the material output (kg) and bk_b refers to the dry weight of the input material (kg). The dry weight of the input material can be calculated using Eq. 9 by Jading *et al.*[12]:

$$bk_b = \frac{bp_b}{(1 - \frac{M_{ob}}{100})} \quad (9)$$

where, bk_b refers to the dry weight of the input material (kg), bp_b refers to the weight of the solid input material (kg) and M_{ob} refers to the final water content of the material (% wb). The weight of the solid input material can be calculated using Eq. 10 by Jading *et al.*[12]:

$$bp_p = \frac{m_{ib}}{(1 - \frac{M_{ib}}{100})} \quad (10)$$

where, bp_b refers to the weight of the solid input material (kg), m_{ib} a refers to the mass of the input material (kg) and M_{ib} refers to the initial moisture content of the (input) material (% wb).

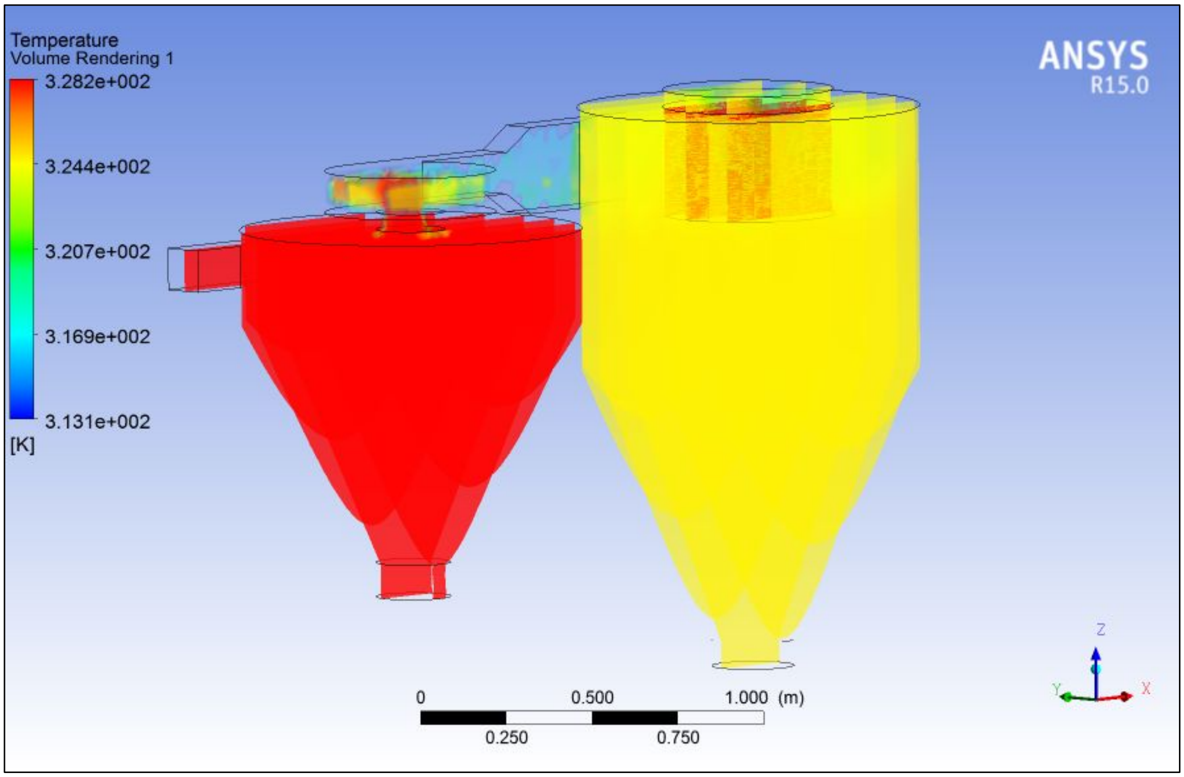
Statistical analysis: The statistical analysis used in this research was the one-way ANOVA test, followed by Duncan's test using the software IBM SPSS Statistics 23 (copyright IBM Corporation 2015, New York, USA). The one-way ANOVA test followed by Duncan's test were used to determine the effect of each variation variable on the value of the moisture content of the material output (M_{ob}) and effectiveness of the recirculating cyclones and cyclones of the material output. The assumptions or hypotheses used were the initial hypothesis (H_0) that there is no difference in the average results generated by the treatment of the variables to the efficiency of effectiveness and the alternative hypothesis (H_a) that there is difference in the average results generated by the treatment of the variables to the efficiency of effectiveness, with the level of significance (a) by 0.05. An analysis with the one-way ANOVA test was also used by Nimmol and Devahastin[20] to evaluate the performance and usage of energy on impinging stream dryers.

RESULTS AND DISCUSSION

Temperature distributions within recirculating cyclones and cyclones of the material output: The simulation results for temperature distributions within recirculating cyclones and cyclones of the material output done using the CFD analysis using the software Fluid Flow (Fluent) or Ansys Fluent (Ver. 15) can be seen in Fig. 3-15. Figure 3-5 presents air temperature distributions of dryers within recirculating cyclones and cyclones of the material output with the following variation: T_{u3} (75, 100, 125°C), v_u 28 m sec^{-1}, L_{scrb} 0.27 m, D_{Acrb} 0.1016 m, L_{Acrb} 0.2 and v_{ucrb} 15.75 m sec^{-1}. The temperature distribution pattern indicated that the temperature was evenly distributed with a value of about 55°C (3.282×10^2 K) in Fig. 3, 80.05°C (3.532×10^2 K) in Fig. 4 and 105.05°C (3.782×10^2 K) in Fig. 5. And which was marked in red in the image of volume rendering in the simulation. While the temperature distribution of the cyclones of the material output was about 51.25°C (3.244×10^2 K) in Fig. 3, 72.55°C (3.457 K) in Fig. 4 and 93.75°C (3.669×10^2 K) in Fig. 5, which was marked in yellow, with the air velocity of dryers reaching approximately 3.75 m sec^{-1}, which was marked in green and blue.

Figure 6-15 shows the effect of variation in the velocity of the dryer (v_u) and the dimensions of the

(a)



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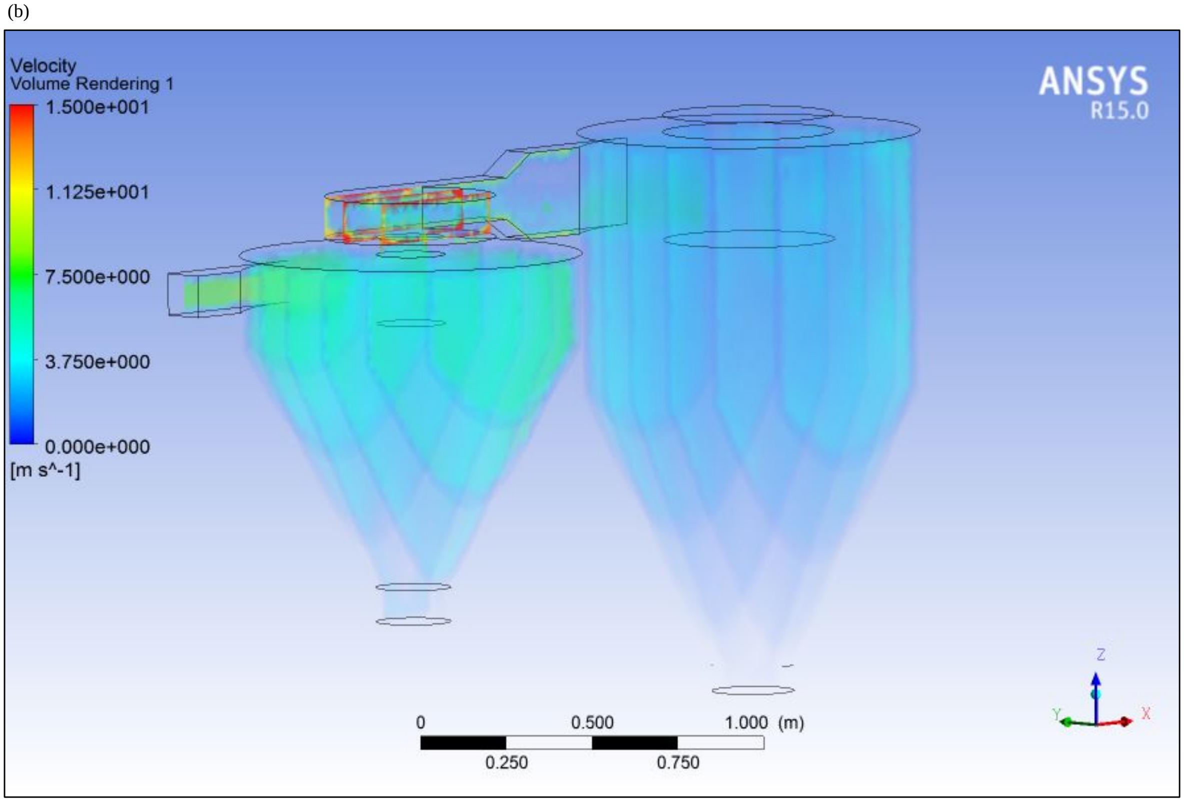
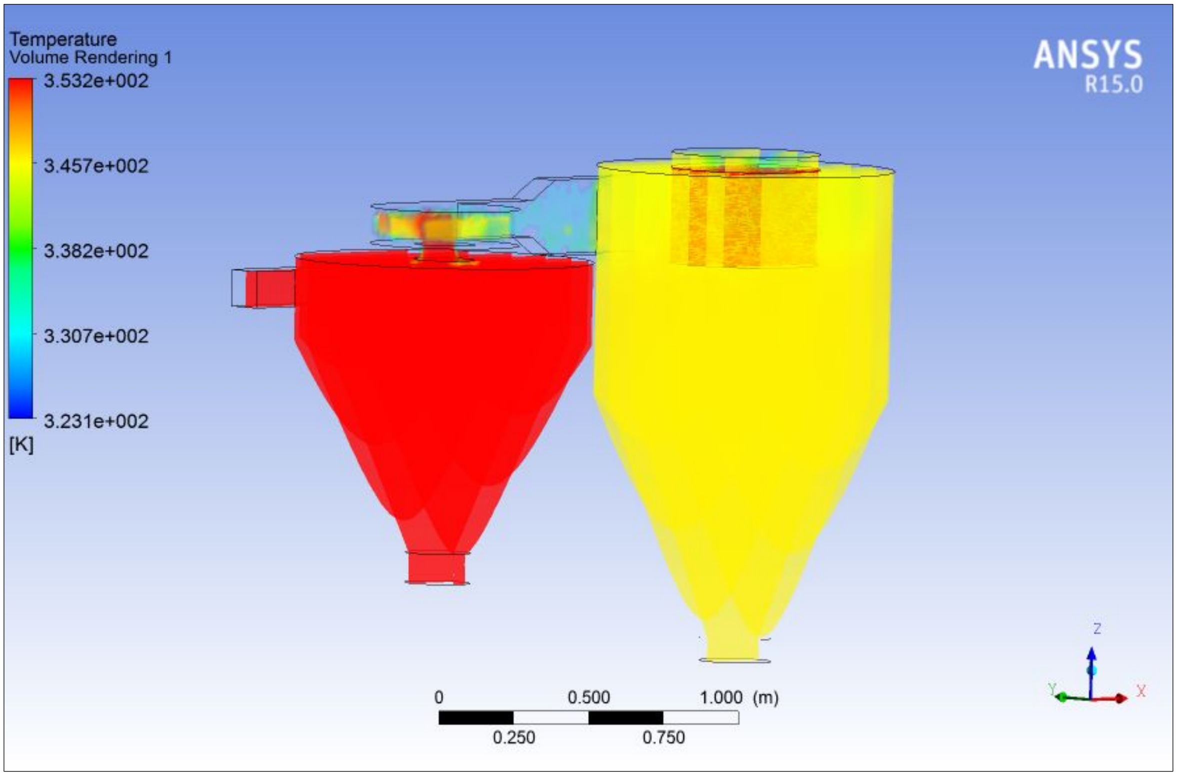


Fig. 3(a-b): Temperature variation T_{u3} 75°C, (a) Temperature and (b) Velocity

(a)



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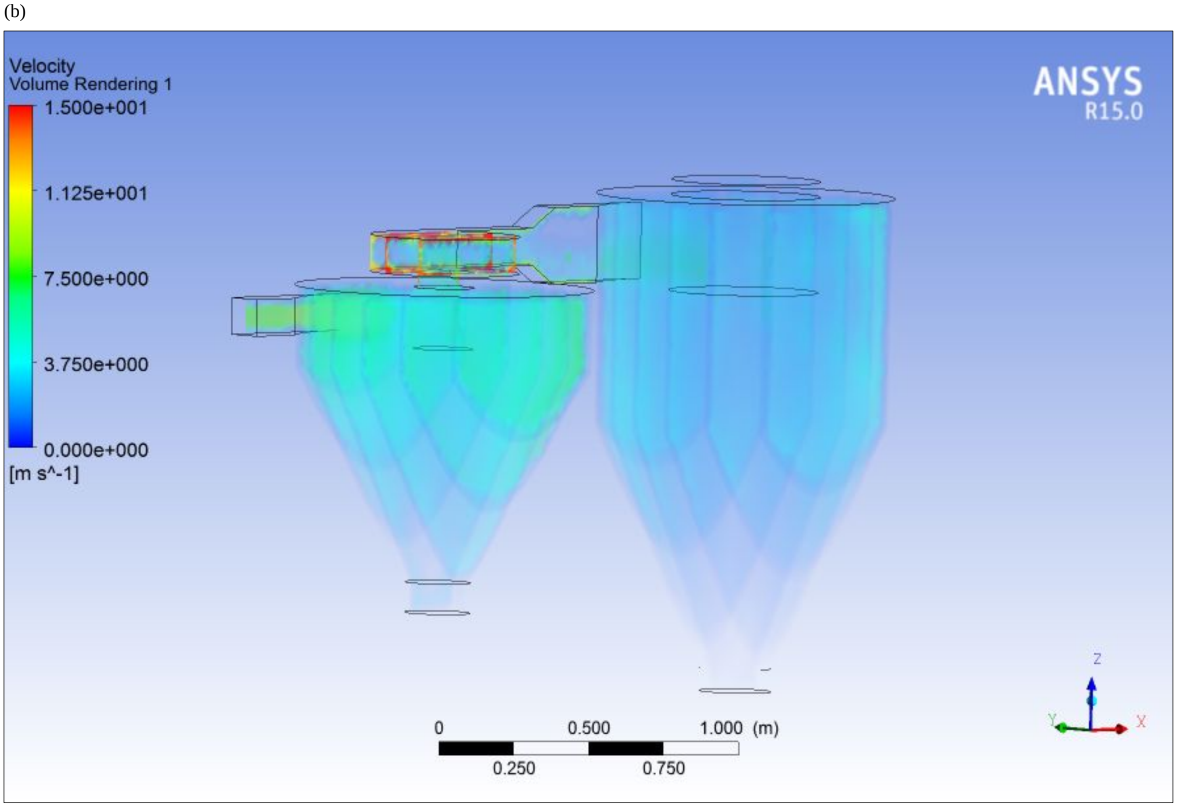
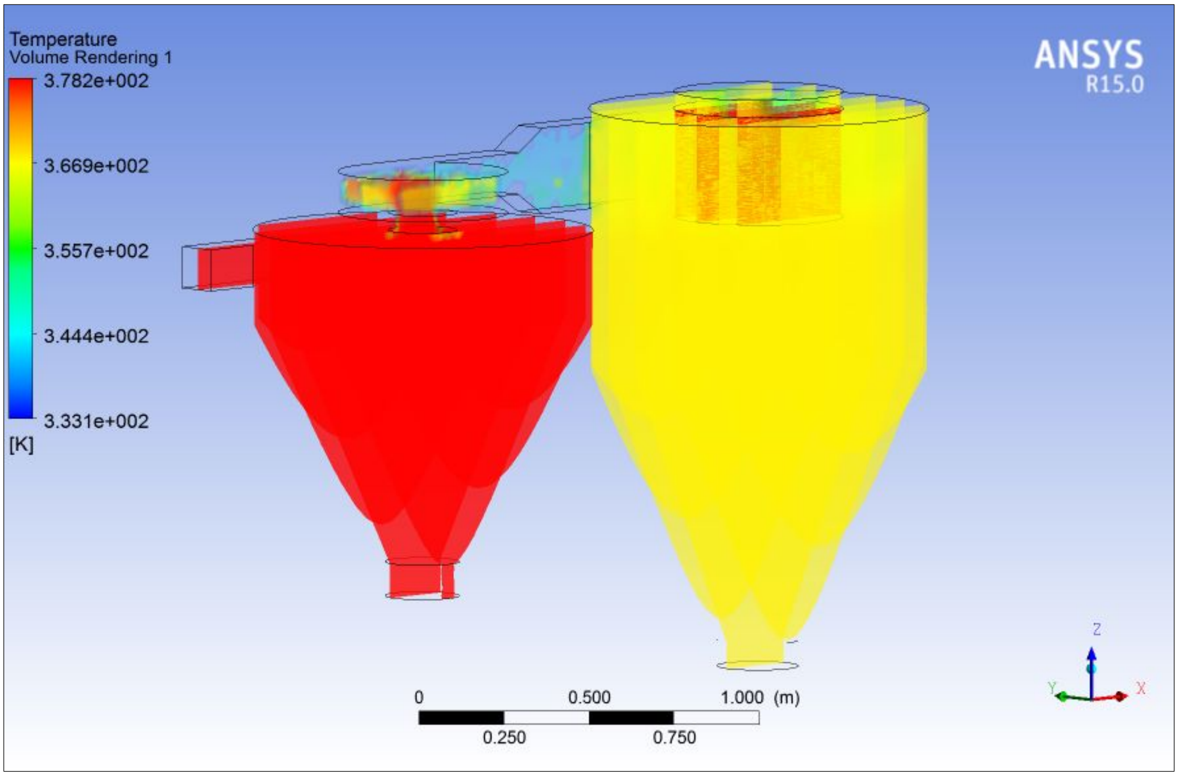


Fig. 4(a-b): Temperature variation T_{u3} 100°C, (a) Temperature and (b) Velocity

(a)



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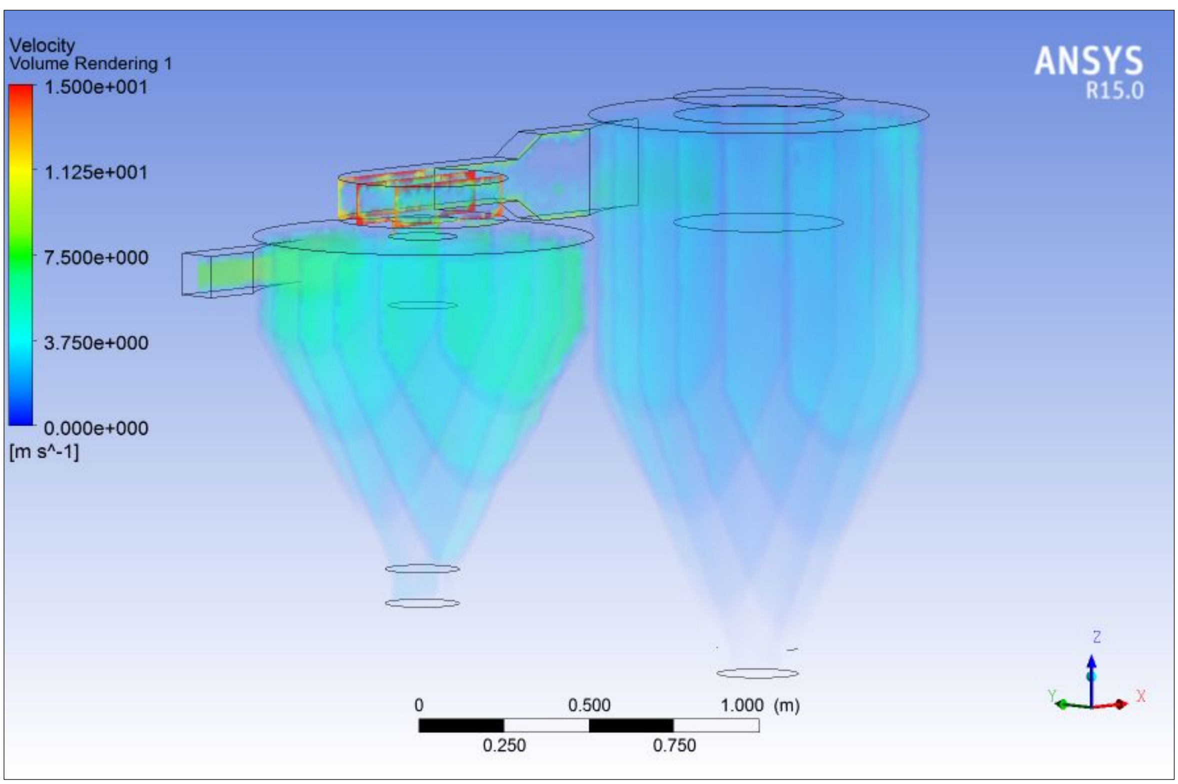
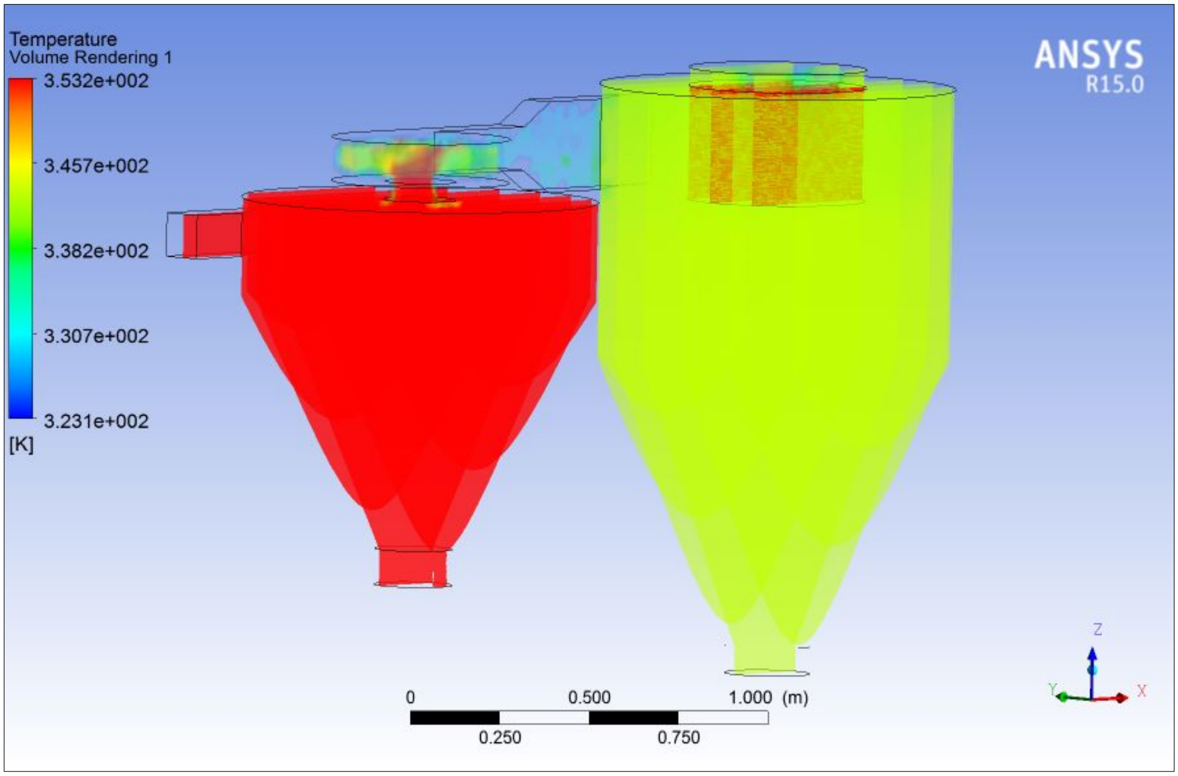


Fig. 5(a-b): Temperature variation T_{u3} 125°C, (a) Temperature and (b) Velocity

(a)



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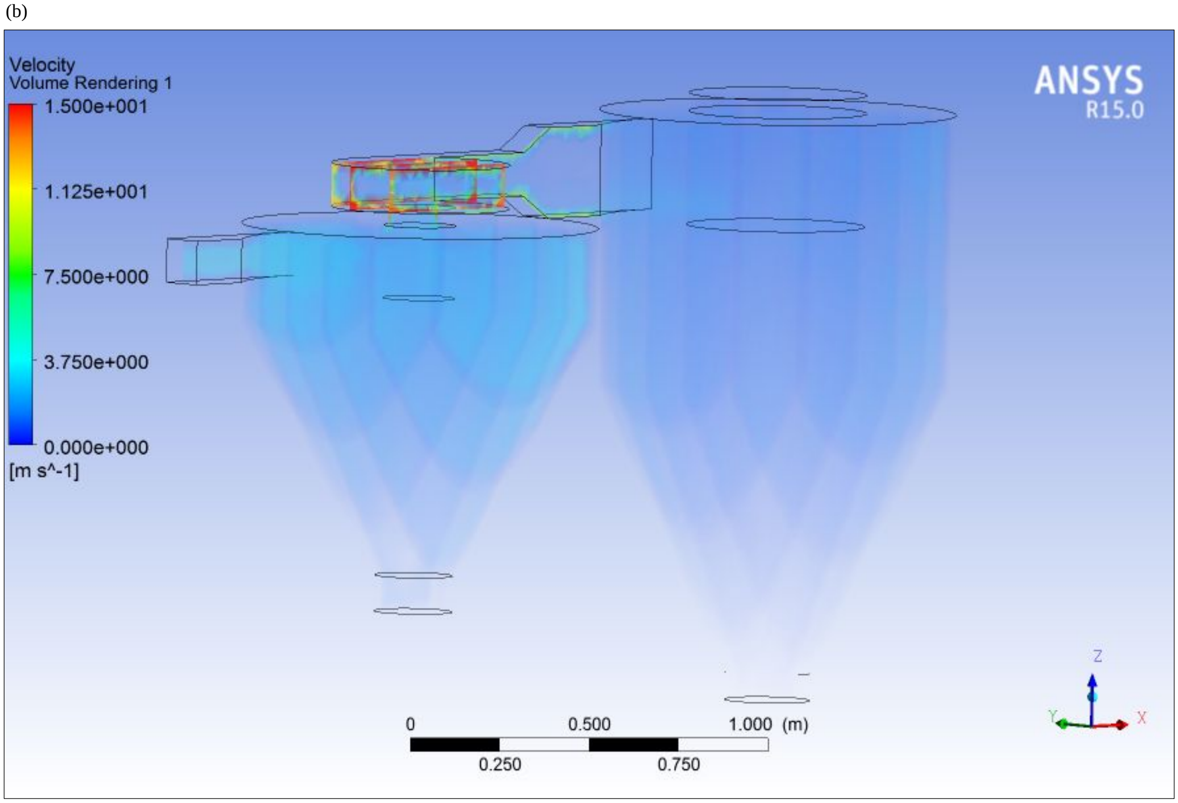
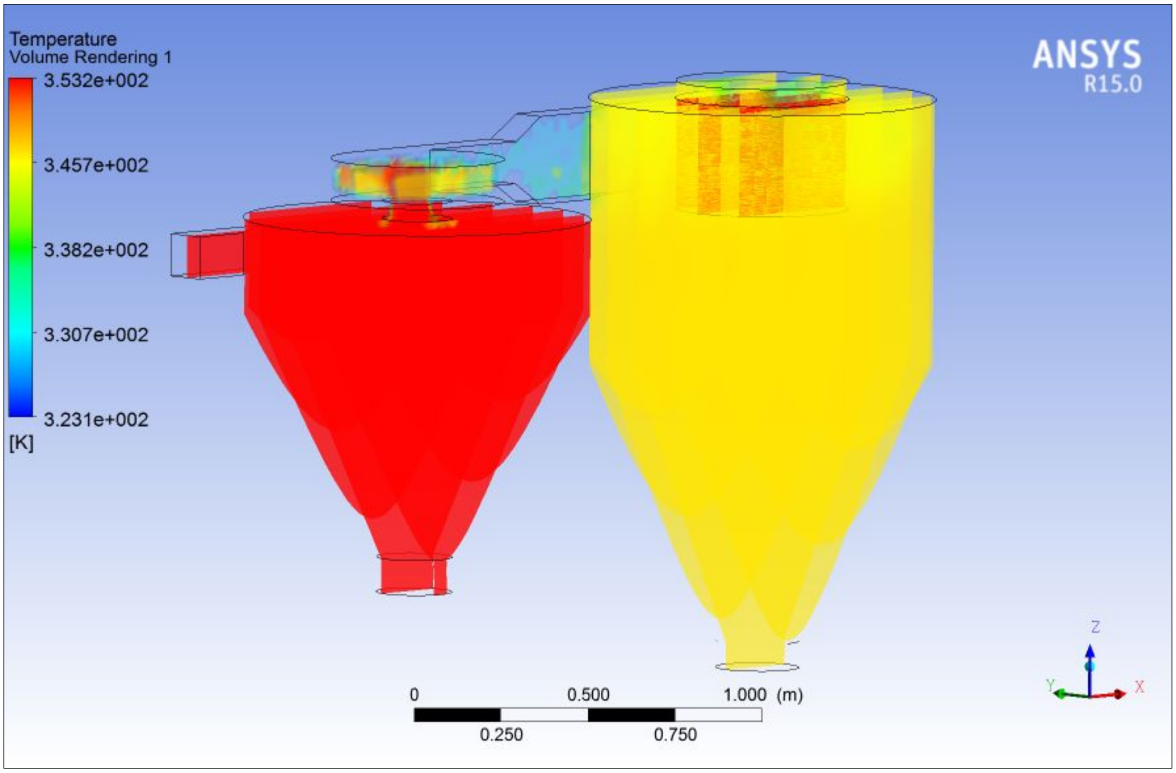


Fig. 6(a-b): Velocity variation v_u 15 m sec^{-1}, (a) Temperature and (b) Velocity

(a)



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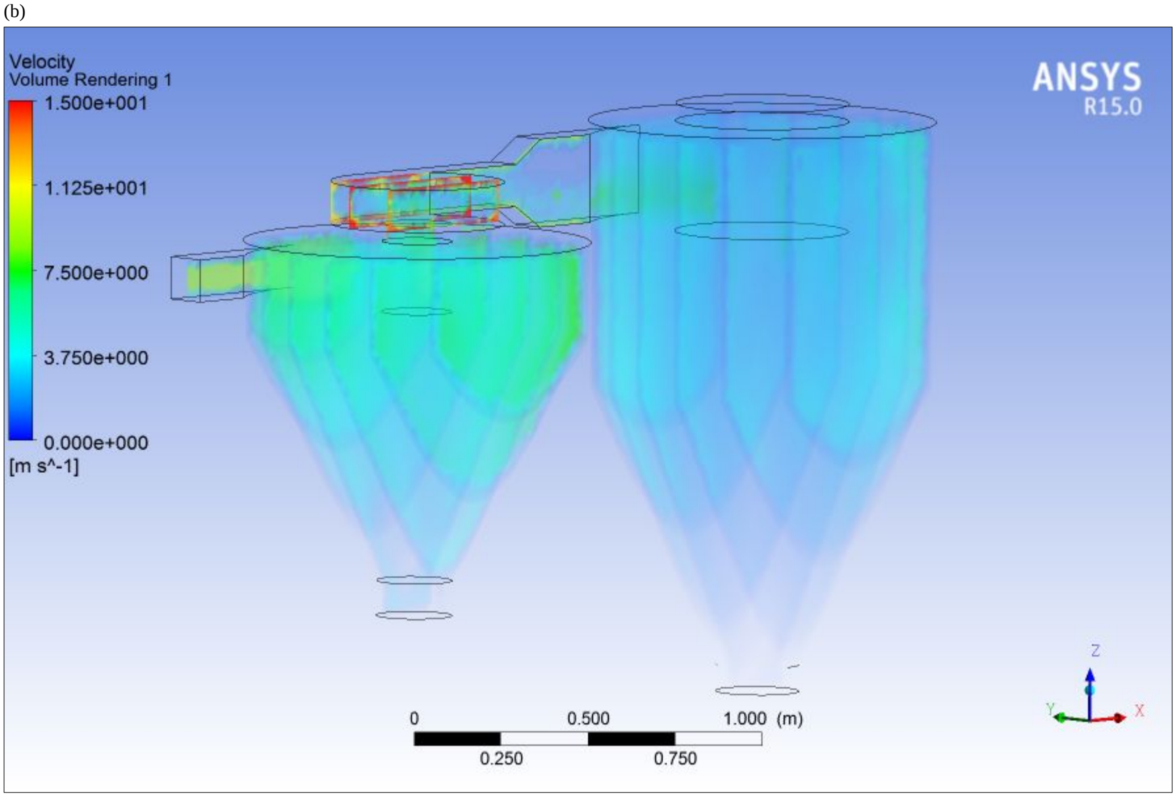
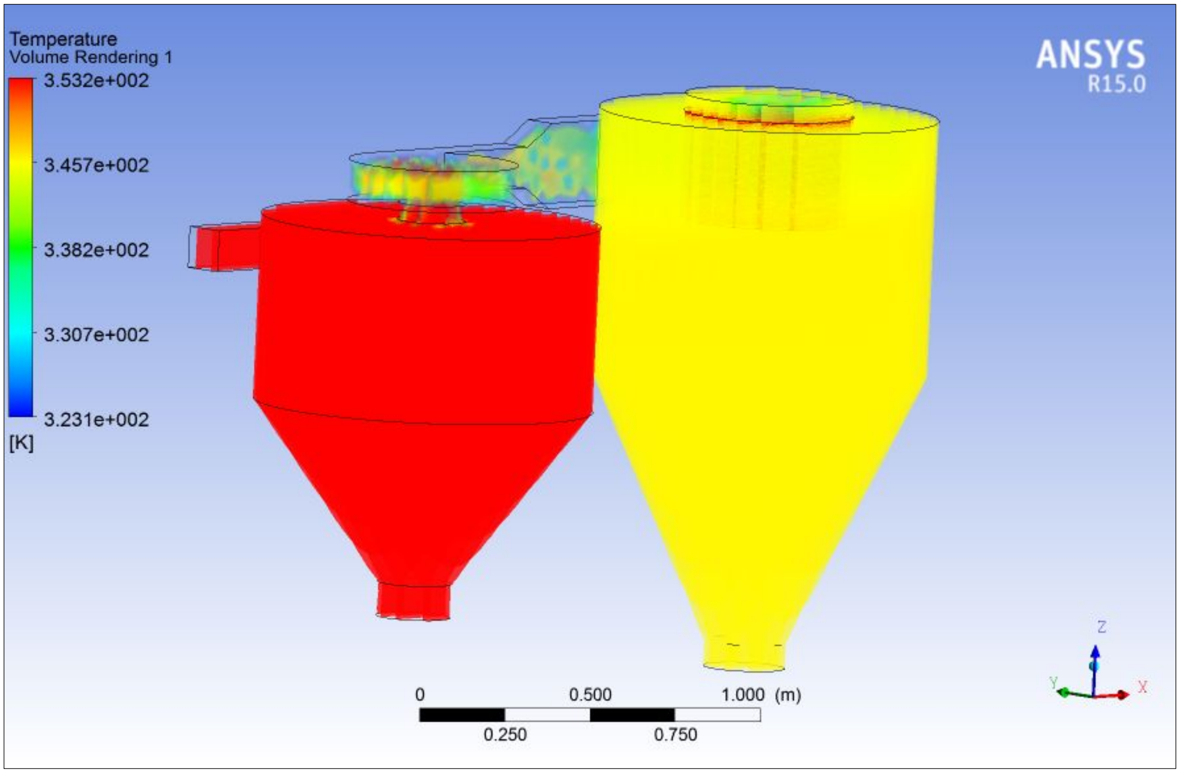


Fig. 7(a-b): Velocity variation v_u 31 m sec^{-1}, (a) Temperature and (b) Velocity

(a)



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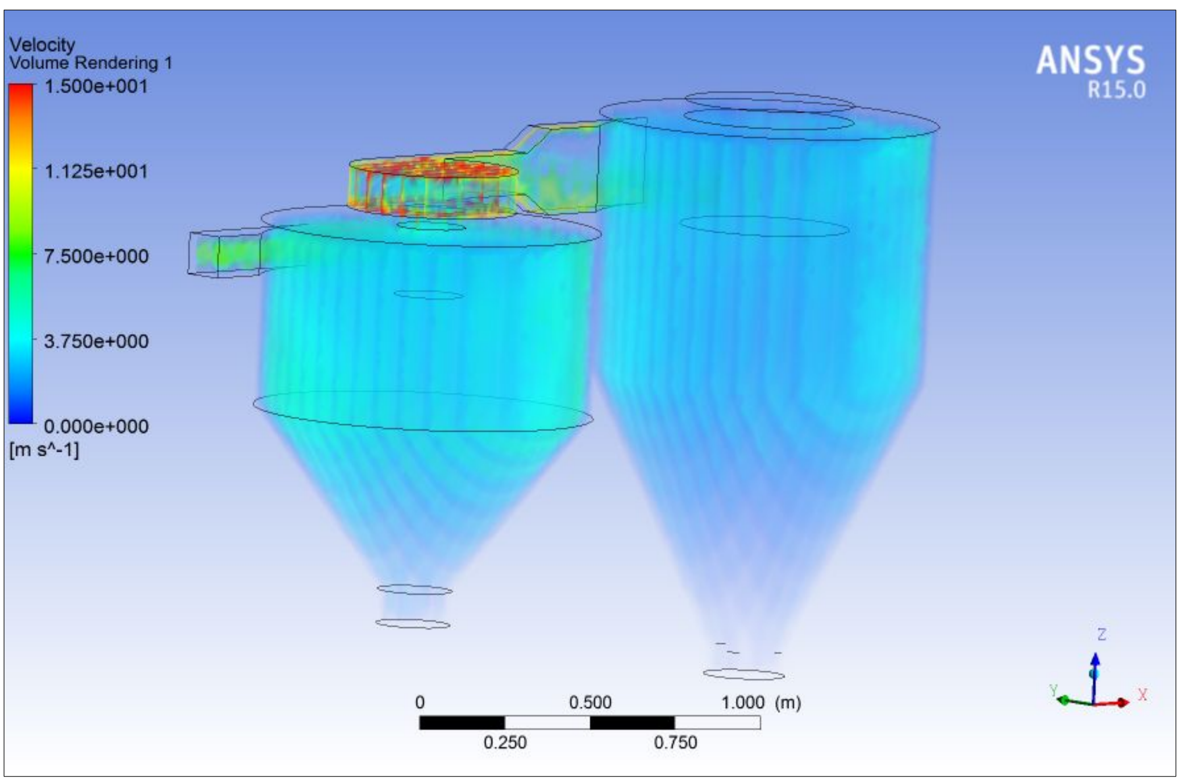
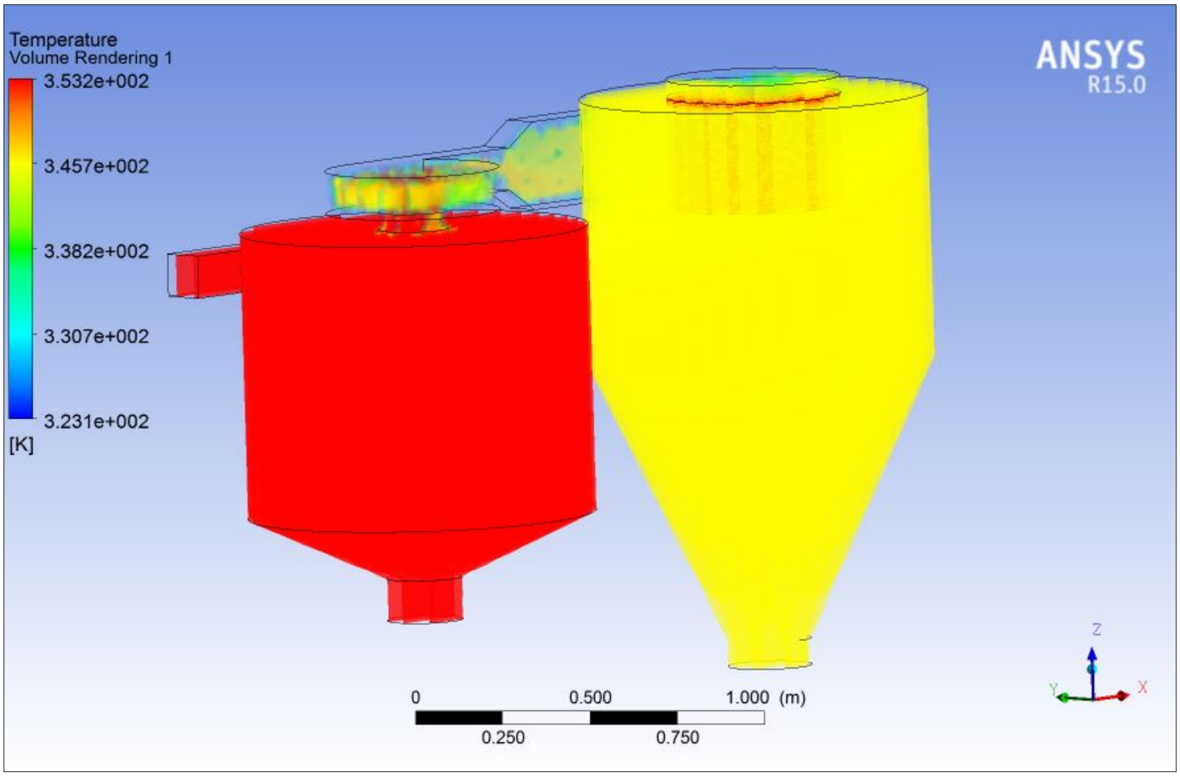


Fig. 8(a-b): Height of the cylinder variation L_{scrb} 0.54 m, (a) Temperature and (b) Velocity

(a)



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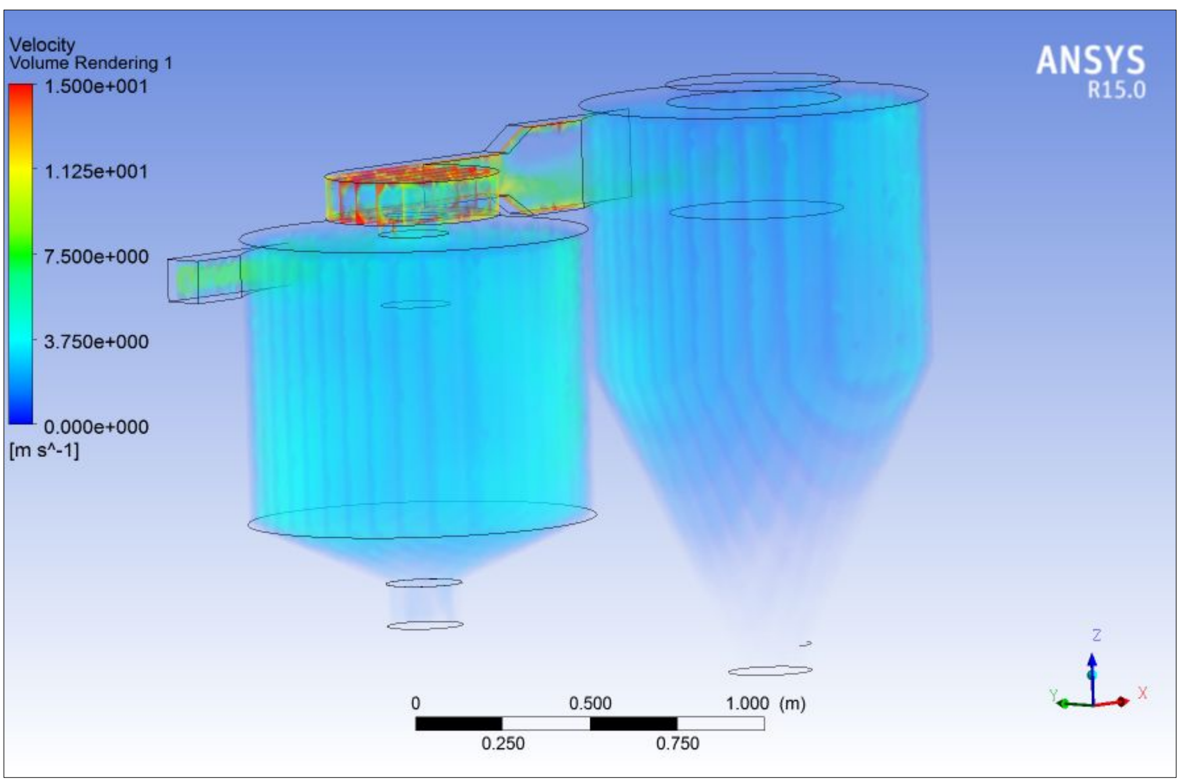
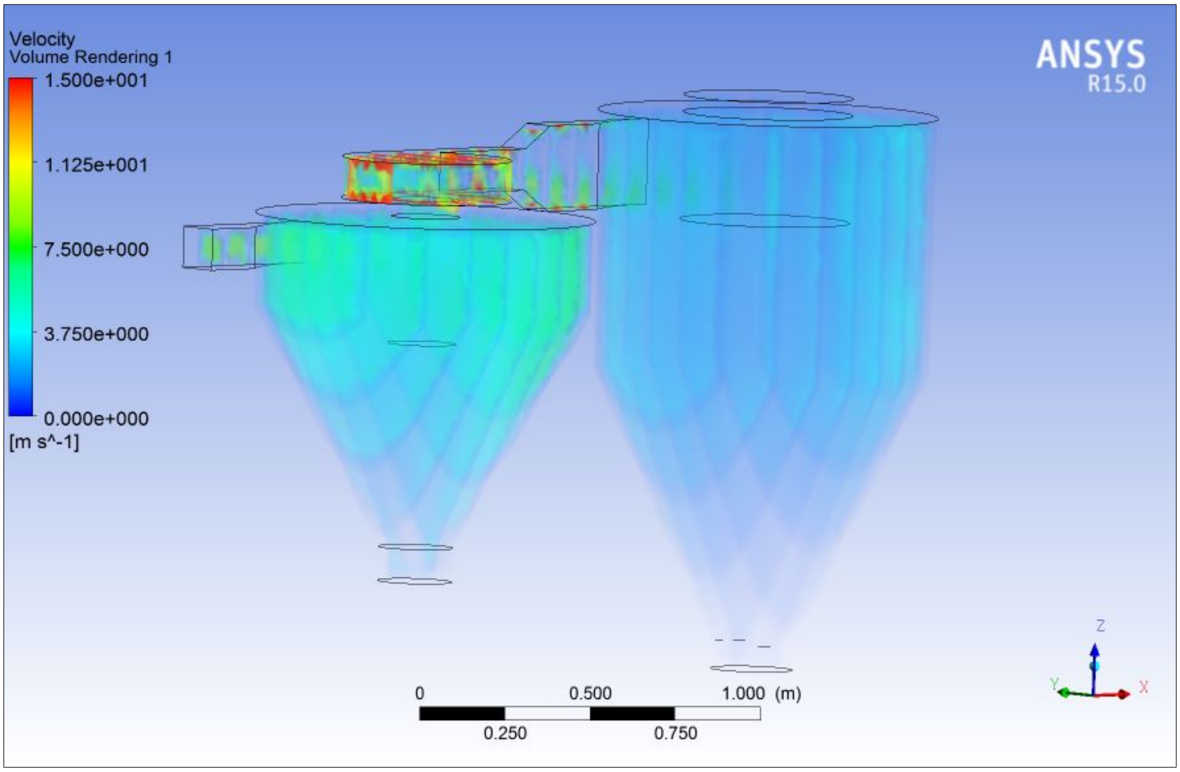


Fig. 9(a-b): Height of the cylinder variation L_{scrb} 0.81 m, (a) Temperature and (b) Velocity

(a)



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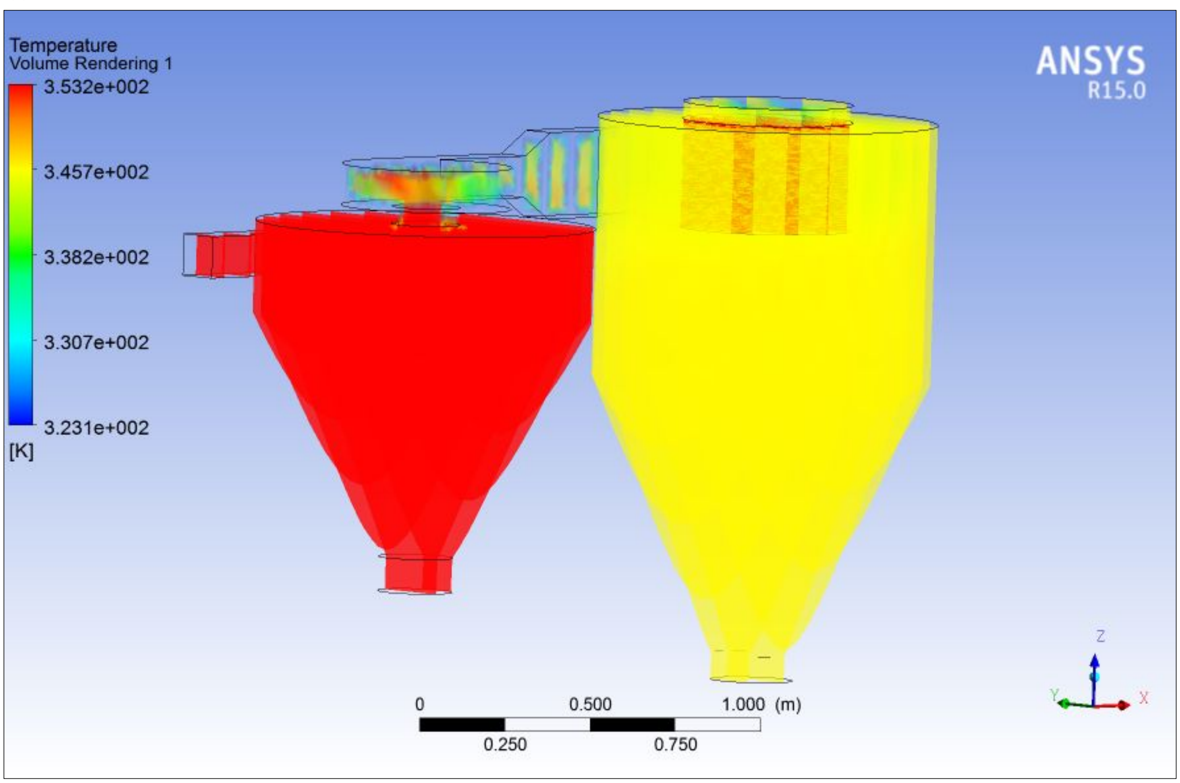
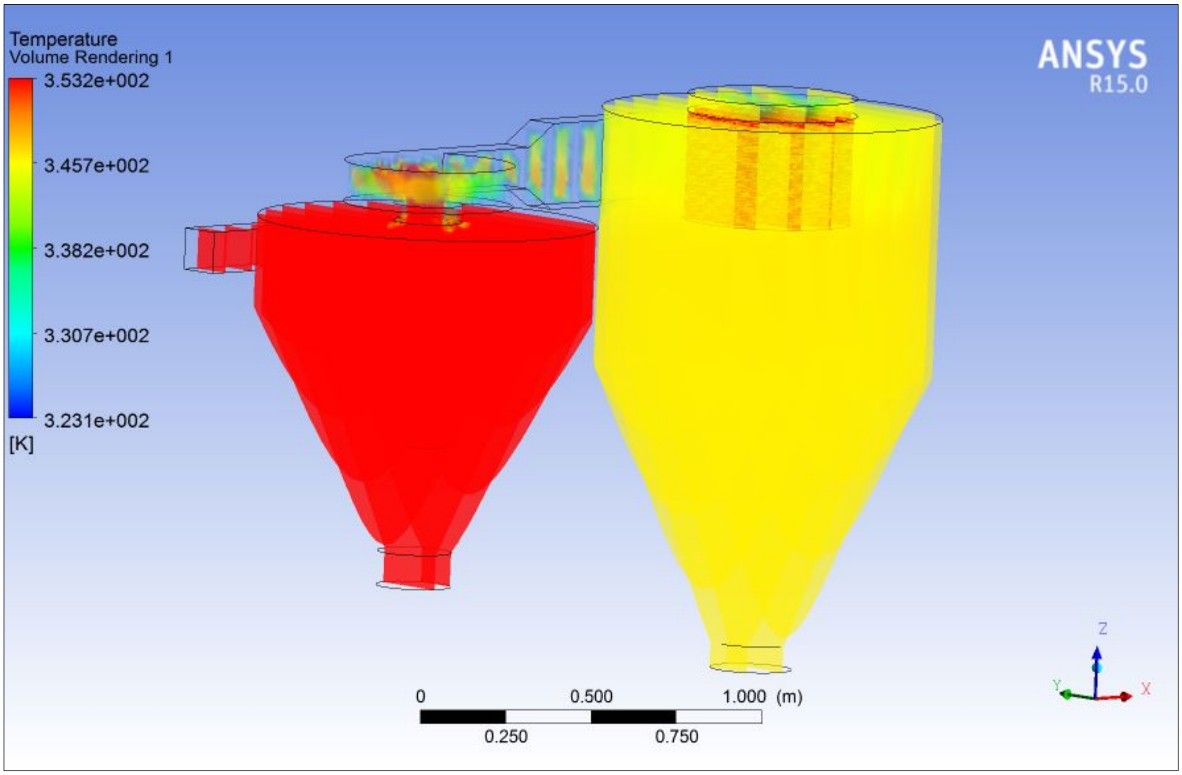


Fig. 10(a-b): Length of the upper outlet pipe variation L_{Acrb} 0.37 m, (a) Temperature and (b) Velocity

(a)



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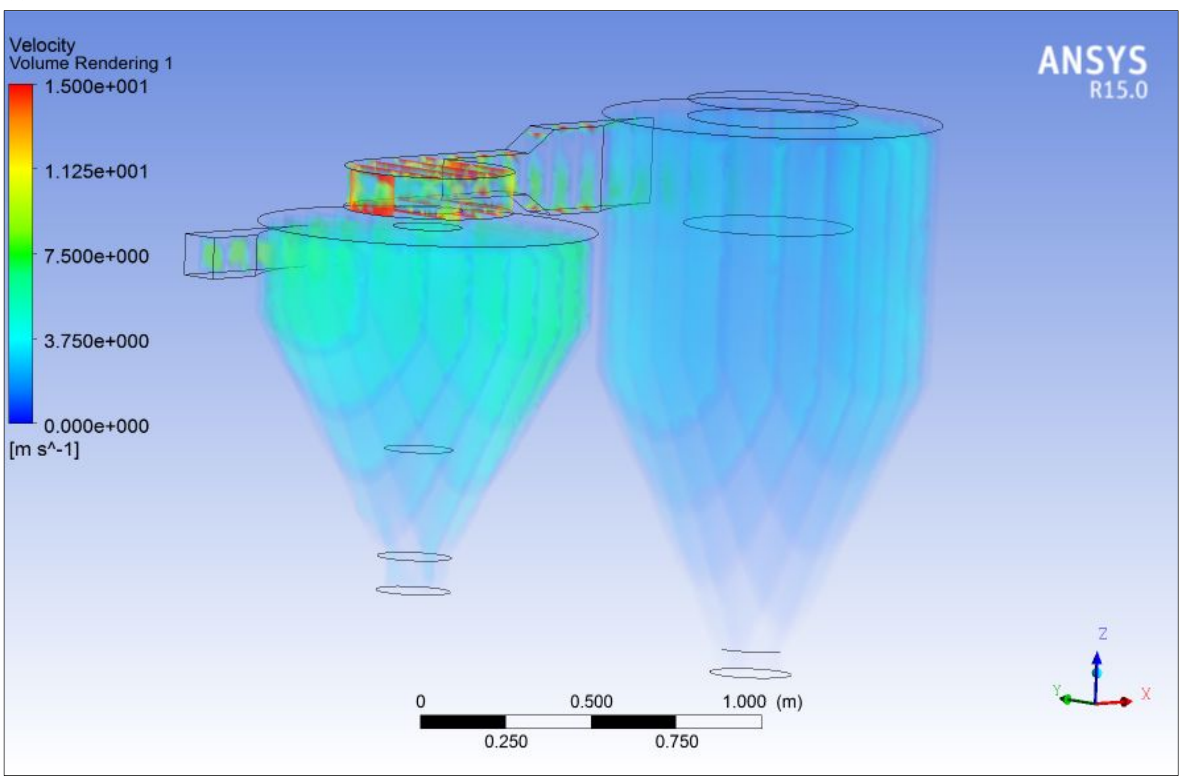
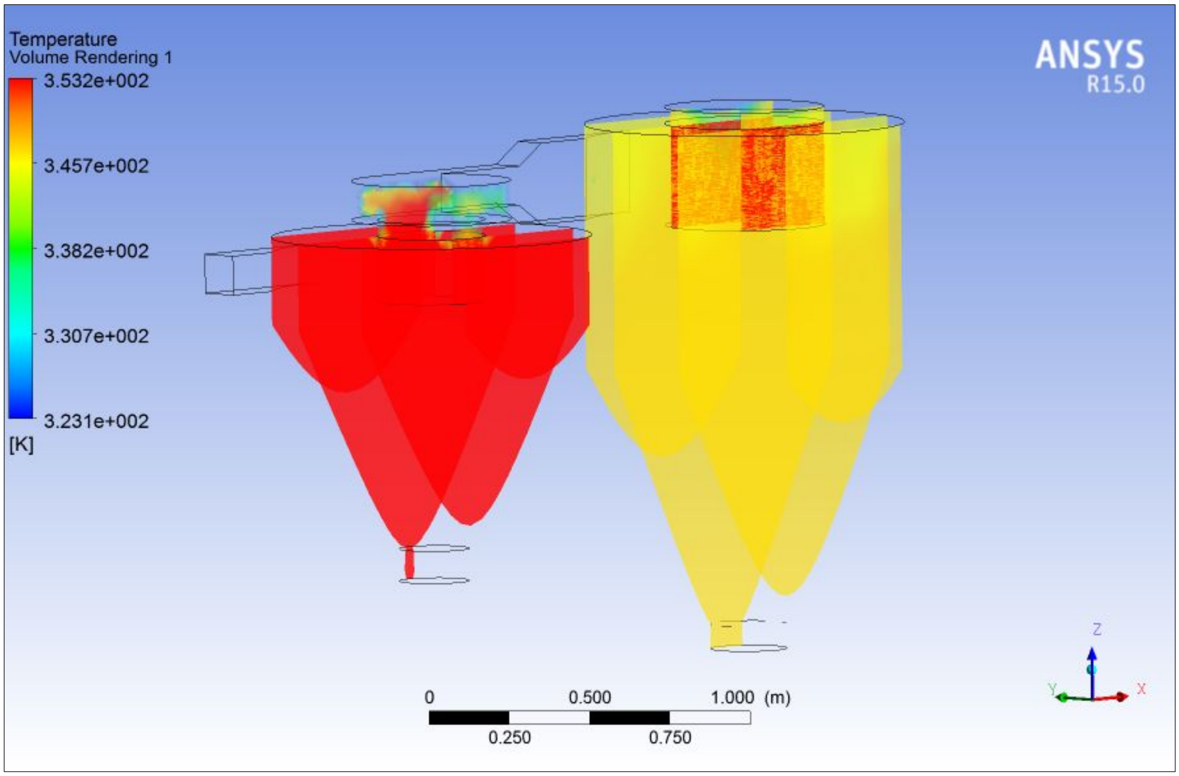


Fig. 11(a-b): Length of the upper outlet pipe variation L_{Acrb} 0.65 m, (a) Temperature and (b) Velocity

(a)



(b)

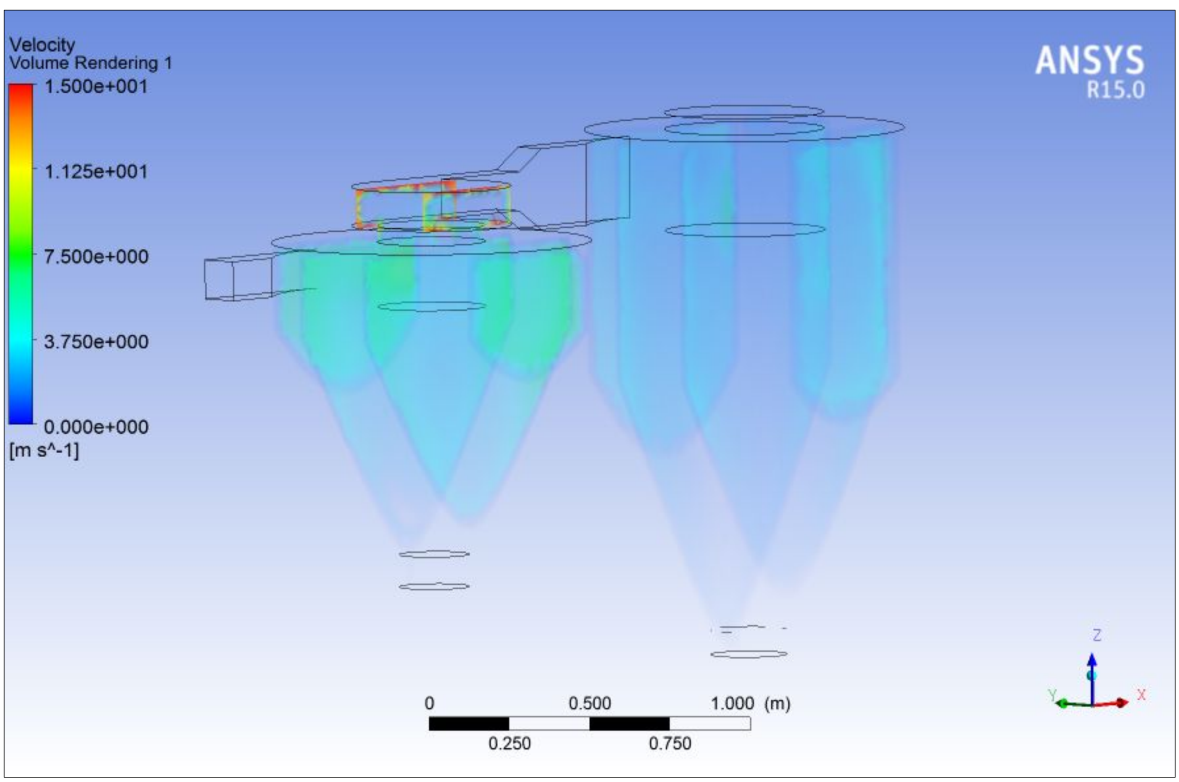
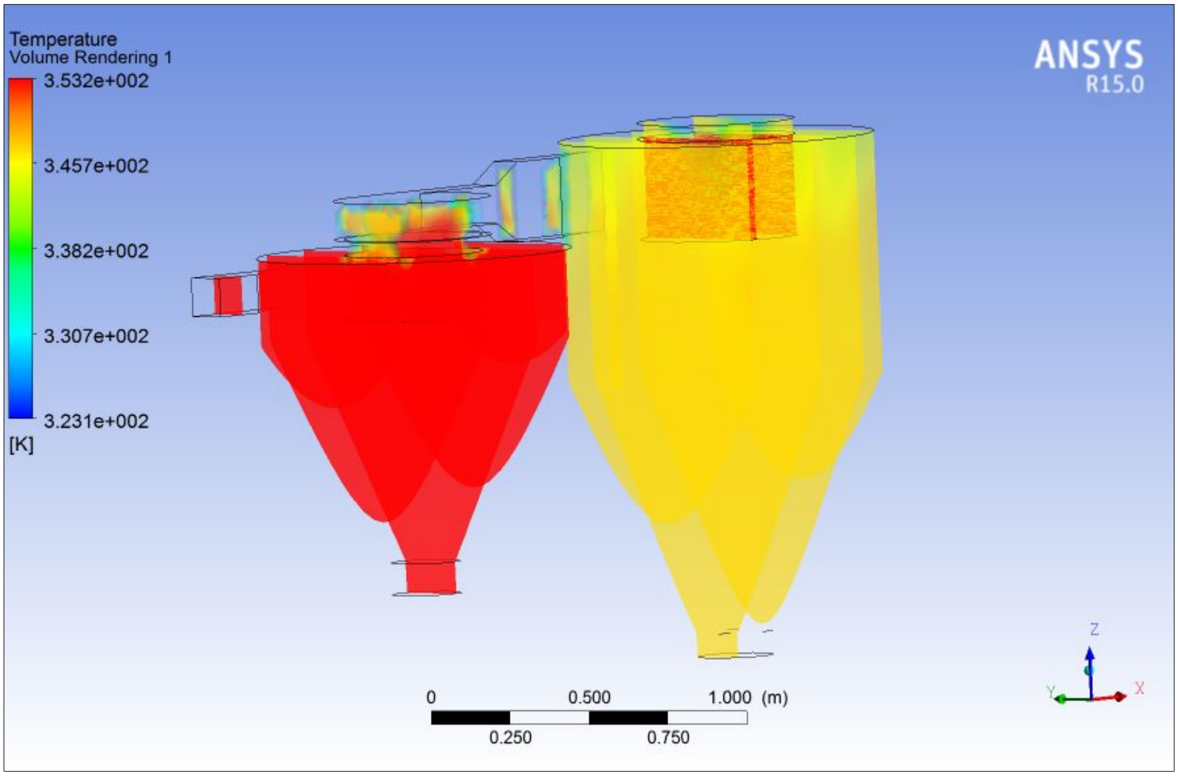


Fig. 12(a-b): Diameter of the upper outlet pipe variation D_{Acrb} 0.17 m, (a) Temperature and (b) Velocity

(a)



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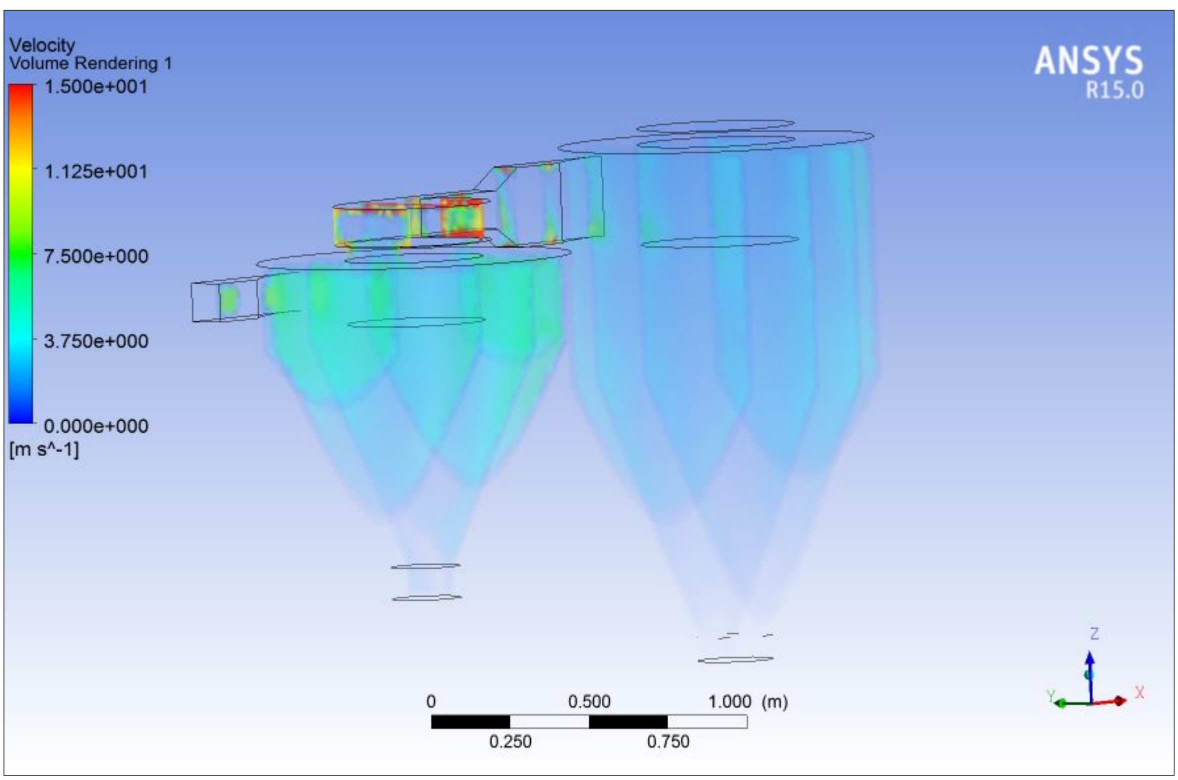
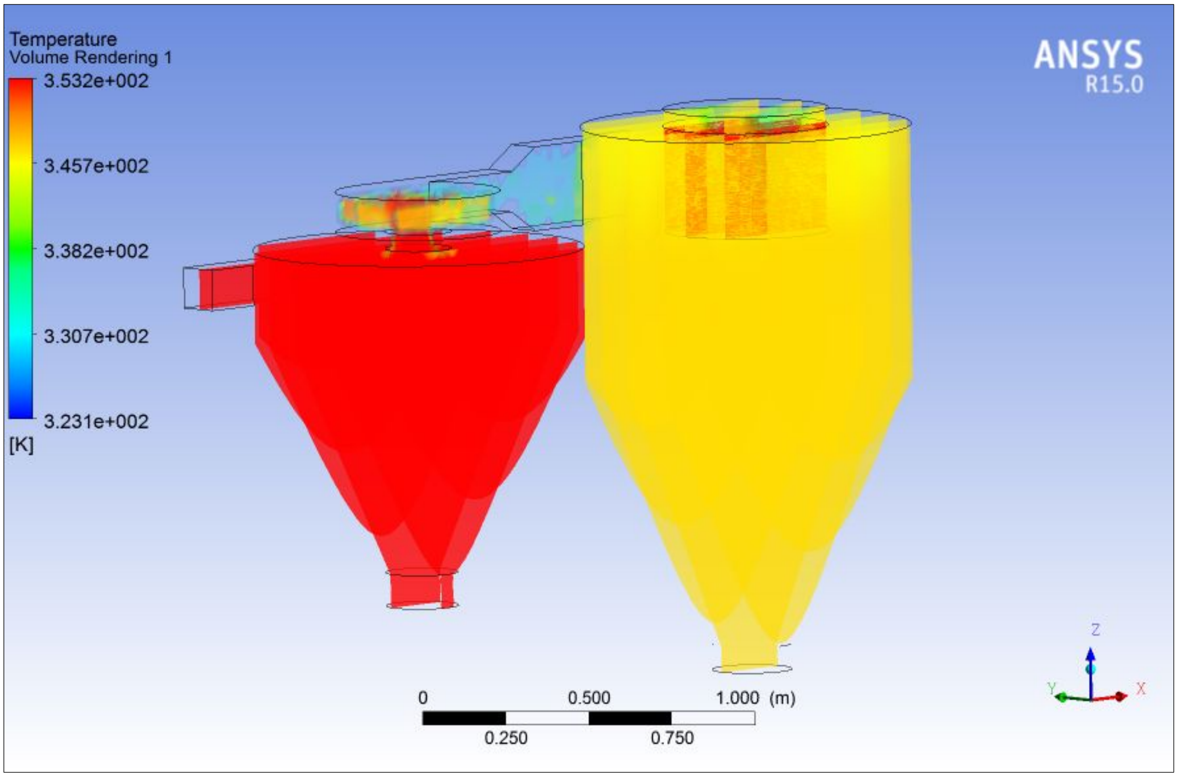


Fig. 13(a-b): Diameter of the upper outlet pipe variation D_{Acrb} 0.22 m, (a) Temperature and (b) Velocity

(a)



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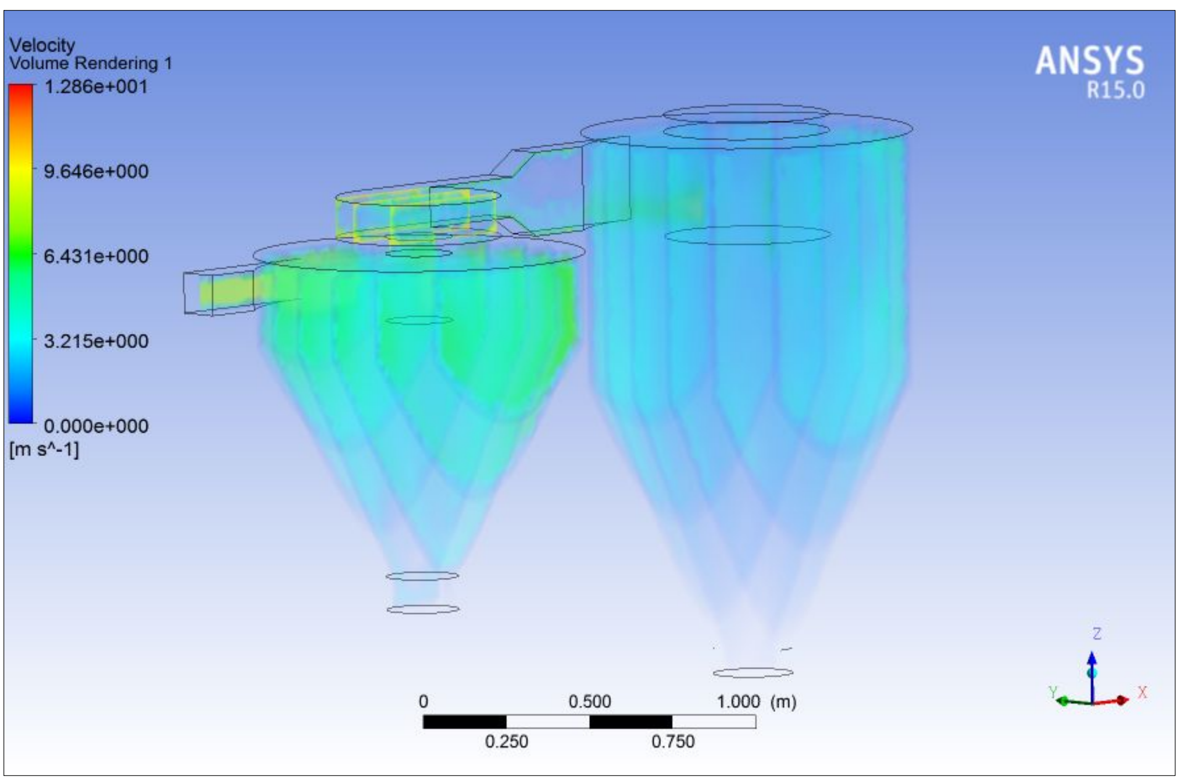

Fig. 14(a-b): Air velocity of centrifugal blower variation v_{ucrb} 10.75 m sec^{-1}, (a) Temperature and (b) Velocity

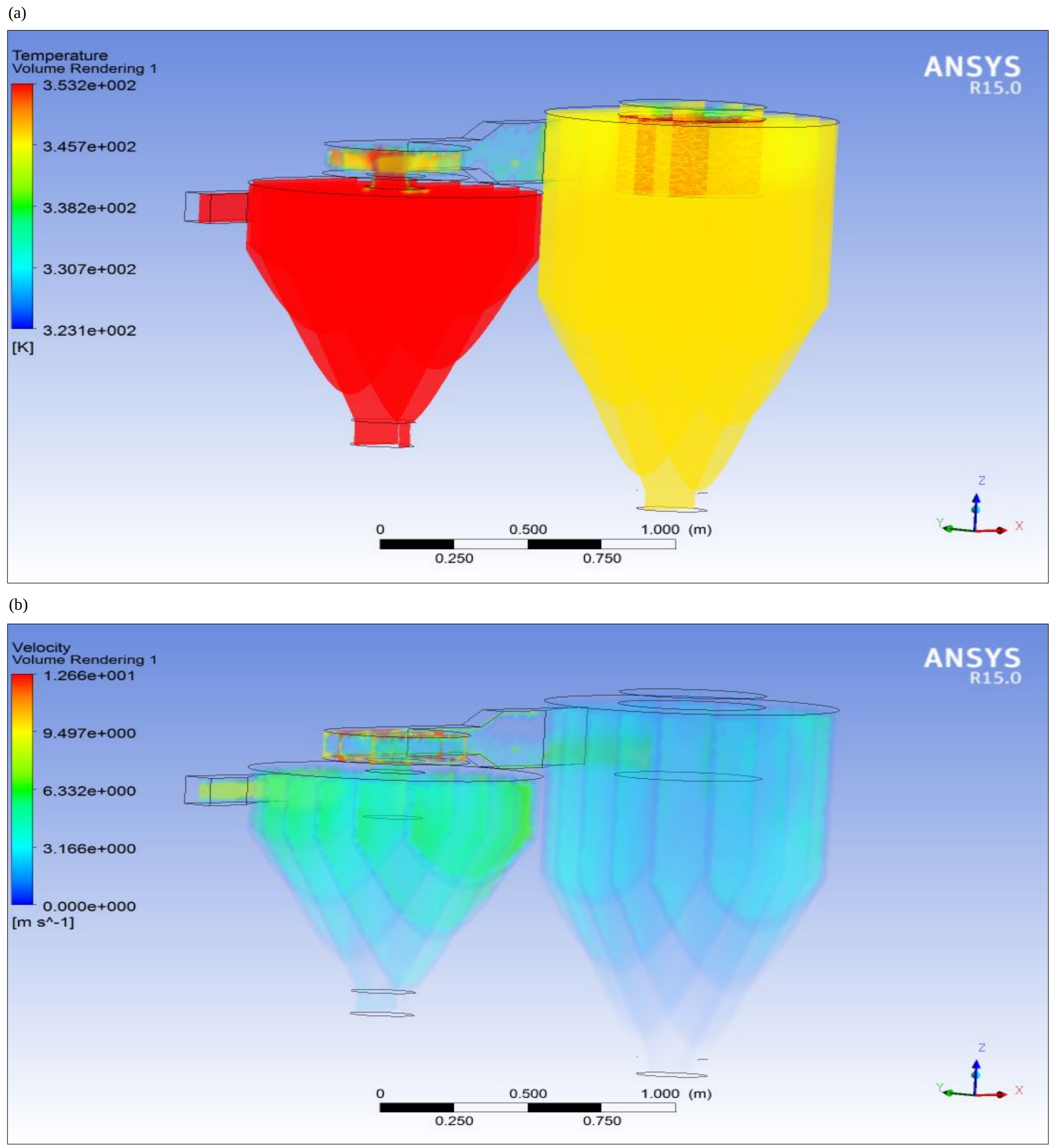

Fig. 15(a-b): Air velocity of centrifugal blower variation v_{ucrb} 12.75 m sec^{-1}, (a) Temperature and (b) Velocity

recirculating cyclone (L_{scrb}, L_{Acrb}, D_{Acrb} and v_{ucrb}), to the temperature distribution pattern and the drying air velocity in the recirculating and the material output cyclones. The simulation results show that all variation variables produce the same pattern and temperature distribution values but were not uniformly distributed. Nevertheless, the drying airflow velocity in each variation variable varies.

The temperature inside the recirculating cyclone was about 80.05°C (3.532×10^2 K), which was marked in red. The temperature inside the cyclone output of the material was about 72.55°C (3.457×10^2 K), which was indicated by the yellow color, except in Fig. 6. In Fig. 6 the temperature inside the cyclone output of material was smaller than 72.55°C (3.457×10^2 K), which was marked in green, It was caused by a smaller air velocity (15 m sec^{-1})[6]. The drying air velocity in

Fig. 6-15 varies: 3.75 m sec^{-1} (Fig. 6), higher than 3.75 m sec^{-1} (Fig. 7-10), 3.75-7.5 m sec^{-1} (Fig. 11), lower Than 3.75 m sec^{-1} (Fig. 12-13), lower than 3.215 m sec^{-1} (Fig. 14) and 3.166 m sec^{-1} (Fig. 15).

Results of the validation for the temperature of the simulation and that of the observation can be seen in Fig. 16. This figure shows that the error values generated by the input of recirculating cyclones and cyclones of the material output are quite low, i.e., less than 5%, namely 2.044 and 4.594%, respectively. Such low error values indicate that simulations using CFD can be used as a reference to make a design[17,18,21], which in this case are recirculating cyclones and cyclones of the material output. The simulation results approached the observation value or the real condition of PCRD machines.

Performance of recirculating cyclones and cyclones of the material output: A mathematical analysis of the performance values based on changes in the final moisture content of the material and effectiveness of recirculating cyclones of the material output had been conducted using Eq. 7-10. The observation data used were obtained from the testing of recirculation cytoplasm and material output using the material of wet sago starch containing the initial moisture content by 31% wb (wet basis). Results of the mathematical analysis generated the average values of the final moisture content of the material (M_{ob}) and the effectiveness of recirculating cyclones and cyclones of the material output of PCRD machines for sago starch drying were 8.93% wb and 89.6%, respectively. The resulting values of the moisture content of the material output have met the 13% wb quality standard required in the Indonesian National Standard (SNI, 3729)[22]. The values of the final moisture content (M_{ob}) and effectivity of each variable of the drying process of recirculating cyclones and cyclones of the material output of PCRD machines can be seen in Fig. 17.

The graph shows that the M_{ob} values of variables v_u, T_{u3} and L_{scrb} decreased, namely from 9.83% wb to 8.33%, from 9-7% wb and from 10.75-7.10% wb, respectively. While for variables D_{Acrb}, L_{Acrb} and v_{ucrb}, the M_{ob} values increased, namely from 9-10% wb, from 9-11% wb and from 7-9% wb, respectively. The graph also shows that the values of effectiveness for the variables v_u, T_{u3}, D_{Acrb} and v_{ucrb} decreased, namely from 90.60-85.02%, from 91.22-88.79%, from 89.24-86.52% and from 91.65-89.68%, respectively. Conversely, the values of effectiveness for variables L_{scrb} and L_{Acrb} increased, namely from 89.24-91.65% and from 89.24-94.59%, respectively. This suggests that the higher the air velocity (v_u) and air temperature (T_{u3}) values of dryers are, the lower the resulting moisture content of the material output (M_{ob}) is but the effectiveness value decreases. As for the variation in the dimension of the height of the diameter (L_{scrb}) of recirculating cyclones, it is revealed that the higher the diameter is, the lower the M_{ob} value, while the value of effectiveness increases.

Another cyclone dimension variable, i.e., the diameter of the upper outlet pipe (D_{Acrb}), suggests that the greater the diameter is, the higher the M_{ob} value is but the value of effectiveness decreases. While the variation in the dimension of the diameter length of the upper outlet pipe (L_{Acrb}) shows that the higher the length value is, the higher the M_{ob} value is and the value of effectiveness is high. Variation in the air velocity of the centrifugal blower (v_{ucrb}) of recirculating

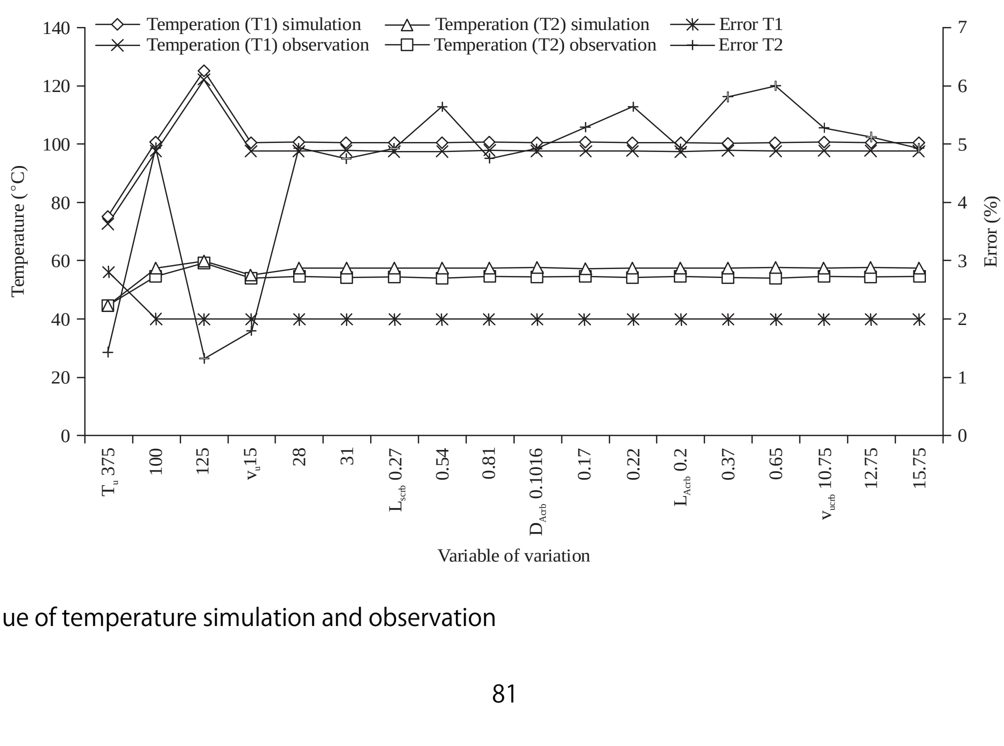

Fig. 16: Error value of temperature simulation and observation

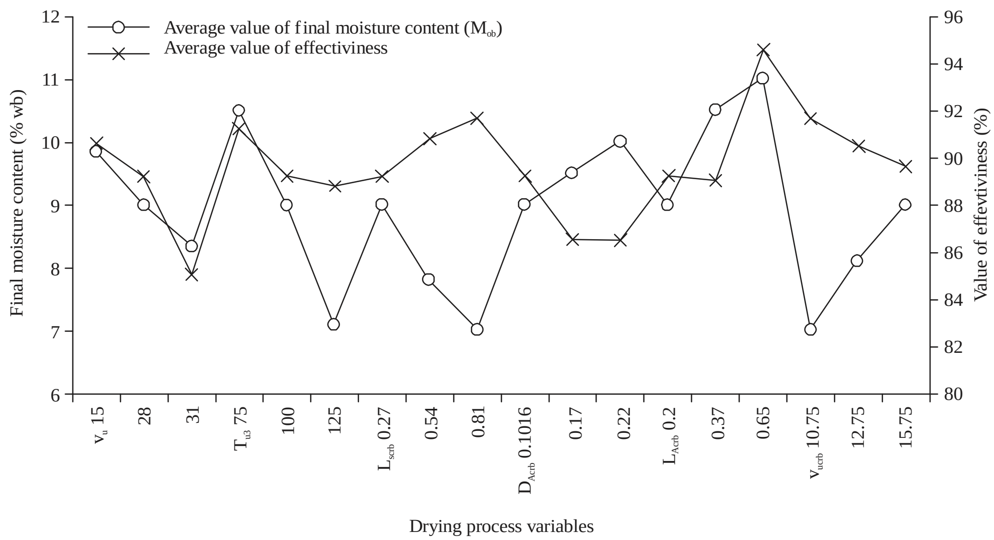

Fig. 17: Moisture content output materials (M_{ob}) and effectiveness values each variables

Table 3: Effect of drying process of variable for M_{ob} and effectiveness value

Drying process variable	M_{ob} ANOVA (α = 0.05)	M_{ob} Duncan	Effectiveness ANOVA (a = 0.05)	Effectiveness Duncan
T_{u3}	0.001[a]	3 group	0.108[b]	1 group
v_u	0.000[a]	3 group	0.025[a]	2 group
L_{scrb}	0.000[a]	3 group	0.002[a]	2 group
D_{Acrb}	0.000[a]	3 group	0.003[a]	2 group
L_{Acrb}	0.000[a]	3 group	0.003[a]	2 group
v_{ucrb}	0.000[a]	3 group	0.003[a]	3 group

[a]Significant, [b]Not Significant, [a]Level of significance

cyclones indicates that the higher the value of variation in velocity is, the higher the M_{ob} value is but the value of effectiveness decreases.

To determine the effect of each drying variable on the values of M_{ob} and effectiveness of recirculating cyclones and cyclones of the material output, a statistical analysis with a one-way ANOVA test followed by Duncan's test was performed, as shown in Table 3. The assumption with (α = 0.005) generated analysis results indicating that each group of variation in the drying process variables had a significant effect on the final moisture content of the material (M_{ob}). While the effect of variation in the drying process variables on the effectiveness of recirculating cyclones and cyclones of the material output was also significant in two different groups, except for the variable of the air temperature of dryers (T_{u3}).

This suggested that the effectiveness of the performance of recirculating cyclones and cyclones of the material output of PCRD machines has worked well, i.e., they managed to separate dry materials from water vapor with a high effectiveness value[2,3,8].

CONCLUSION

Results of the simulation suggest that temperature distributions within recirculating cyclones and cyclones of the material output were well distributed. Results of the comparison between the simulation results and the observation results generated a low error value. The error value of the recirculation cyclones was equal to 2.044%, while the value of the cyclones of the material output was equal to 4.594%. Simulation results approached the observation value or the real condition of PCRD machines. Testing results of recirculating cyclones and cyclones of the material output generated the average value of the moisture content of the material output by 8.93% wb and the value of effectiveness by 89.6%. Each variation in variables greatly affected the value of the moisture content of the material output and the effectiveness of recirculating cyclones and cyclones of the material output, except for the temperature variable (T_{u3}). This suggests that the designs of recirculating cyclones and cyclones of the material output of PCRD machines are highly feasible to be implemented for the drying process of starchy substances.

SIGNIFICANCE STATEMENT

This study discover the recirculating cyclone dimensional design model that can be beneficial for development of pneumatic conveying recirculated dryer for sago starch drying. This study will help the researcher to uncover the critical areas of drying process material with continuous material recirculation that many researchers were not able to explore. Thus a new theory on the development of the process model of the material recirculation in a continuous form of cyclone may be arrived at. The study found a continuous process of pneumatic drying of materials for the drying of materials containing high moisture content to increase the residence time. This research will help researchers to reveal the critical areas of the effect of the process of continuous recirculation of materials on the quality of dry matter.

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