A Container Volume Flow Rate and Heat Transfer Analysis for Portable Gummy Cooking Apparatus

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Abstract: *Integrating technology in Technical and Vocational Education and Training (TVET) is crucial for bridging the gap between educational curricula and industry demands. However, in Malaysia, TVET institutions face significant challenges due to the limited availability of equipment, particularly in specialized fields such as gummy-making courses. The reliance on obsolete tools, such as mixing equipment and heater systems, hampers the learning experience. Additionally, the high costs associated with advanced equipment and their maintenance further exacerbate these challenges. This paper addresses these issues by proposing a low-cost portable gummy cooking apparatus simulation study. The apparatus focuses on optimizing container volume flow rate and heat transfer analysis to ensure efficient and consistent gummy production. Hence, the findings revealed that a fully cylindrical geometry with a flat bottom, offers the most uniform thermal distribution and heat retention, making it ideal for consistent temperature applications, though its high velocity may cause turbulence. Next, Aluminum 3003 H14 is optimal for heat transfer, while stainless steel excels in durability and structural integrity for extreme conditions. By leveraging simulation study in SolidWorks, the design findings aim to develop a cost-effective, scalable, and industry-relevant solution for TVET institutions and Small and Medium Enterprises (SMEs) food industries in future.*

Keywords: Gummy Making; Portable Cooking Apparatus; Thermal Distribution; Flowrate Analysis

1. INTRODUCTION

In Malaysia, Technical and Vocational Education and Training (TVET) is evolving to meet industry demands, specifically supporting Small and Medium Enterprises (SMEs) by fostering stronger industry collaborations for hands-on training. Food preparation, bakery and culinary arts are examples of TVET programs, that offer courses in cooking techniques, food safety, kitchen management, and specialized skills like pastry, baking, and gummy making. The program also covers food presentation, customer service, and business management to ensure graduates are career-ready with extensive practical training.

However, the availability and quality of technology and equipment are significant challenges in Malaysia's TVET landscape. Many TVET institutions still rely on older or obsolete equipment that does not match the technology used in the international food industries today. Moreover, higher equipment costs may result in increased maintenance expenses. On top of that, food industries in Malaysia, especially SMEs, are facing several problems such as practicing traditional technology [1] and a shortage of skilled human capital [2][3]. On the other hand, Dandago, M. A., & Igwe, E. C. (2012) also highlighted that the food processing and confectionery industries in Kano have been significantly influenced by foreign contributions, particularly from Arab merchants, Lebanese entrepreneurs, and more recently, Chinese and Indian investors often importing advanced machinery [4]. Let us explore the gummy-based confectionary industries, gummy and jelly products have evolved from traditional sweets into a popular category of functional foods, offering health benefits beyond basic nutrition and targeting specific wellness goals [5,6,8]. Combining nutrition and indulgence, gummies and jellies are now key players in both the functional food and confectionery markets, appealing to a broad range of consumers. As a result, TVET courses in gummy making have become increasingly essential to equip students with practical skills and industry knowledge. The gummy manufacturing process undergoes several stages of preparation to produce a good quality of gummy candy.

Figure 1 shows the basic process of making gummy candies. It begins with gathering the raw materials for the gummy ingredients' formula, such as gelatin, sweeteners, flavorings, and colorings, which are thoroughly mixed to create a homogeneous solution. The mixture is then heated and cooked at a temperature between 70°C and 75°C to dissolve the gelatin and combine the ingredients [6]. The mixture or hot molten liquid called slurry before fills to mold cavities [7]. Once fully dissolved, the solution is poured into the molds that determine the shape of the gummies. After filling, the gummies are cooled at room temperature for about 30 minutes and then refrigerated for up to 24 hours to ensure they set properly. Finally, the hardened gummies are removed from the molds, completing the production process. Each step requires precision and consistency to achieve uniform texture, taste, and appearance. In small-scale production, where batch sizes are limited, the design of the cooking apparatus plays a crucial role in achieving these objectives. Optimizing cooking apparatuses, particularly in terms of thermal distribution and flow dynamics is essential for maintaining product quality and energy efficiency. The geometry of the cooking container, heat transfer and the thermal properties of the material are key factors influencing the efficiency and uniformity of the cooking process of gummy in the confectionary industries.

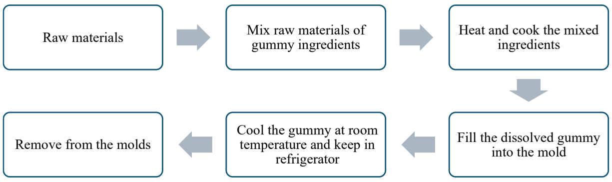


Fig. 1. Flow diagram of the gummy preparation [6].

Hence, the production of gummy candies has evolved significantly over the years, transitioning from manual processes to highly automated systems. The state-of-the-art gummy cooking apparatus integrates advanced technologies to enhance precision, efficiency, and consistency in gummy production. In Malaysia, the gummy manufacturing industry still largely relies on imported automated machines, particularly from the Netherlands, China, and the United States, due to their advanced technology, precision, and compliance with international standards. While local manufacturers are making strides in producing smaller-scale and semi-automated machines, the lack of technical expertise and high research and development (R&D) costs hinder the development of advanced, industrial-grade equipment.

For example, China, represented by companies like Saintytec and Sino Fude Group, is a major player in the industry, providing cost-effective, highly automated, and customizable gummy making machines as shown in Figure 2. These manufacturers focus on small to medium-scale production, offering end-to-end solutions that comply with international standards. Their machines are popular in Asia, Africa, and South America due to their affordability and versatility in producing gelatin, pectin, and starch-based gummies.

Fig. 2. A commercial gummy making machine. (Retrieved from: https://sinofudegroup.com/gummy-making-machine/open-type-cooking-kettles/)

In the United States, manufacturers like Baker Perkins and Heat and Control focus on large-scale, energy-efficient production lines with integrated quality control systems, targeting high-capacity confectionery producers. Tanis Confectionery located in the Netherlands, specializes in designing and manufacturing advanced gummy making machines. It offers versatile, customizable, and automated solutions for high-quality gummy production. With a focus on innovation, hygiene, and efficiency, Tanis provides reliable machinery and comprehensive support for confectionery producers worldwide.

On the other hand, Kanokwan Promjeen et al. (2023) designed and evaluated the performance of a semi-automatic gummy jelly dropping machine. The authors focused on optimizing the dropping process, which is crucial in ensuring the consistency and quality of the final product [9]. The semi-automatic system they developed incorporated precise control over the flow of gummy mixture, allowing for more accurate and consistent dropping of the jelly into molds. Their machine significantly reduced human error and labor costs, while also improving the overall efficiency of the production process.

In addition, Smith (2020) focused on the development of a innovative molding technique designed to produce a unique gummy confectionery product [10]. His study introduced an innovative approach to mold design, which significantly improved the texture and appearance of gummies by allowing more precise control over the cooling and solidification processes. This technique reduced the risk of defects, such as air bubbles and uneven shaping, ensuring higher quality products. Smith's work further emphasized the need for innovation in mold design to meet the growing demands of the functional food market, particularly in terms of consistency and visual appeal.

While for simulation study, most researchers applied computational fluid dynamic (CFD) software to improve the quality and safety of food products in the food industry [11]. Previously, CFD has been used in cleaning of food-contact surfaces study [12], drying process [13] and shell egg pasteurization analysis [14]. Besides that, MacKenzie, D.S. and Zhang, X. (2024) examines the effectiveness of an agitation apparatus in determining heat transfer coefficients under various flow and surface temperature conditions [15]. The research focuses on the CFD model of the Qingpu agitation device and determines the uniformity of the flow upwards through the inlet tube and compares measured values from an impeller-type flowmeter to those calculated by CFD. This is not suitable to be applied for semi-automatic gummy machines which deal with different properties of materials.

Based on our knowledge, the thermal properties of container materials are also critical for gummy making machine, especially in applications requiring precise temperature control. Materials like stainless steel and aluminium are commonly used due to their durability and heat transfer capabilities. A study by Alabi, O. A., and Adeoluwa, Y. M. (2020), compared various materials and concluded that high thermal conductivity materials, such as copper, ensure more consistent temperature distribution but may be cost-prohibitive [16]. Conversely, stainless steel, though less conductive, provides a practical balance of affordability and performance.

In short, these studies collectively highlight the existence of commercial gummy making machines and emphasize the importance of computational fluid dynamic study and material selection in designing efficient and cost-effective cooking apparatus. For portable gummy cooking devices, stainless steel emerges as a practical choice, offering a balance between thermal performance, durability, and affordability. This is particularly relevant for TVET institutions facing budget constraints.

In other words, this study aims to explore the impact of container geometry and material selection on volume flow rate, heat transfer and thermal distribution in small-scale gummy cooking apparatuses using CFD analysis. By focusing on these parameters, the research seeks to provide actionable insights for improving the design and efficiency of gummy production systems, catering to the needs of artisanal producers, TVET learning process and small businesses.

2. METHODS

Figure 3 outlines a systematic methodology for designing and conducting a simulation study on a container for small-scale gummy cooking apparatus, emphasizing precision and efficiency. The process begins by creating multiple container designs using AutoCAD software.

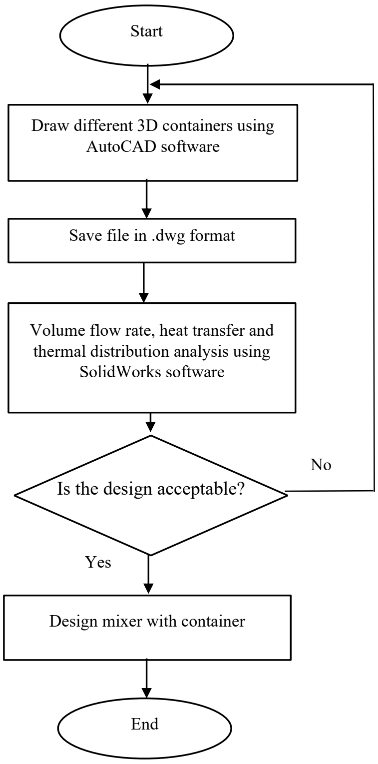


Fig. 3. Flow of project work.

This step allows the visualization of various 3D shapes and configurations tailored to the specific needs of gummy cooking, such as proper heat distribution and ease of flow. Once the designs are finalized, they are saved in the standard .dwg format, to ensure compatibility with simulation tools and fabrication systems. Afterwards, the saved designs undergo a volume flow rate, heat transfer and thermal distribution analysis using Solidworks software to evaluate their performance. The flowrate analysis ensures smooth and consistent movement of the gummy mixture, while the thermal distribution analysis assesses heat transfer uniformity, preventing hotspots and ensuring thorough cooking.

Following the analysis, a decision is made on whether the design meets the required criteria. If the design is not acceptable, the process loops back for modifications and further optimization. Once a design passes the evaluation, the final stage design in centimeter units involves integrating a mixer into the container design as shown in Figure 4. This integration ensures the gummy mixture remains homogeneous during cooking, maintaining consistency in both flow rate and temperature. Designing a container with a mixer for a gummy cooking machine is essential to ensure uniformity, efficiency, and quality in the gummy production process.

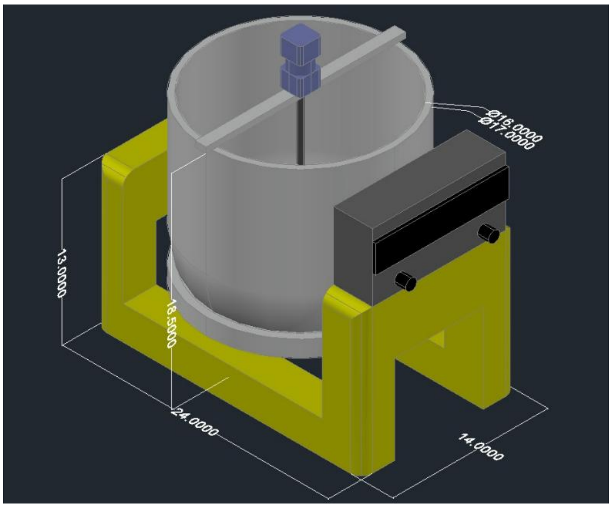


Fig. 4. Container with Mixer Design.

Gummy mixtures typically consist of gelatin, sugar, flavoring, and coloring agents, which must be evenly blended and heated to achieve the desired consistency and texture. Without proper mixing, the ingredients may not combine uniformly, leading to inconsistencies in the final product, such as uneven texture, air bubbles, or improper setting. The inclusion of a mixer in the container design ensures that the mixture is continuously stirring during the heating and pouring processes, maintaining homogeneity and preventing issues like ingredient separation or localized overheating.

Moreover, incorporating a mixer into the container design enhances the overall efficiency of the gummy cooking process. It ensures that the heat is evenly distributed throughout the mixture, which is crucial for achieving the precise temperature needed for gelatin activation and sugar caramelization. This not only reduces cooking time and energy consumption but also improves product quality. Additionally, a well-designed mixing container minimizes manual labor and errors, making the production process more scalable for small-scale or semi-automated operations. Overall, the mixer-equipped container plays a pivotal role in achieving consistent and high-quality gummy products while optimizing the cooking process.

Thus, this methodology ensures a balance between design innovation and practical application, resulting in a container that meets the operational demands of gummy cooking. By following this structured approach, the study provides a scientific and efficient method for optimizing container performance while minimizing waste in both the design and production stages.

3. RESULTS AND DISCUSSION

Solidworks software is one of the powerful computational fluid dynamics (CFD) tools that enables the simulation of fluid flow, heat transfer, and related processes by solving governing differential equations. These equations, such as the Navier-Stokes equations, continuity equation, and energy equation, are essential for modeling the conservation of mass, momentum, and energy within fluid systems [17]. Table 1 presents the volume flow rate analysis at a temperature of 75°C. It is crucial to evaluate the performance of six container designs for a small-scale gummy cooking apparatus. The results depict the flow behavior of the gummy mixture within each container under a set volume flow rate of 150 ml/min or 2.5×10^{-6} m³/s.

Specifically, the results focus on the maximum velocity of the fluid in each design, providing insights into how well the container's geometry facilitates the flow. This parameter is essential for determining whether the container can deliver a smooth, consistent flow of the gummy mixture during cooking and pouring, ensuring product quality and operational efficiency. Note that the volume flow rate is a measure of the volume of fluid that passes through a given cross-sectional area per unit of time in fluid flow analysis. The equation for volume flow rate, Q is depicted in Equation (1) as follows [18]:

$$Q = A.\upsilon \qquad (1)$$

where A is cross-sectional area of the flow and υ is the average velocity of the fluid. The losses of head for flowing liquids can occur due to friction, inlet and outlet irregular surface of the pipe [19].

Table 1. Volume Flow Rate Analysis at 75°C

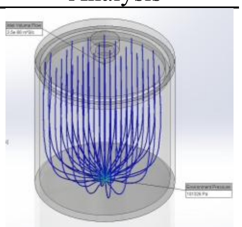
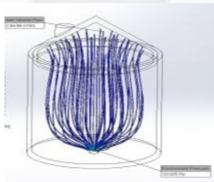
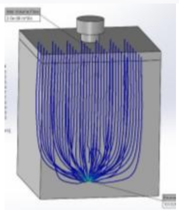
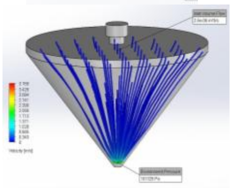
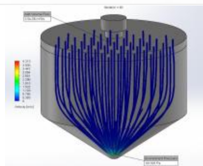
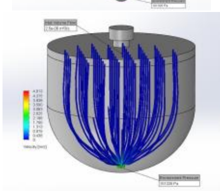
Geometry	Maximum Velocity (m/s)	Volume Flow Rate Analysis
Design 1	3.917	
Design 2	3.820	
Design 3	4.394	
Design 4	3.769	
Design 5	4.213	
Design 6	4.813	

Table 1 illustrates each design demonstrates unique flow characteristics. Design 1, with a maximum velocity of 3.917 m/s, shows moderate flow efficiency, balancing speed and stability. Design 2 achieves a slightly lower maximum velocity of 3.820 m/s, which might indicate more controlled and uniform flow behavior. On the other hand, design 3 exhibits a relatively higher maximum velocity of 4.394 m/s, potentially resulting in turbulence or uneven mixing within the container. Design 4 stands out with the most stable flow performance, showing the lowest maximum velocity of 3.769 m/s, suggesting a well-optimized geometry that minimizes turbulence and ensures consistent flow. Design 5 reaches a higher velocity of 4.213 m/s, indicating faster flow but with the possibility of increased resistance in specific areas. Finally, design 6, with the highest maximum velocity of 4.813 m/s, may face challenges such as localized pressure drops or excessive turbulence, which could negatively impact mixing and flow stability.

From the analysis, it is evident that achieving the right balance between flow velocity and stability is crucial for the gummy cooking container apparatus. Excessively high velocities, as seen in Designs 3, 5, and 6, could lead to operational issues such as turbulence, uneven heat distribution, or structural stress on the container. Conversely, lower velocities, like those in Designs 1, 2, and 4, suggest smoother flow behavior, which is ideal for maintaining homogeneity in the gummy mixture. Among these, Design 4 offers the best combination of flow stability and velocity, making it the most promising candidate for practical implementation. However, further experimental testing under real conditions is necessary to validate these findings and ensure that the chosen design meets all operational requirements for the gummy cooking process.

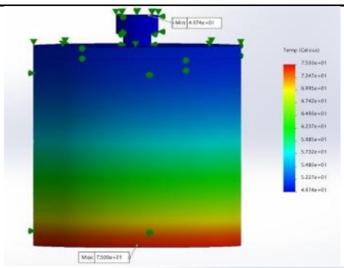
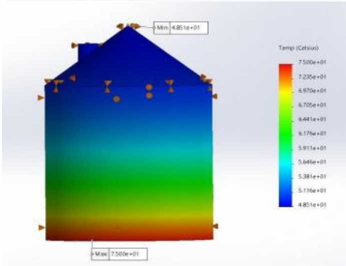
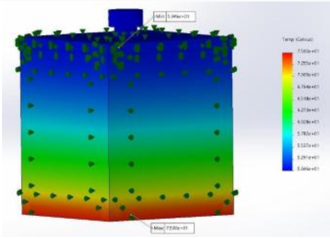
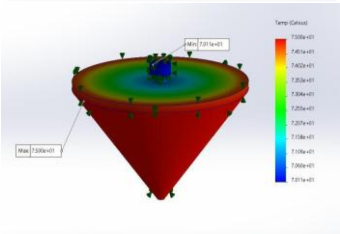
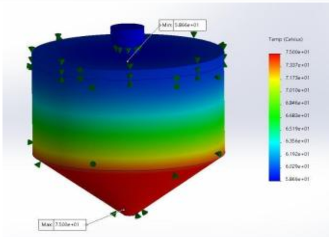
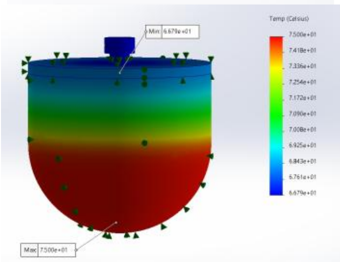
Next, the thermal distribution analysis of chrome stainless steel at 75°C across different container geometries reveals significant variations in heat transfer efficiency as illustrated in Table 2. In this part, heat transfer analysis through the heat convection was observed to evaluate the heat transfer between a solid surface of container and a moving fluid, which is described by Equation (2):

$$q = h(T_s - T_f) \qquad (2)$$

where q is heat flux, h is convective heat transfer coefficient, T_s is surface temperature and T_f is fluid temperature.

From Table 2, Design 1 depicts a range from 49.74°C to 75°C and Design 2 produces a range from 48.51°C to 75°C, which exhibit the widest temperature ranges, indicating less uniform heat distribution and lower thermal efficiency. The temperature range of Design 3 is between 50.46°C and 75°C, which shows slightly improved uniformity but still has a broad temperature range. In contrast, Design 4 yields a temperature range from 70.11°C to 75°C, achieves the smallest temperature range of 4.89°C, indicating the most uniform and efficient heat distribution among all designs. Design 5 yields a temperature range between 58.66°C and 75°C, which provides moderate thermal uniformity but falls short compared to Design 4.

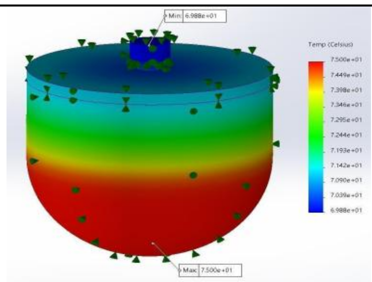
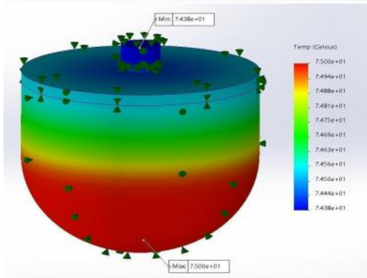
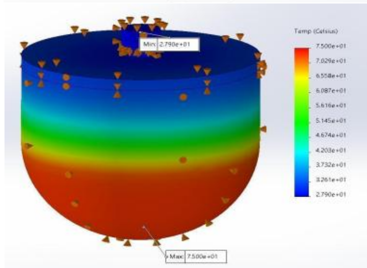
Table 2. Thermal Distribution Analysis at 75℃ for Different Container Chrome Stainless Steel

Geometry	Thermal Analysis
Design 1	
Design 2	
Design 3	
Design 4	
Design 5	
Design 6	

Based on this analysis, Design 4 emerges as the optimal geometry for achieving efficient thermal distribution and maintaining a consistent surface temperature, making it suitable for applications prioritizing energy efficiency and uniform heat retention. From Table 2, it shows the thermal distribution analysis at 75°C for chrome stainless steel containers shows that Design 4's inverted conical shape has steep thermal gradients, with the highest temperature of 75°C at the bottom and minimum temperature is 70.1°C near the top edges. Design 5 illustrated cylindrical body with a conical bottom exhibit improved heat distribution, with a minimum temperature of 68.5°C at the top. Design 6 with fully cylindrical and flat bottom achieves the most uniform thermal distribution, with a minimum temperature of 66.7°C at the top and better heat retention due to its flat-bottom geometry. Among the three analyzed designs, Design 4 with inverted conical shape achieves the most uniform heat distribution, while Design 6 with fully cylindrical and flat bottom demonstrates the best heat retention.

Lastly, the thermal distribution analysis in Table 3 provides a comparison of heat transfer characteristics for three materials; such as (1) stainless steel, (2) aluminium 3003 H14, and (3) polyethylene terephthalate (PET), under a fixed cylindrical geometry. Stainless steel shows a moderate temperature range from 69.88°C to 75°C, indicating slower heat transfer due to its lower thermal conductivity but a relatively uniform temperature profile. Aluminium 3003 H14 has a minimal temperature range between 74.38°C and 75°C, reflecting its excellent thermal conductivity and near-uniform heat distribution. PET, with a wide temperature range from 27.9°C to 75°C, highlights its poor thermal conductivity, causing significant temperature variations and inefficient heat transfer.

Table 3. Heat Transfer Analysis of Different Materials with Fixed Cylindrical Geometry

Material	Heat Transfer Analysis
Stainless Steel	
Aluminium 3003 H14	
Polyethylene Terephthalate (PET)	

In terms of material durability, stainless steel stands out for its excellent resistance to thermal and mechanical stress, making it ideal for high-temperature applications. Aluminium offers superior heat transfer but is less durable than stainless steel under extreme conditions like corrosion or wear. PET, being a plastic material, has limited durability in high-temperature environments, as it

is prone to deformation or melting. Overall, aluminium is best suited for applications demanding efficient heat transfer, stainless steel strikes a balance between durability and moderate thermal efficiency, while PET is more appropriate for lightweight, low temperature uses.
Based on the analysis, aluminium 3003 H14 is the optimum design choice for applications requiring efficient and uniform heat transfer, as it maintains the highest and most consistent surface temperature. However, for applications needing durability in extreme conditions or structural integrity, stainless steel is a better option due to its excellent thermal and mechanical resilience. PET, while lightweight and suitable for low-temperature uses, is not ideal for heat-intensive applications due to its poor thermal performance and limited durability.

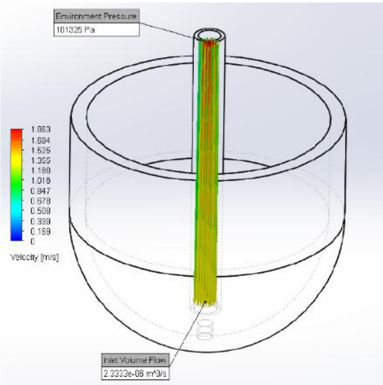


Fig. 5. Volume Flow Rate Analysis of Gummy Slurry with Specific Diameter Tube

The next analysis will be focused on the velocity of hot fluid or specifically gummy slurry from lowest level in container to mold cavities through stainless steel tube. On the other hand, increasing the air velocity will increases the mass flowrate indirectly [20]. Figure 5 shown one of simulation process done with predetermined volume flow rate and specific diameter. This process will evaluate each specification to determine the best flow rate will be practised by the motor pump in the system to fill the gummy slurry to mold cavities in practical period. Based on Table 4, there are 3 different sizes of tube diameter analysed with 3 different flow rates. The volume flow rate of gummy slurry implemented in this simulation based on the capability range can be done by the motor pump.

Table 4. The Comparison Result of Maximum Velocity (m/s) for Each Predetermined System

Volume Flow Rate, Q	Tube Diameter		
	5 mm	4 mm	2 mm
80 ml/min	0.147	0.259	1.153
100 ml/min	0.177	0.309	1.396
140 ml/min	0.233	0.405	1.863

Commercial manufacturers operating at an industrial scale typically select large trays with a high number of cavities to maximize production efficiency. In contrast, home-based gummy makers generally prefer smaller-sized molds that are easier to handle and better suited for small-batch production. In line with the objective of this project to bridge TVET with SME players or home-based gummy makers, the common smaller-sized molds with volume of 4ml per cavity [7] will be considered. The comparison presented in Table 4 was conducted to determine a practical volumetric flow rate for use with the motor-driven pump. Although the system configured at a flow rate of 140 ml/min with a tube diameter of 2 mm recorded the highest dispensing velocity, this setting is deemed less practical due to the small mold cavity size, which may lead to excessive gummy slurry being pumped. Therefore, a more appropriate volumetric flow rate is identified at 80 ml/min with a 2 mm diameter tube. In addition to achieving an optimal dispensing velocity, this setting allows the motor sufficient delay time to pump the gummy slurry effectively with the practical tube length per period (1.153 meter/second) as calculated below.

$$80\ ml/\min = 1.333\ ml/s$$

while 1 mold cavity = 4 ml, so

$$4\ ml \div 1.333\ ml/s = \mathbf{3\ second}$$

4. CONCLUSION

In conclusion, a comprehensive analysis of container volume flow rate, thermal distribution, and heat transfer characteristics for a small-scale portable gummy cooking apparatus has been conducted. The findings highlight the critical interplay between flow dynamics, thermal management, and heat transfer efficiency in ensuring consistent and optimal gummy production. Key observations include the importance of uniform thermal distribution within the cooking container to prevent localized overheating or underheating, which can adversely affect product quality. Additionally, the flowrate of the gummy mixture was found to significantly influence heat transfer rates, with optimal flow conditions identified to maximize energy efficiency and minimize cooking time.
The results highlight the necessity of integrating robust thermal insulation and precise flow control mechanisms in the design of portable gummy cooking devices. Furthermore, the study provides valuable insights into the scalability of such systems, suggesting that similar principles can be applied to larger-scale production units. Future work should focus on experimentally validating the proposed models and exploring advanced materials that optimize thermal conductivity and energy efficiency. Overall, this research contributes to the optimization of portable cooking apparatuses, paving the way for improved performance and broader applicability in the SME food industry and TVET learning process.

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