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# CFD Analysis of Pure Waterjet Nozzle for Fruit Peeling and Cutting Process

Yaghthiswara Seran[1], Muhamad Safwan Muhamad Azmi[1,*], Abdul Halim Ismail[2], Kamarulzaman Kamarudin[2], Lam Chee Kiang[2], Norasmadi Abdul Rahim[2], Wan Mohd Nooriman Wan Yahya[2], Tan Kian Yew[3], Lum Wei Min[3]

[1] Faculty of Mechanical Engineering & Technology, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia
[2] Faculty of Electrical Engineering & Technology, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia
[3] Walta Engineering Sdn. Bhd., 13600 Prai, Pulau Pinang, Malaysia

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**ABSTRACT**

Waterjet Technology has been used vastly in our world nowadays due to its advantages and it can be implemented in many industrial sectors or even in the medical sector and food industry sector. Nozzle is a component that has been utilized in waterjet which is employed in a wide range of engineering applications to control the rate of flow, velocity, and the jet pressure of the water. This paper discusses the CFD analysis on a pure waterjet nozzle to obtain the output of the water that jets out from three different diameters of nozzle and select the effective nozzle diameter to be used for the fruit peeling and cutting process. The pressure used for the analysis are 200MPa, 300MPa and 400MPa, which was analysed for three different nozzle diameter 0.76mm, 1.02mm and 1.27mm. From CFD analysis, it is established that as the pressure loss of the water jet increases, the outlet velocity of the jet increases. Furthermore, for fruit peeling and cutting process the impact angle of the nozzle should be prioritised as the peeling of the fruit should be smooth and even before cutting the fruit. Thus, the most suitable parameters were found to be 400MPa and 1.02mm of pressure and nozzle diameter respectively. This will allow for the intended fruit cutting process with a stand-off distance that can be ranged from 1mm to 9mm.

## 1. Introduction

Waterjet Machining is a process that use to cut materials or workpieces using only pressurized water or a combination mixture of an abrasive and water [1, 2]. Since 1930s, this process has become more popular, because in this process there is an absence of toxic gases, and it does not create any flammable liquids or vapours. There are no heat impacted zones or mechanical stresses on a water jet cut surface. Water jet cutting or cold cutting is fast, flexible, and relatively accurate, and they've become more user-friendly in recent years [3, 4]. They utilize the technology of high-pressure water being thrust through a small hole (frequently referred to as an "orifice" or "jewel") to concentrate a huge amount of energy in a small area. There are two types of waterjet pure waterjet and abrasive waterjet [5].

[*] *Corresponding author.*
*E-mail address: safwanazmi@unimap.edu.my (Muhamad Safwan Muhamad Azmi)*

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Pure waterjet machining has recently been popular in the food sector because the waterjet applies very little force to the food, so it does not crush it, and when used at a proper angle, it may reduce waste [6, 7]. Image processing for instance using segmentation such as automatic image thresholding method [8] can be utilized to guide the waterjet in order to cut and peel the fruits and foods automatically [9]. The edge of the fruits can be the main data to guide the waterjet motion [10]. Waterjets provide a means of avoiding chuck contact and automating with computer numerical control [11, 12]. If the food contains bone, its hardness usually requires the addition of an abrasive to the waterjet [13]. The quality of the water is important as the water should be around 4 degrees to 6 degrees because it tends to get warmer as it will be pressurized, and the Total Dissolved Solids, TDS value should be near 20 which is considered good quality water, as discussed by Latif *et al.,* [14] where the quality of wastewater is important for meat processing. Moreover, nowadays sandblasting is replaced by pure waterjet to remove paint from bridges in United States due to environmentally friendly [15].

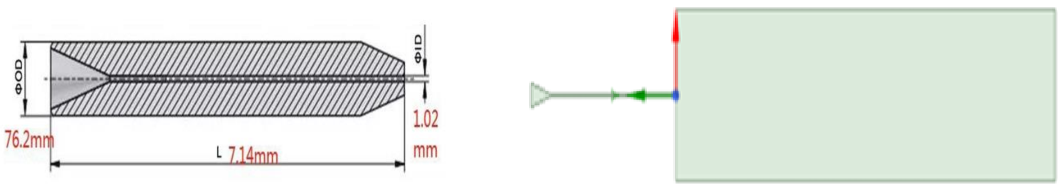
The material removal rate and cutting mechanism are affected by pressure. Some works on jet nozzle considers the environmental temperature in modeling the nozzle [16]. The higher the pressure, the faster the jet and the greater the kinetic energy of the water when it is in contact with the material. The nozzle diameter utilized in this study ranges from 0.15mm to 1mm. As a result, the depth of the cut increases significantly as the nozzle diameter increases because of lower volumetric flow rates and water pressures with larger nozzle sizes generate this effect [5]. The increased diameter of the nozzle is subjected to the decrease in the velocity of the water as pressure is inversely proportional to the velocity. The use of different nozzle exit diameters gives different results on different materials. Use of the smallest or larger exit diameter of the nozzle can produce a fine cut that can't be considered [17]. As the nozzle exit diameter increases, the cut depth increases. Meanwhile, as the nozzle exit diameter increases, the jet velocity drops [18].

This paper reports our works on the modeling and CFD analysis of a pure waterjet nozzle for fruit peeling and cutting, which could assist significantly in designing and modeling the nozzle for a specific application. To our knowledge, there is no study yet on relating the CFD analysis of the waterjet to the fruit peeling and cutting process. This study focus on the jet flow of pure waterjet using CFD to obtain the flow characteristic of water when jets out of a round shaped nozzle.

## 2. Methodology

### *2.1 Geometry and Parameters of Nozzle*

Figure 1(a) shows the geometry of the nozzle that was used for this CFD analysis. The inlet nozzle diameter, length of inlet and focus length were fixed for the simulation. As for the nozzle diameter 5mm were used for this study [19]. Moreover, the converging angle of the nozzle was calculated according to the nozzle exit diameter before drawing the geometry in CFD Fluent. A domain of 50×100mm which acts as the surrounding was designed below the nozzle geometry as shown in Figure 1(b) to obtain and study the output parameters when water jets out of the nozzle.




(a) (b)

**Fig. 1.** Nozzle design (a) Nozzle geometry [9] and (b) Design nozzle and domain using CFD FLUENT

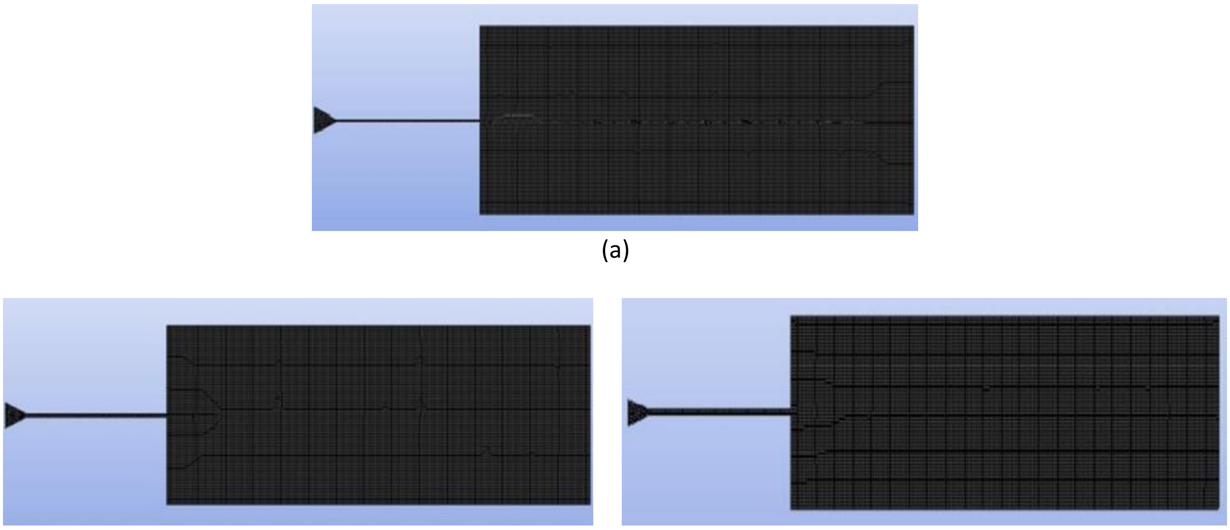
Table 1 shows the parameters investigated in this analysis in order to select and use the nozzle diameter that are efficient for peeling and cutting process. Each result of respective nozzle was compared and three result with highest velocity for each nozzle will be considered for further comparison on velocity and stand-off distance.

**Table 1**
Simulation parameters and conditions

| Pressure (MPa) | Nozzle diameter (mm) | | |
| --- | --- | --- | --- |
| | A | B | C |
| 200 | 0.76 | 1.02 | 1.27 |
| 300 | 0.76 | 1.02 | 1.27 |
| 400 | 0.76 | 1.02 | 1.27 |

### *2.2 Boundary Conditions and Computational Methods*

The nozzle geometries will be meshed where the mesh setting will be set according to the diameter of the nozzle. The element size was set to 0.0005m under body sizing. The inlet of the nozzle was determined and the wall of the nozzle was defined. The domain below the nozzle was selected as outlet. Figure 2 below shows the meshed nozzle geometry and the outlet domain for (a) 0.76mm, (b) 1.02mm and (c) 1.27mm. Boundary condition setting, inlet will be defined as velocity inlet and the parameter of velocity inlet will be set as 1m/s (constant) and the pressure was varied 200MPa, 300MPa and 400MPa. The temperature value is given as 300K.



(a) (b) (c)

**Fig. 2.** Meshed nozzle geometry and domain for (a) 0.76mm, (b) 1.02mm and (c) 1.27mm

The gravitational acceleration was activated in the Y direction for the simulation. In the model setting, firstly energy equations have been activated. Then the k-omega model has been selected from the viscous settings and, as a wall function, SST models. Hybrid initialization is applied, and 100 iterations are defined, solved and converged for each simulation. Each model is converged. Water is used as material and its properties are default.

Iteration is all about repeating the mathematical of computational applied to the solution to get closer approximation to the exact solution. Residual graph was generated for each parameter at an iteration of 100 to test the applied equation generates best solution for the situation applied to the analysis of the nozzle as shown in Figure 3. Thus, by increasing the iteration value the approximation value to the exact solution will be closer. As shown in Figure 3, the main focus of this analysis is at the point of y-velocity direction and energy level, which has an approximation of $3 \times 10^{-3}$ differences from the exact solution and this value was same for all parameters.

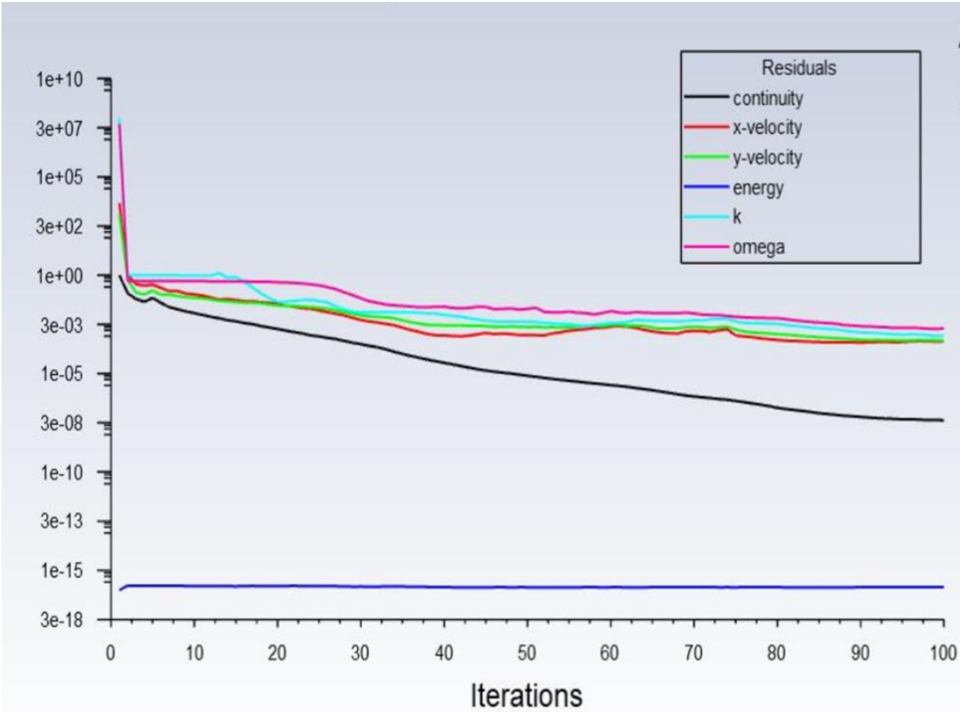


**Fig. 3.** Residual graph for 100 iteration

## 3. Results

The results obtained from the CFD solution were recorded and plotted to compare the cumulative pressure loss along the outlet domain, velocity along the outlet domain and the distance of water jets out at the outlet domain.

### *3.1 Velocity and Cummulative Pressure Loss for Different Nozzle Diameter*

Figure 4(a) shows the graph plotted for velocity of water along the outlet domain for the 0.76mm nozzle diameter. Velocity for 400MPa along the outlet domain is the highest 9.82m/s compared to velocity for 200MPa (8.97m/s) and 300MPa (9.01m/s), as velocity of water for both the pressure are approximately equal with a difference of 0.04m/s. From the graph, we can infer that the decrease pattern of velocity for all the pressure is identical as water jets out further away from the nozzle outlet, the velocity decreases. Figure4(b) shows the graph plotted for cumulative pressure loss in water along the outlet domain for the 0.76mm nozzle diameter. Cumulative pressure loss for the water pressure at 400MPa was recorded as the highest with a total pressure loss of 2.1MPa along the outlet domain. Meanwhile, cumulative pressure loss for water pressure at 200MPa is 1.75MPa and 300MPa is 1.76MPa. The minimum pressure loss for all the three parameters was at the outlet of the nozzle.

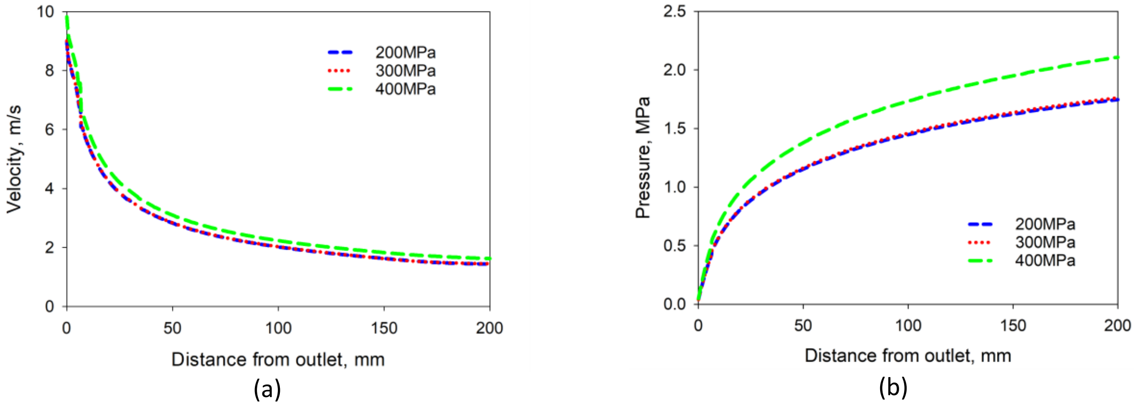



**Fig. 4.** Graph for 0.76mm nozzle (a) Velocity vs Distance from outlet and (b) Cumulative pressure loss vs Distance from outlet

Figure 5 shows 0.76mm nozzle velocity contour at the outlet domain for (a) 200MPa, (b) 300MPa and (c) 400MPa respectively. From the figures, we can observe the flow of the distribution of velocity contour for 400MPa is sharper compared to 200MPa and 300MPa. Therefore, for this case, by considering the highest velocity and the characteristic of the velocity contour distribution, 400MPa pressure data will be used for further comparison.

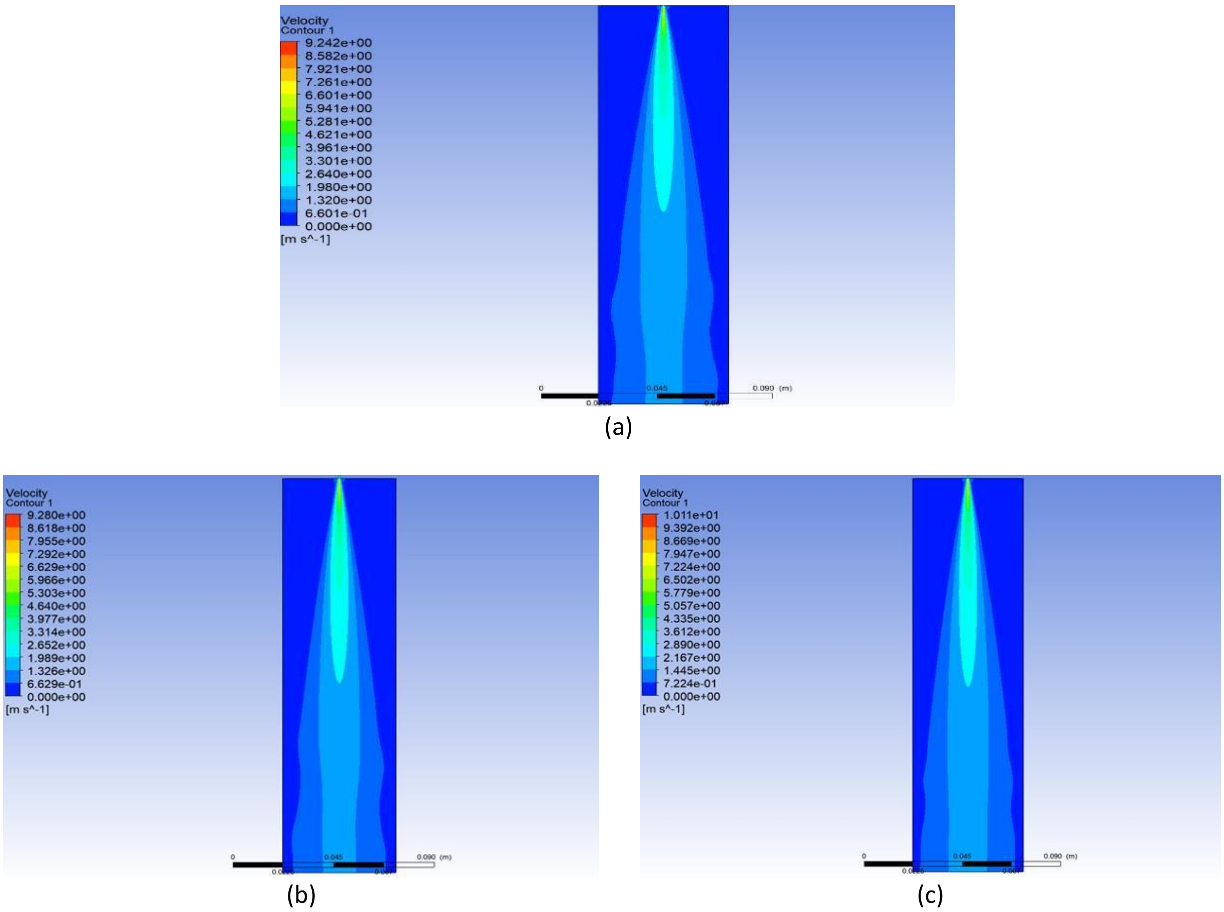
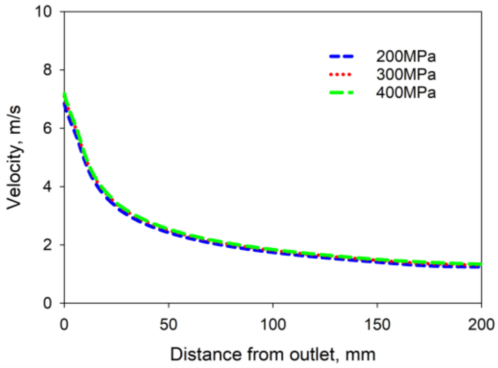
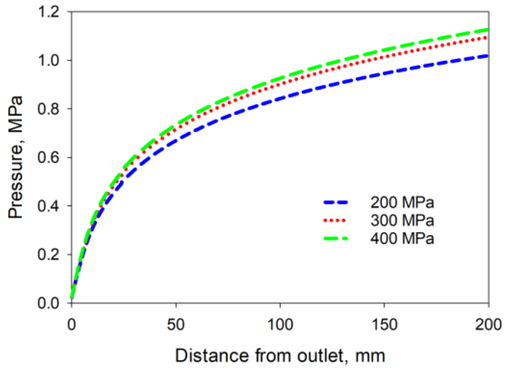



**Fig. 5.** 0.76mm nozzle velocity contour for (a) 200MPa, (b) 300MPa and (c) 400MPa

Figure 6(a) shows the graph plotted for velocity of water along the outlet domain for 1.02mm nozzle diameter. The difference between 200MPa, 300MPa and 400MPa velocity for the 1.02mm nozzle is significantly small. As for the highest velocity recorded was 7.19m/s when the pressure is 400MPa at the inlet of the nozzle with initial velocity of 1m/s where else 200MPa produces the lowest velocity of water at the outlet which is 6.85m/s. From Figure 6(b) the cumulative pressure loss for the water pressure at 200MPa is 1.02MPa which is lower compared to 300MPa with a cumulative pressure loss of 1.1MPa. Meanwhile, cumulative pressure loss for water pressure at 400MPa is 1.13MPa which is the highest.




(a)




(b)

**Fig. 6.** Graph for 1.02mm nozzle (a) Velocity vs Distance from outlet and (b) Cumulative pressure loss vs Distance from outlet

Figure 7 shows velocity contour at the outlet domain for (a) 200MPa, (b) 300MPa and (c) 400MPa respectively. From the figures, we can perceive that the velocity for the three pressures is same because of the small difference between the velocity value. However, we can observe the smooth distribution of velocity contour for 400MPa compared to 200MPa and 300MPa. This smooth distribution of velocity will be able to cut the fruit evenly. Thus, for the further comparison 1.02mm with 400MPa pressure will be selected as well as it records the highest velocity for this case.

Figure 8(a) shows the graph plotted for velocity of water along the outlet domain for 1.27mm nozzle diameter. The difference between 200MPa and 300MPa is 0.02m/s as 200MPa recorded 5.48m/s. Meanwhile the highest velocity recorded was 5.55m/s at the outlet of the nozzle when the pressure is 400MPa. Thus, from the result we can summarize that the difference in velocity for different pressure is outstandingly small for the 1.27mm nozzle. From Figure 8(b) the cumulative pressure loss for the water pressure at 200MPa and 300MPa are 0.55MPa and 0.553MPa. Meanwhile, cumulative pressure loss for water pressure at 400MPA is 0.56MPa which is the highest.

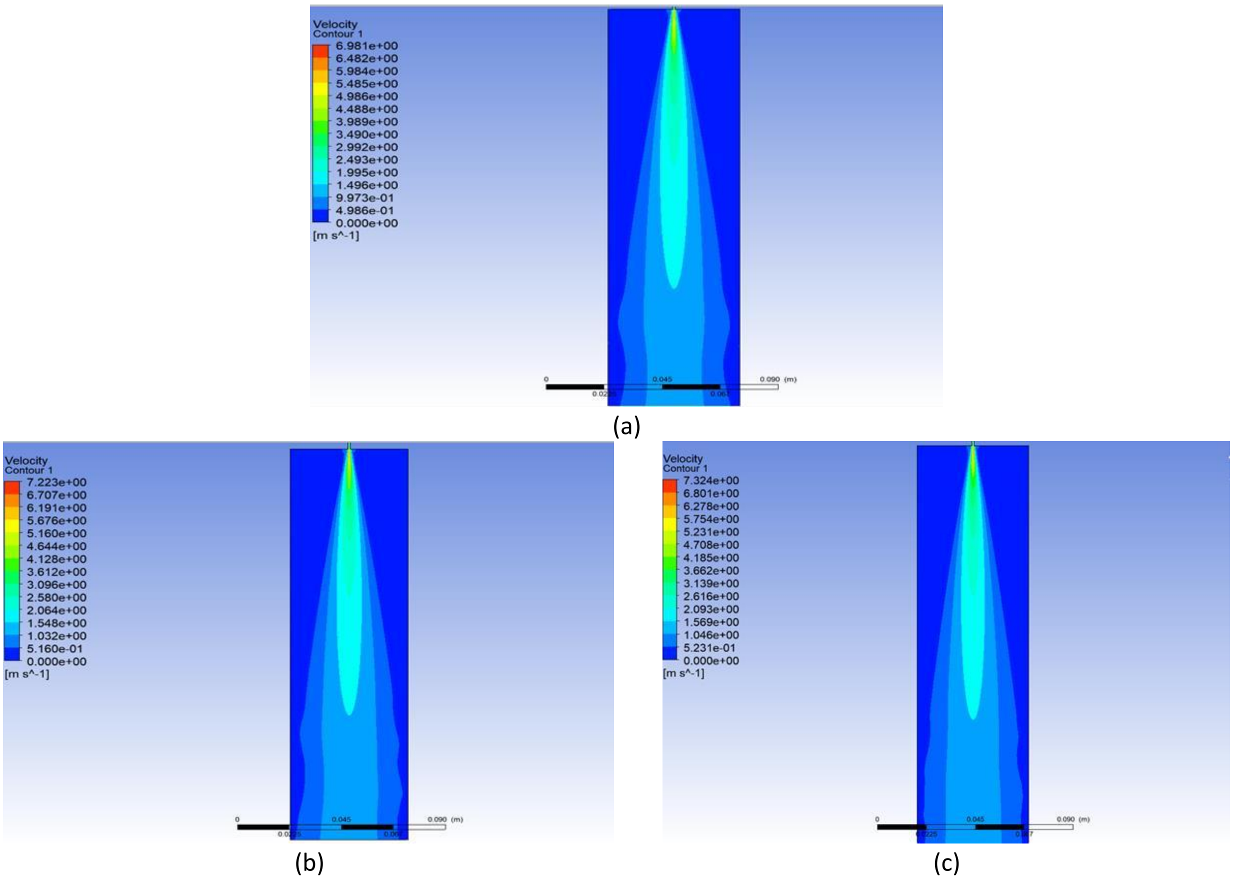



**Fig. 7.** 1.02mm nozzle velocity contour for (a) 200MPa, (b) 300MPa and (c) 400MPa

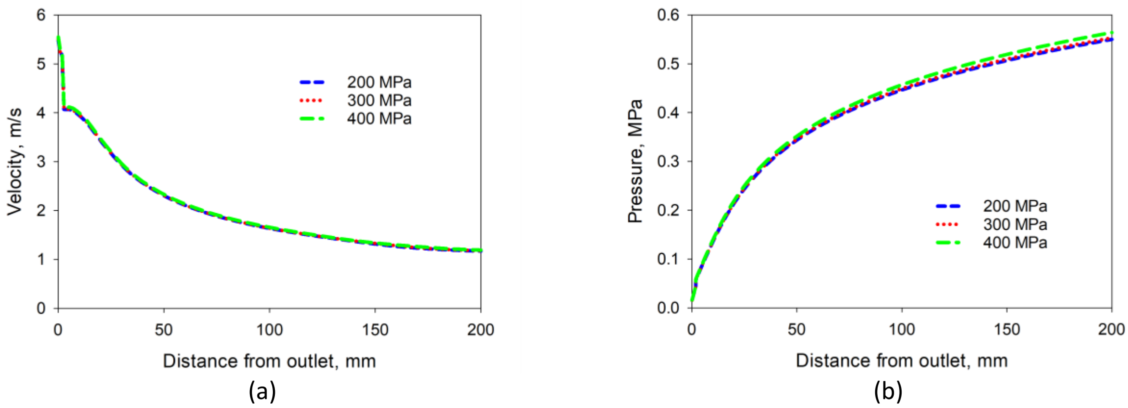



**Fig. 8.** Graph for 1.27mm nozzle (a) Velocity vs Distance from outlet and (b) Cumulative pressure loss vs Distance from outlet

Figure 9 shows contour of water velocity at the outlet domain for (a) 200MPa, (b) 300MPa and (c) 400MPa respectively. From the figures, we can observe the flow distribution of velocity contour for the three pressures are identical to each other. Therefore, for this case, by considering the highest velocity, 400MPa pressure will be used for further comparison.

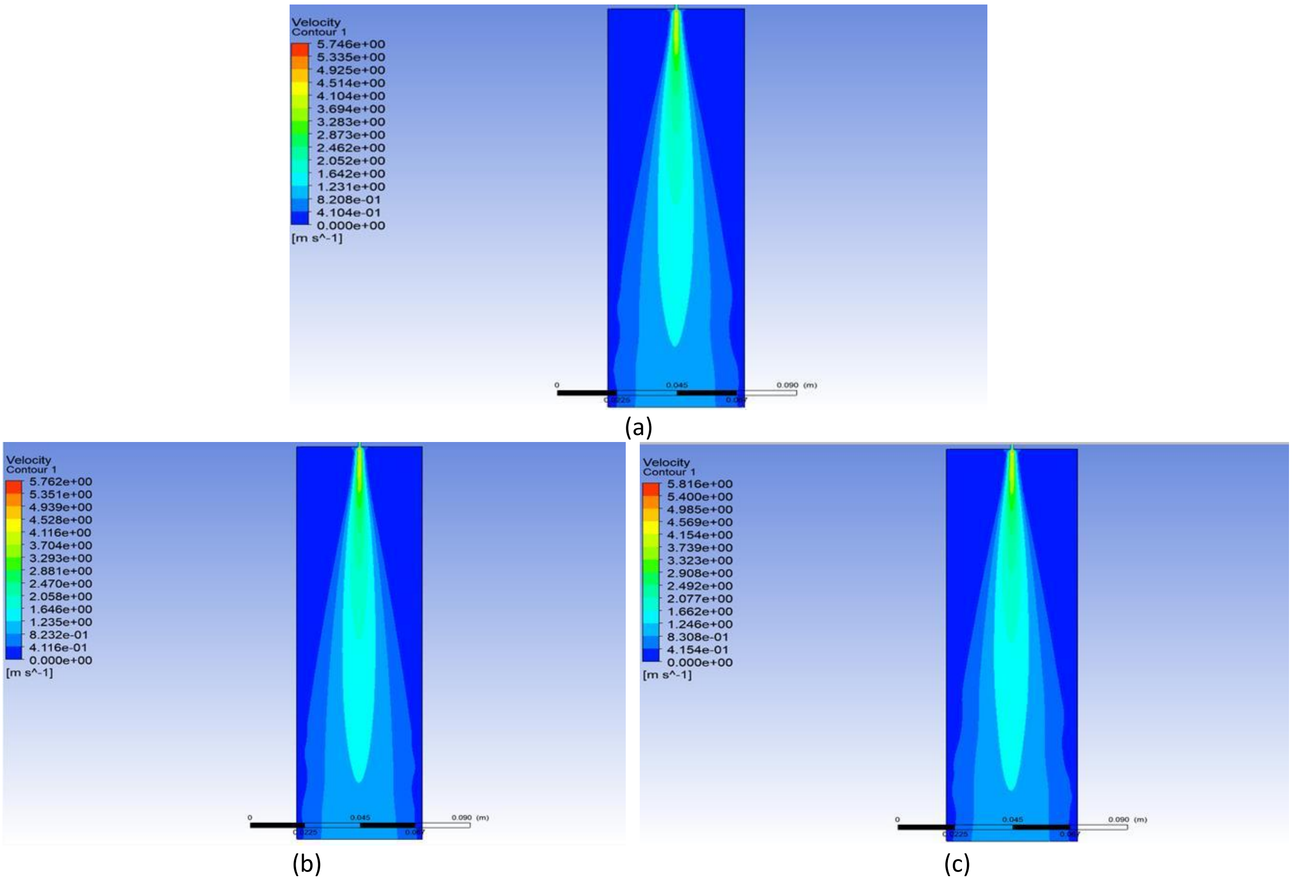



**Fig. 9.** 1.27mm nozzle velocity contour for (a) 200MPa, (b) 300MPa and (c) 400MPa

### *3.2 Correlation for Each Nozzle Diameter*

From the graph in Figure 10 below, we can state that the nozzle diameter 0.76mm shows the highest velocity at each standoff distance and the total calculated percentage decrease in the velocity from 1mm to 9mm stand-off distance for the nozzle is 32.63%. Moreover, for nozzle diameter 1.02mm the velocity decreases linearly as the stand-off distance increases and the calculated total percentage decrease in velocity is 23.19%.

Based on the Pearson's correlation coefficient formula, the correlation coefficient for each nozzle diameter is obtained. The correlation coefficient for the nozzle diameter of 0.76 mm and 1.02 mm is -0.98867 and -0.99688 respectively. This implies that stand-off distance and velocity for both the nozzle diameter of 0.76mm and 1.02mm has a very strong negative relationship in terms of correlation coefficient as both the value is near to -1. As can be observed, velocity decreases gradually as the stand-off distance increases which can be seen in Figure 10. The correlation coefficient for the nozzle diameter of 1.27mm is -0.74890 where this shows that stand-off distance and velocity for the nozzle diameter of 1.27mm has a negative relationship in terms of coefficient correlation but not as strong as compared to the correlation coefficient for nozzle diameter of 0.76mm and 1.02mm.

Furthermore, 1.27mm nozzle records the lowest velocity at all the stand-off distance and the total percentage decrease in velocity is 23.38%. Furthermore, three linear regression equations for each nozzle were obtained from the graph where Eq. (1), Eq. (2) and Eq. (3) are for 0.76mm, 1.02mm and 1.27mm nozzle diameter respectively.

$$y = -0.7827x + 10.016 \quad (1)$$

$$y = -0.4007x + 7.3154 \quad (2)$$
$$y = -0.2558x + 5.0951 \quad (3)$$

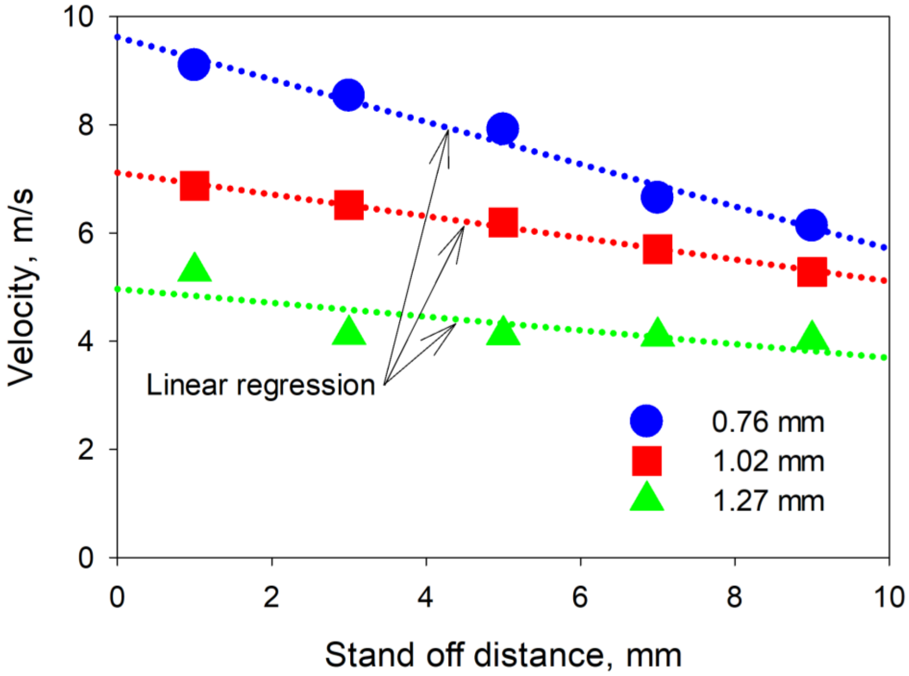
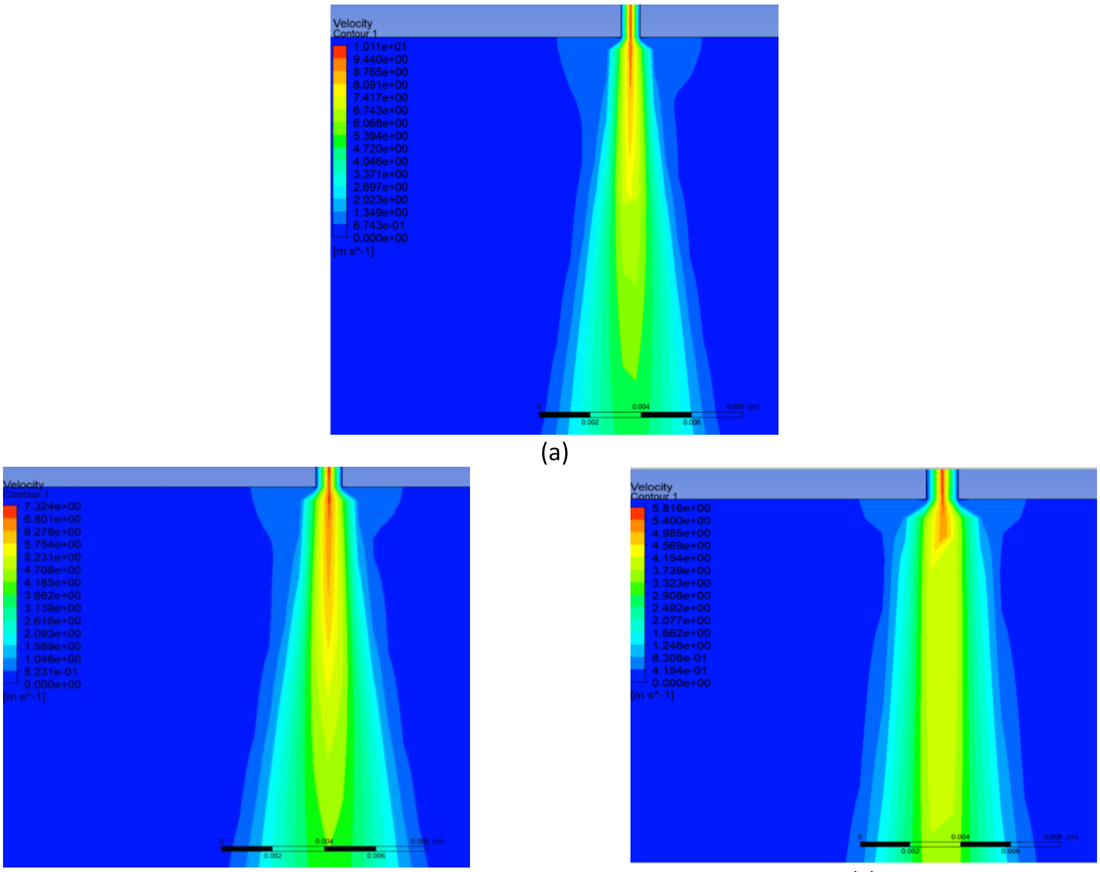



**Fig. 10.** Comparison graph for velocity vs stand off distance for 0.76mm, 1.02mm and 1.27mm nozzle diameter (400MPa)

Figure 11(a) shows the enlarged region of velocity contour of 0.76mm nozzle. From the contour we can clearly see the dispersion of water near the outlet is less but the angle of impact (red-yellow) becomes wider as it flows further away from the nozzle outlet. Therefore, pressure loss at the outlet is higher which results in producing highest outlet velocity compared to the other nozzle diameter. This proves the theory; pressure is inversely proportional to velocity. Meanwhile, the angle of contact becomes wider as it gets further away from the nozzle outlet. Thus, the apple can be placed in a range of 1 mm to 3mm (obtained from the contour using probe tool) if this nozzle is to be employed.

Figure 11(b) shows the enlarged region of velocity contour of 1.02mm nozzle. From the contour we can clearly see the dispersion of water near the outlet is less and the angle of impact increases gradually as we can observe in Figure 11(a) which results in sharp and fine flow of the jet although it is further away from the nozzle outlet. In contrast, of the 0.76mm nozzle impact angle, the impact angle of 1.02mm nozzle diameter maintain the flow sharpness although the angle of impact gets wider as further away from the nozzle outlet. The increase in angle of impact for 1.02mm nozzle is smooth enough to be for the fruit peeling and cutting process, by using the probe tool the stand-off distance can be varied from 1mm to 9mm.

Figure 11(c) shows the enlarged region of velocity contour of 1.27mm nozzle. From the contour we can clearly see the dispersion of water near the outlet is larger compared to 0.76mm and 1.02mm nozzle. Meanwhile, the angle of impact becomes wider as the water jets out of the nozzle as we can observe in Figure 11(c). The 1.27mm diameter nozzle produces a wider cone angle and impact angle than the other diameter nozzle. Therefore, the apple should be placed near to the outlet with a stand-off distance of 1mm if this nozzle is to be utilized. This will be efficient for only cutting the apple (as the nozzle exit diameter increases the pressure at outlet will be higher) (the pressure loss will be small resulting in producing low outlet velocity) but will not be applicable for peeling the thin layer of apple's skin before cutting because increase in nozzle diameter is linearly proportional to cutting depth. Therefore, by using the probe tool the effective stand-off distance that can be applied for this nozzle is approximately 1mm.



(a)

(b) (c)

**Fig. 11.** 1.27mm nozzle velocity contour for (a) 200MPa, (b) 300MPa and (c) 400MPa

## 4. Conclusions

This study is important for identifying the effective nozzle diameter that can be utilized for the fruit peeling and cutting process. In addition, for peeling the fruit skin, the jet velocity should be high meanwhile for cutting the fruit, the depth of cut should be deep enough to cut the fruit thoroughly meanwhile when the pressure of water and velocity of the motor that rotating the fruit is constant throughout the peeling and cutting process, the stand-off distance should be varied. From the analysis and discussion, 1.02mm nozzle with an inlet pressure of 400MPa will the most effective and efficient nozzle diameter and pressure for peeling and cutting an apple compared to the other nozzle diameter.

Alternatively, a 1.02mm diameter nozzle provides a high and consistent outflow angle. This criterion is important for producing a perfect and nice cutting quality. Whereas 0.76mm nozzle and 1.27mm nozzle is undesirable due to their short coverage distance. From the analysis that was conducted the velocity of 1.02mm nozzle seems to be effective to peel and cut the apple. As for peeling process, the nozzle stand-off distance can be set at 9mm and for the cutting process the stand-off distance can be reduced for an even and precise cutting.

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## References
[1] Liu, Xiaochu, Zhongwei Liang, Guilin Wen, and Xuefeng Yuan. "Waterjet machining and research developments: A review." *The International Journal of Advanced Manufacturing Technology* 102 (2019): 1257-1335.https://doi.org/10.1007/s00170-018-3094-3

[2] Fairfield, C. A. "Spatial, temporal, and thermal analysis of a cavitating high-pressure water-jet." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 18, no. 1 (2016): 1-19.

[3] McGeough, J. A. "Cutting of Food Products by Ice-particles in a Water-jet." *Procedia Cirp* 42 (2016): 863-865. https://doi.org/10.1016/j.procir.2016.03.009

[4] Bańkowski, Damian, Piotr Młynarczyk, and Irena M. Hlaváčová. "Temperature Measurement during Abrasive Water Jet Machining (AWJM)." *Materials* 15, no. 20 (2022): 7082.https://doi.org/10.3390/ma15207082

[5] A. Dixit, V. Dave, and M. R. Baid, "Water jet machining: An advance manufacturing process," *Int. J. Eng. Res. Gen. Sci.*, vol. 3, no. 2 (2015), pp. 288–292.

[6] Carreño-Olejua, René, Werner C. Hofacker, and Oliver Hensel. "High-pressure water-jet technology as a method of improving the quality of post-harvest processing." *Food and bioprocess technology* 3 (2010): 853-860.https://doi.org/10.1007/s11947-010-0428-z

[7] Tapia, M. R., M. M. Gutierrez-Pacheco, F. J. Vazquez-Armenta, G. A. González Aguilar, J. F. Ayala Zavala, Mohammad Shafiur Rahman, and Mohammed Wasim Siddiqui. "Washing, peeling and cutting of fresh-cut fruits and vegetables." *Minimally Processed Foods: Technologies for Safety, Quality, and Convenience* (2015): 57-78. https://doi.org/10.1007/978-3-319-10677-9_4

[8] Ismail, A. H., and M. H. Marhaban. "A simple approach to determine the best threshold value for automatic image thresholding." In *2009 IEEE international conference on signal and image processing applications*, pp. 162-166. IEEE, 2009.https://doi.org/10.1109/ICSIPA.2009.5478623

[9] Tan, Sean Huey, Chee Kiang Lam, Kamarulzaman Kamarudin, Abdul Halim Ismail, Norasmadi Abdul Rahim, Muhamad Safwan Muhamad Azmi, Wan Mohd Nooriman Wan Yahya *et al.*, "Vision-Based Edge Detection System for Fruit Recognition." In *Journal of Physics: Conference Series*, vol. 2107, no. 1, p. 012066. IOP Publishing, 2021.https://doi.org/10.1088/1742-6596/2107/1/012066

[10] Ali, Nasr Abdalmanan Nasr, Kamarulzaman Kamarudin, Chee Kiang Lam, Muhamad Safwan Muhamad Azmi, Abdul Halim Ismail, Norasmadi Abdul Rahim, Wan Mohd Nooriman Wan Yahya *et al.,* "3D Reconstruction of Fruit Shape based on Vision and Edge Sections." *Journal of Electronic & Information Systems* 4, no. 1 (2022): 26-32.https://doi.org/10.30564/jeisr.v4i1.4585

[11] Hreha, Pavol, Sergej Hloch, Dagmar Magurová, Jan Valicek, Drazan Kozak, Marta Harnicarova, and Marko Rakin. "Water jet technology used in medicine." *Tehnicki vjesnik* 17, no. 2 (2010): 237-240.. http://TechnoRep.tmf.bg.ac.rs/handle/123456789/1538

[12] Cui, Dandan, Hongwen Li, Jin He, Qingjie Wang, Caiyun Lu, Hongnan Hu, Xiupei Cheng, and Chunlei Wang. "Applications of water jet cutting technology in agricultural engineering: A review." *Applied Sciences* 12, no. 18 (2022): 8988.https://doi.org/10.3390/app12188988

[13] Alitavoli, M., and J. A. McGeough. "An expert process planning system for meat cutting by high pressure water-jet." *Journal of Materials Processing Technology* 84, no. 1-3 (1998): 130-135. https://doi.org/10.1016/S0924-0136(98)00087-9

[14] Ahmad Latiff, Nur Atikah, Radin Maya Saphira Radin Mohamed, Vicky Airama Shanmugan, Najeeha Mohd Apandi, Ramlah Mohd Tajuddin, and Amir Hashim Mohd Kassim. 2020. "Characteristics of Water Quality from Meat Processing Wastewater". Journal of Advanced Research in Applied Sciences and Engineering Technology 17 (1):78-84.

[15] G. S. Yadav and B. K. Singh, "Study on Water Jet Machining and Its Future Trends," *Int. J. Recent Res. Asp.*, vol. 3, no. 2 (2016), pp. 50–54.

[16] Ismail, Zurita, Saleha Maarof, Mohamed Faris Laham, Kai Xin Siah, Muhamamd Rezal Kamel Ariffin, and Nizam Tamchek. "CFD Simulation Using ANSYS FLUENT of Jet Nozzle of Ethanol at Temperature of 360 K." *Journal of*

*Advanced Research in Fluid Mechanics and Thermal Sciences* 96, no. 1 (2022): 168-178.https://doi.org/10.37934/arfmts.96.1.168178

[17] Valco, T. D., C. G. Coble, and J. H. Ruff. "Water jet cutting of sugarcane." *Transactions of the ASAE* 32, no. 2 (1989): 373-0378.https://doi.org/10.13031/2013.31012

[18] Perotti, Francesco, Massimiliano Annoni, Aldo Calcante, Michele Monno, Valerio Mussi, and Roberto Oberti. "Experimental study of abrasive waterjet cutting for managing residues in no-tillage techniques." *Agriculture* 11, no. 5 (2021): 392.https://doi.org/10.3390/agriculture11050392

[19] Atmaca, Mustafa, Berkay Çetin, Cüneyt Ezgi, and Ergin Kosa. "CFD analysis of jet flows ejected from different nozzles." *International Journal of Low-Carbon Technologies* 16, no. 3 (2021): 940-945.https://doi.org/10.1093/ijlct/ctab022