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Design of a Portable Water Purification Flask Using a Mini Diaphragm Pump System

Jonathan Chong Kar Yew[1], Sia Chee Kiong[1]*

[1] *Faculty of Mechanical and Manufacturing Engineering*
Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, 86400, MALAYSIA

*Corresponding Author: sia@uthm.edu.my
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Abstract

Access to safe drinking water remains a global challenge, particularly for outdoor enthusiasts and individuals in remote areas. This study aims to design a compact, lightweight, and user-friendly portable water purification flask that integrates a manual diaphragm pump, dual-stage filtration, and UV-C disinfection. The project adopted a structured engineering design methodology, incorporating ergonomic analysis and material selection, and utilized SolidWorks for conceptual and embodiment design. The final product measures 267.3 mm in height, with a 75 mm base diameter and an empty weight of 455 g, making it suitable for outdoor use. Performance analysis revealed that the mini manual diaphragm pump operates at 25 strokes per minute, delivering 10 mL per stroke, resulting in a nominal flow rate of 250 mL/min. After accounting for filtration resistance, the effective flow rate is 175 mL/min, enabling the purification of 500 mL of water in approximately 3 minutes. Drop test results indicated a maximum von Mises stress of 10.5 MPa and a maximum displacement of 25.4 mm, both within safe limits for HDPE material. These findings confirm the design's practicality, durability, and efficiency, providing a promising solution for reliable water purification during outdoor activities.

1. Introduction

Access to clean drinking water remains a global challenge for remote, disaster-prone, and underserved communities. Approximately 2.2 billion people worldwide currently lack access to safely managed drinking water. [1], particularly in conditions, and in outdoor functions such as hiking and camping, where safe sources of water are rare and the existing portable purifiers are either heavy or require a continuous power supply. The aim of this project is to design a compact and lightweight portable water purification flask that combines filtration and UV disinfection systems, providing an efficient, practical, and self-sustaining solution for outdoor enthusiasts and emergency use. The significance of this study lies in its potential to improve access to safe drinking water during extended outdoor activities or emergencies, helping to prevent dehydration and enhance overall safety.

The aim of this study is to design a portable water purification flask by first conducting a thorough review of existing products and technologies, then developing an innovative, compact, and lightweight concept. The project involves analyzing recent patents and literature to understand current advancements, followed by brainstorming and creating detailed technical drawings and 3D models in SolidWorks, with a focus on optimizing efficiency, portability, and sustainability in the final design.

The design of the portable water purification flask prioritizes efficiency, portability, durability, safety, and user convenience. To be effective for outdoor and emergency use, the flask should be compact and lightweight for easy transport, use robust and food-grade materials for safety and longevity, and be simple to operate and maintain in the field. Ergonomic considerations, such as a comfortable grip and manageable weight, further enhance usability for extended use. These criteria were central to the design of the portable water purification flask, ensuring the device meets the needs of outdoor enthusiasts in practical situations.

A multi-stage filtration approach is commonly adopted in high-performance portable purifiers, combining several layers to target different types of contaminants. [2] Typically, the first stage employs a sediment filter to remove large particles, such as sand and dirt, followed by an activated carbon filter to remove chemical pollutants and odors. For microbial safety, a UV-C disinfection unit is often incorporated as the final stage to destroy bacteria, viruses, and pathogens. [3] This combination enhances water quality and ensures comprehensive purification, as implemented in the present design.

The choice of pump is crucial in portable purifiers, as it affects both energy efficiency and practicality. Manual pumps, such as piston or diaphragm pumps, are favored for their independence from external power sources, making them ideal for remote or off-grid environments. Diaphragm pumps offer advantages including self-priming capability, low maintenance, and reliable operation even with particulate-laden water. [4]

2. Methodology

The engineering design process presented by George E. Dieter was carefully adopted in this project to present a structured, effective and creative method in designing the portable water purification flask. This is an iterative framework that balances functionality and constraints that include cost, safety, and sustainability and encourages innovations and ethical solutions due to broad problem analysis and risk management. [5] Fig. 1 illustrates the project flow chart in designing the portable water purification flask.

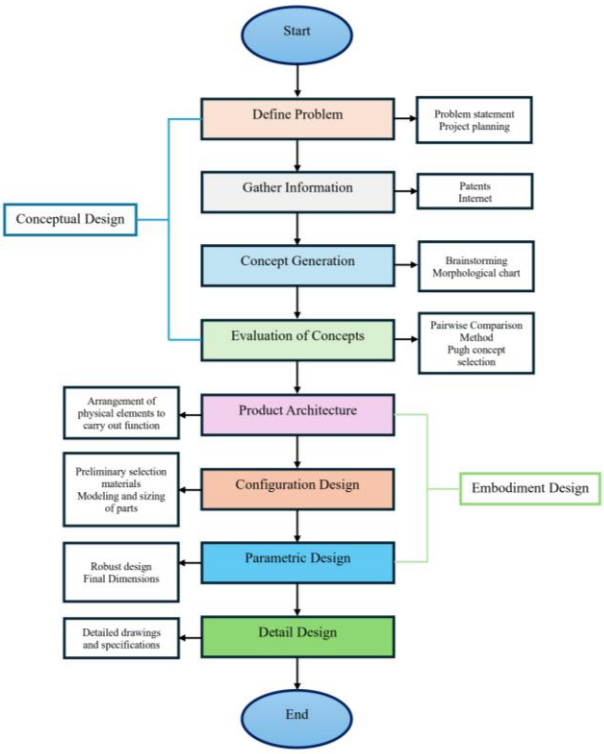

Fig. 1 *Project Flow Chart [5]*

2.1 Portable Water Purification Flask Design Flowchart

Fig. 2 shows an overview of the design process of the portable water purification flask. Once the parameters are identified and some basic research completed, the comparative data is identified, compiled, and checked. Appropriate material is then chosen, and a detailed design is created.

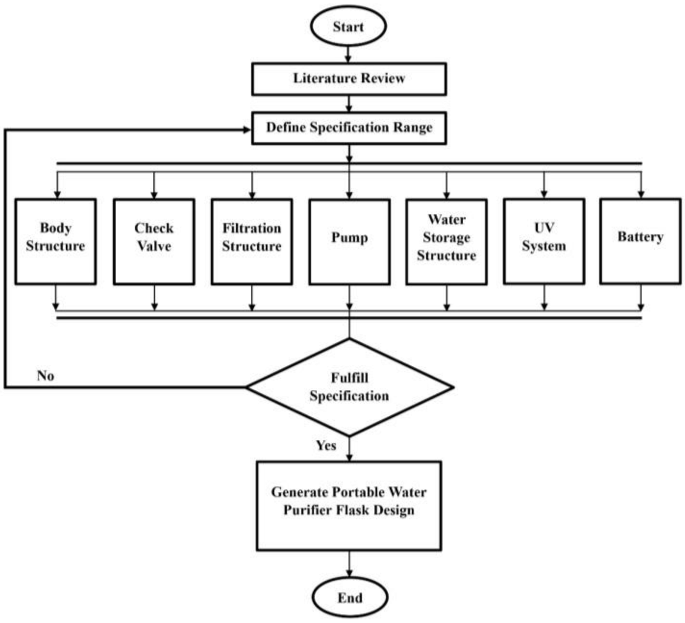

Fig. 2 *Portable water purification flask Design Flowchart*

3. Results and Discussion

3.1 Concept Generation

Product architecture determines physical structure and combinations of components that provide product functions, and bundle products into modules according to the structure of functions. Figure 3 illustrates the product architecture of the portable water purification flask.

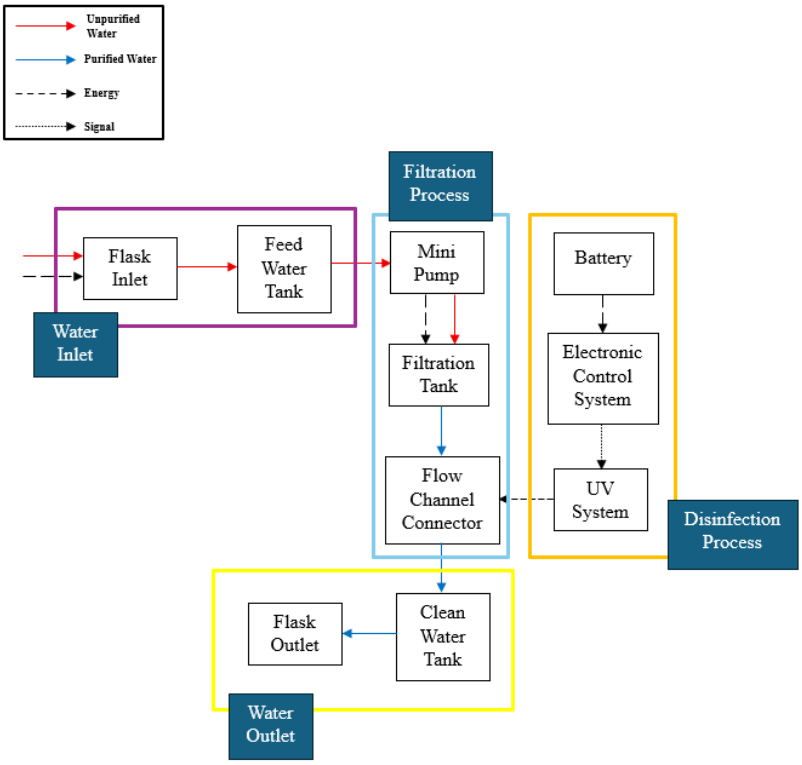

Fig. 2 *Schematic Diagram Showing Components Clustered into Modules for Portable Water Purification Flask*

3.2 Product Design of Portable Water Purification Flask

3.2.1 Ergonomic and Anthropometric Study in Product Design

The size and dimensions of the portable water purification flask were based on anthropometric hand data to ensure ergonomic comfort and ease of use [6]. Table 1 shows the design specifications of a portable water purification flask based on the consideration of an anthropometric study.

Table 1 *Design Specifications of Portable Water Purification Flask*

Specification	Parameter
Flask Width	Approx. 7.5 cm – 9.5 cm
Flask Height	Approx. 25 cm – 28 cm
Flask Weight	Approx. 450 g – 500 g

3.2.2 Component Design and Material Selection

Size, dimensions, and materials for each component of the portable water purification flask are detailed in Table 2.

Table 2 *Size / Dimension and Material of Each Component Used*

Component	Size / Dimension	Material
Inlet and Outlet Caps	3.5 cm – 5 cm (Diameter)	HDPE
Feed Water Tank	500 mL – 750 mL (Capacity)	HDPE
Clean Water Tank	350 mL – 500 mL (Capacity)	HDPE
Filtration Structure		
Sediment Filter (Outer Layer)	3 mm (Thickness)	Combination of Polypropylene (PP) And Pleated Fabric
Activated Carbon Filter (Inner Layer)	7 mm (Thickness)	Coconut Shell Activated Carbon
Hollow Core (Centre)	10 mm (Diameter)	
Mini Manual Diaphragm Pump	Length: 55 mm – 60 mm Diameter: 24 mm – 26 mm Height: 35 mm – 40 mm	Pump Body: PVC Diaphragm: EPDM 60 Durometer
UV System	Length: 30 mm – 35 mm Width: 10 mm – 12 mm Height: 10 mm – 12 mm	UV Lamp Sleeve: Fused Quartz Glass UV System Housing: ABS
Battery	Diameter: 14.5 mm Length: 50.5 mm	Lithium-ion
Check Valve	Inner Diameter: 6 mm Length: 15 mm – 20 mm	Delrin® 2700 NC010
Elbow Connector	Inner Diameter: 6 mm	Delrin® 2700 NC010

3.3 Product Tree Diagram

A product tree diagram is a visual representation of the hierarchy of a product's main parts and sub-parts. The visual layout shows the main assemblies, sub-assemblies, and individual parts of the product in a tree-like way. The diagram makes it easier to study the product's structure, lead the design process, and control the Bill of Materials (BOM). The product tree diagram for the Portable Water Purification Flask, Utilizing a Mini Diaphragm Pump System, is included in Appendix A.

3.4 Performance Testing

3.4.1 Pump Performance Estimation

3.4.1.1 Flow Rate

To calculate the flow rate, the mini manual diaphragm pump's speed is estimated at 25 strokes per minute, with each stroke delivering about 10 milliliters. This allows the flow rate of water to be determined as shown in Eq. 1.

Flow Rate = Pumping speed of mini manual diaphragm pump x stroke volume (1)

= 25 stroke / minute x 10 milliliters / stroke

= 250 milliliters/minute

A 5-micron sediment filter removes sand, rust, and dirt, typically causing a 5–10% flow reduction as it clogs. Activated carbon filters further increase resistance, potentially reducing flow by 15–25%. Considering these factors, the effective flow rate is estimated at 70%. This is supported by studies showing that diaphragm pumps achieve volumetric efficiencies of 70.6%–98.3% [7].

Effective Flow Rate = 250 milliliters / minute x 0.7 = 175 milliliters / minute (2)

4.4.1.2 Time Taken to Purify the Water

With a feed water tank capacity of 500 milliliters and an effective flow rate of 175 milliliters per minute, the purification time for a full tank is calculated below.

$$\textbf{Time} = \frac{\text{Total Volume of Water to Be Purified}}{\text{Effective Flow Rate}} = \frac{\text{500 milliliters}}{\text{175 milliliters/minute}} = 2.857 \text{ minutes} = 172\text{s}$$

In summary, a mini manual diaphragm pump operates at 25 strokes per minute, and with a 10-milliliter stroke volume, it will filter roughly 250 milliliters of water per minute. Under proper conditions, approximately 2 minutes is needed to purify a feed tank that holds 500 milliliters. Yet, as the flow rate decreases during filtration, especially due to the combined effects of the sediment and activated carbon filters, resulting in filtration resistance and pressure drop, an extra minute is allowed for slower filtration. Consequently, the total time required to purify 500 milliliters of water using this manual system is approximately 3 minutes.

3.4.2 Drop Test

The results of the drop test analysis of the portable water purification flask allow making important conclusions about the integrity of the structure and its ability to withstand impact loads. The selected material for the outer body of the flask is high-density polyethylene (HDPE). Three criteria were considered, which are von Mises stress, displacement, and strain, as shown in Fig. 4, Fig. 5, and Fig. 6.

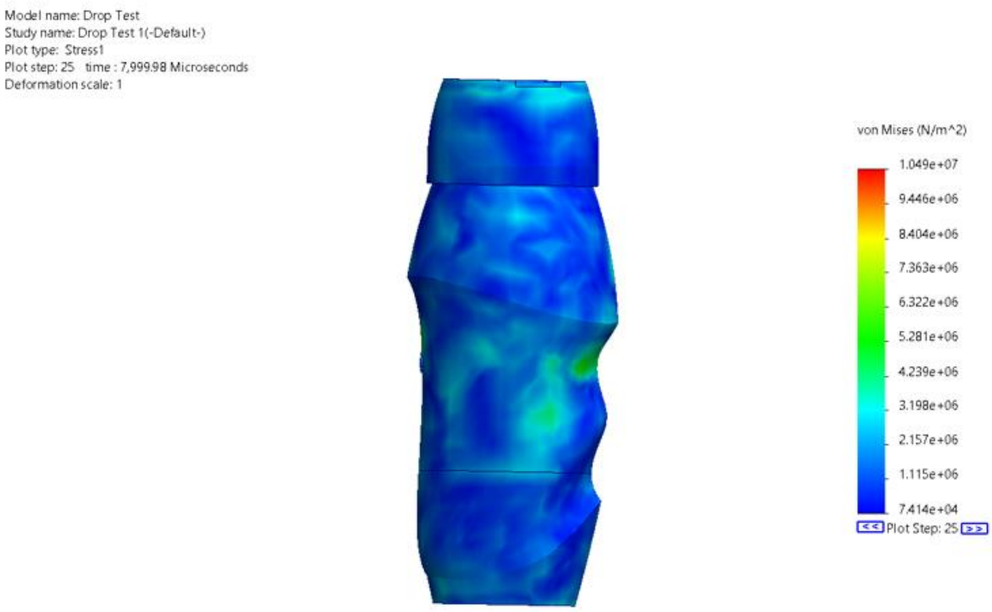

Fig.4 *Von Mises Stress Analysis*

The von Mises Stress analysis in Fig. 4 indicates that the maximum von Mises stress in the flask is 10.5 MPa, which is well below the HDPE yield strength of 22–26 MPa. Most areas experience low stress, with higher stress only at corners. This indicates the flask is unlikely to deform or crack from a single drop.

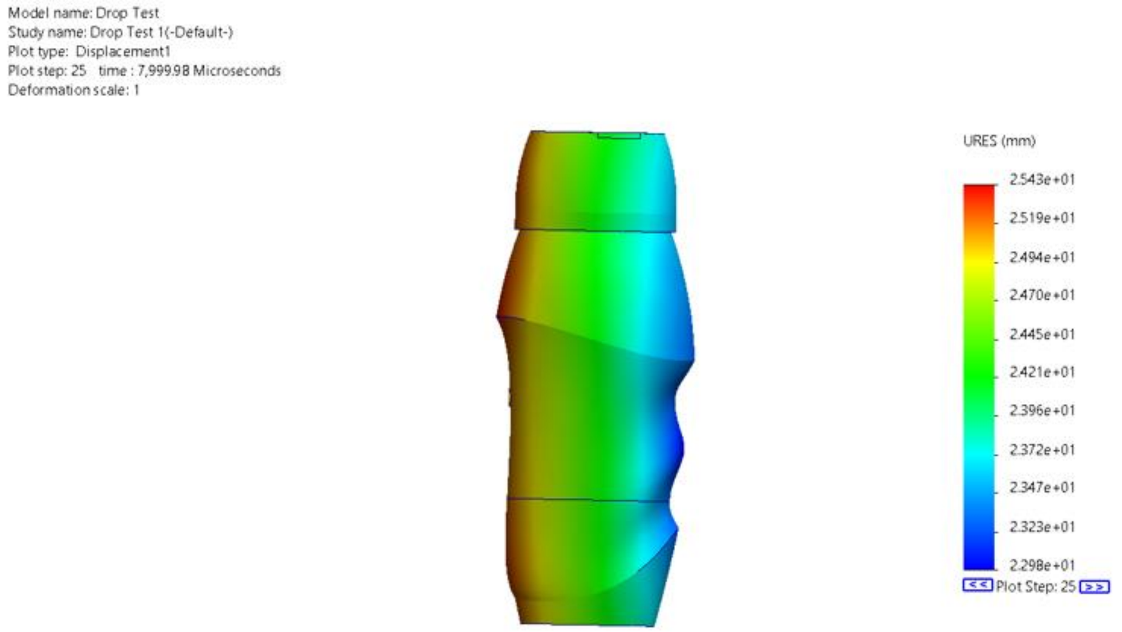

Fig.5 *Displacement Analysis*

Displacement analysis in Fig. 5 shows a maximum displacement of 25.4 mm at the flask's top and bottom during impact. This flexibility is typical of HDPE, which absorbs impact energy. However, it is important to ensure that internal components can withstand this movement without damage or misalignment.

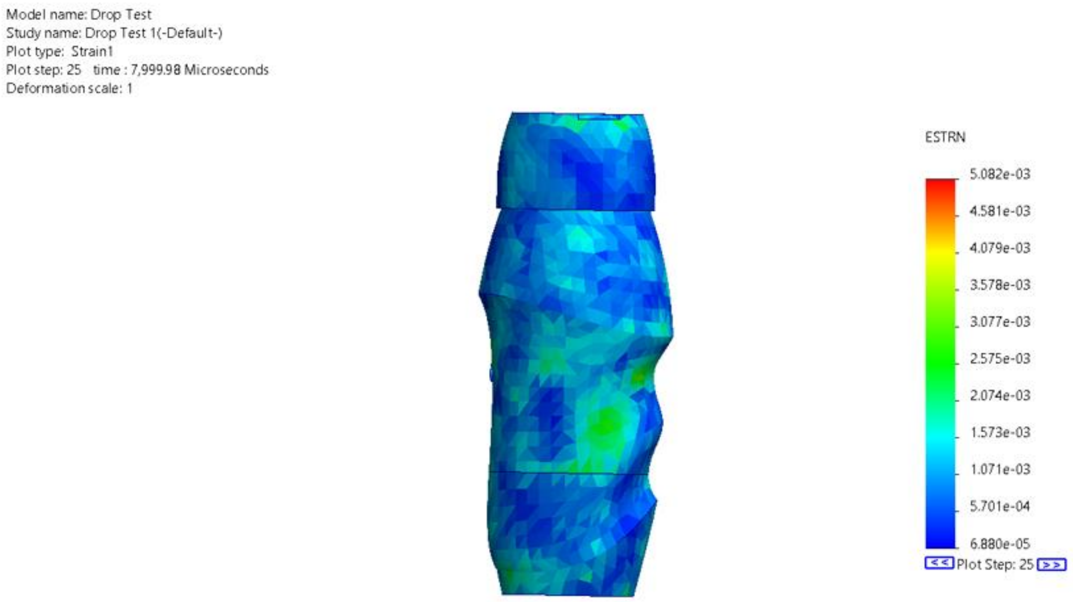

Fig.6 *Strain Analysis*

The strain analysis in Fig. 6 shows a maximum principal strain of 0.51%, far below HDPE's yield strain and elongation at break. This confirms the flask remains within its elastic range and will return to its original shape after impact, without risk of cracking or permanent deformation.

Based on the drop test, it can be concluded that the HDPE flask body is strong and can be used easily in typical applications where it may be accidentally dropped. The stress, displacement, as well as the strain values are well below the safe limit of HDPE, hence assuring both durability and resilience. Although the design in its current form is structurally adequate, some minor optimizations can be made, such as reducing stress concentration points and bracing zones that may experience greater deformation, to increase the service life of the flask and enhance its reliability. This drop test shows that the product is suitable for use, and with appropriate improvements, its lifespan may be extended further.

3.5 Final Product Design Specifications

The final product design specifications for the Portable Water Purification Flask, utilizing a mini diaphragm pump, are detailed and summarized in Table 3.

Table 3 *Final Product Design Specifications*

Specification	Details
Height	267.3 mm
Base Diameter	75 mm
Hand Grip Diameter	91 mm
Weight (Empty)	455 g
Body Material	Food-grade BPA-free HDPE
Feed Water Tank Capacity	500 ml
Clean Water Tank Capacity	500 ml
Filtration Structure	Sediment Filter (Outer Layer) Activated Carbon Filter (Inner Layer)
UV Disinfection System	Low-Power UV-C LEDs (200 – 280 nm wavelength) Powered by AA Lithium-ion Batteries
Check Valve	Ball Check Valve
Pump	Mini Manual Diaphragm Pump
Pump Performance Estimation	
Pumping Rate	25 Strokes Per Minute
Volume Per Stroke	10 ml
Effective Flow Rate	175 ml / minute
Time Taken Purification For 500 ml	172 seconds

4. Conclusion and Recommendations

4.1 Conclusion

This study presents a conceptual design for a compact and portable water purification flask intended for outdoor and remote-use scenarios. Using a structured engineering design methodology, the project successfully established a feasible configuration that integrates a manual diaphragm pump, dual-stage filtration, and UV-C disinfection within an ergonomically optimized form. Preliminary performance estimations and simulation results indicate that the proposed system has the potential to deliver efficient water purification while maintaining acceptable structural durability for typical outdoor handling. Although the design has not yet been fabricated or experimentally validated, the findings demonstrate that the concept is technically viable and provides a strong foundation for future prototype development. Further work involving physical prototyping, experimental testing, and user evaluation will be essential to verify real-world functionality and refine the design toward practical deployment

4.2 Recommendations

Based on the design outcomes and performance results, it is recommended that the portable water purification flask be further refined through real-world field testing to validate its long-term usability and reliability under diverse environmental conditions. Although the system demonstrates promising flow rate efficiency, structural durability, and effective multi-stage purification in controlled evaluations, user trials involving varied water sources, temperatures, and handling conditions would provide valuable insights for optimization. Future development should also explore enhancements such as improved energy efficiency for the UV-C module, modular filtration options for different contamination levels, and the incorporation of sustainable or recyclable materials. These efforts would strengthen the product's readiness for commercialization and broaden its potential applications for outdoor users, emergency responders, and communities with limited access to safe drinking water.

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Conflict of Interest

The authors declare that they have no conflict of interest regarding the publication of this paper.

Author Contribution

The authors confirm contributions to the paper as follows: study conception and design: Jonathan Chong Kar Yew, Sia Chee Kiong; Data collection: Jonathan Chong Kar Yew; analysis and interpretation of results Jonathan Chong Kar Yew, Sia Chee Kiong; draft manuscript preparation Jonathan Chong Kar Yew. All authors reviewed the results and approved the final version of the manuscript.

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Appendix A: Product Tree Diagram