Ultra-Low Pressure Filtration Performance in Campus Domestic Waste

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Abstract. This study aims to determine the effect of ultra-low pressure filtration performance on the permeability of clean water and campus domestic waste. Waste treatment can be carried out by applying an ultra-low pressure membrane filtration process with a Gravity Driven Membrane (GDM) system. Ultra-low pressure membrane filtration has less impact on the environment, low energy use, easy operation, high efficiency in removing pathogens, organic matter and turbidity. The filtration was tested using clean water and campus domestic waste as bait with a duration of 30 minutes each for each pressure, starting from a pressure of 1 kPa-10 kPa with a total time of 780 minutes for one sample. At each pressure, a relaxation time will be given for 10 minutes, this is done to maintain membrane permeability. Long-term filtration was carried out for 35 days and every 7 days the domestic waste was replaced without backwashing the membrane. The results of this study indicate that the permeability of clean water decreases due to compaction that occurs along with increasing pressure. Meanwhile, the permeability of campus domestic waste has decreased due to compaction accompanied by pore blockage in the membrane (fouling).

1. Introduction

Water is a very important element for human life. Water is used in a variety of ways daily activities both for the needs of drinking, bathing, washing, agriculture and so forth. The increasing human population on this earth has the potential to increase the demand for clean water. Indonesia contributes about 6% of the world's water resources. This shows that Indonesia actually has abundant water resources. However, most areas in Indonesia, such as East Nusa Tenggara, Java, Bali, Sulawesi, are experiencing a shortage of clean water supply [1]. As for the impact caused by the high volume of waste that is not managed properly, namely the occurrence of health problems, decreased environmental quality, decreased aesthetics environment, and hampered the country's development [2]–[5]. In addition, the release of untreated wastewater into the environment causes potential

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risks, such as eutrophication, the occurrence of micropollutants and microplastics or water-borne pathogens [4], [6]. Therefore, before disposing of waste, the waste should be managed first so that it can reduce the negative impacts generated. Domestic wastewater is wastewater resulting from kitchen, toilet, sink activities and so on. Domestic waste can be divided into two, namely (greywater) and (blackwater), where greywater is waste originating from washing, bathing, and cooking activities that accommodated in water bodies while black water is waste that comes from toilet wastewater that is accommodated in septic tanks [7], [8].

Domestic waste does not only come from household activities and industrial activities. Several higher education institutions have the potential to produce wastewater from canteens, laboratories, and toilet activities. Characteristics of waste generated from activities in educational institutions. These can be in the form of organic, inorganic, and B3 wastewater [3]. One of them is the Mandalika University of Education (UNDIKMA). At this time, the management of liquid waste on the UNDIKMA campus has not been carried out in an integrated manner. The waste disposal channel at UNDIKMA is connected to the river flow around the campus so that the waste produced will be carried into the river and pollute the surrounding environment. One solution that can be offered is by processing waste or reusing the waste produced. Where the results of processed wastewater are expected to be reused so that in this way it can minimize the volume of waste produced. Waste treatment can be carried out by applying an ultra-low pressure membrane filtration process with a Gravity Driven Membrane (GDM) system [9]–[11].

The workings of the GDM system are that domestic wastewater is passed through the membrane then the contaminants will be ejected into a concentrate, while the water that has been separated from the waste contaminants will pass through the membrane and come out in the form of permeate. Permeate derived from this waste can be reused thereby reducing the use of raw water. This is possible because the membrane process used is capable of rejecting micron to ionic sized contaminants from water to produce quality water that not only meets quality standards but can also be reused [12], [13]. The ultra-low pressure filtration system operates in a dead-end mode, using gravity as the main driving force. During GDM filtration, biofilm formation results from interactions between different processes such as retention of organic particulate matter, solute degradation, predation, etc [14]–[16]. The GDM system was first tested by Swiss Federal Institute of Aquatic 2 Science and Technology (EAWAGS). This system operates under ultra-low pressure (40-60 mbar) with less maintenance compared to traditional membrane filtration systems such as ultrafiltration (UF) [6], [17].

Based on research conducted by [17] showed that fouling on the membrane under ultra-low pressure operation is highly reversible. Excellence and sustainability GDM in flux maintenance and long term operation with high quality effluent production has been demonstrated. In addition, the effect of the presence of biofilms obtained on the filtration process has been described by [14] who showed that tolerating the presence of biofilms on the surface of the membrane has a beneficial effect on the quality of the permeate even if the quantity decreases. Furthermore, things that can affect the amount of flux or permeability stated by [18] showed that deposition of insoluble materials, biologically induced structural changes in the fouling layer and development of immovable impurities are the three main processes that determine fouling and stabilization flux in low pressure filtration-ultrafiltration.

From some of the results of previous studies, the membrane technology is the best choice precisely with its ability as a highly selective separation process to produce quality products. Ultra-low pressure membrane filtration has several advantages including low energy use due to gravity-driven operation via hydrostatic pressure, less impact on the environment, easy operation, high efficiency in removing pathogens, organic matter and

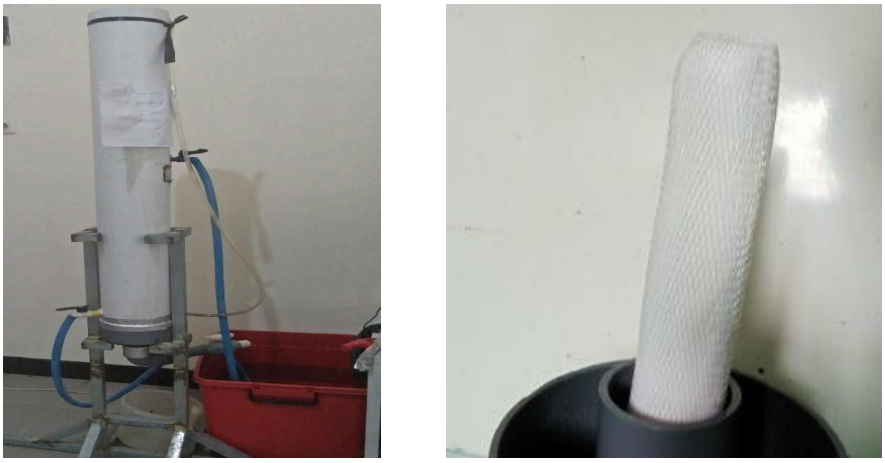
turbidity [19] as well as low maintenance costs with design and construction that is made on a small scale so it is very easy to scale-up and use in room conditions [18].
This study examines the performance of ultra-low pressure filtration in campus domestic waste with the test parameters used being permeability with pressure variations ranging from 1 kPa, 2 kPa, 3 kPa, 4 kPa, 5 kPa, 6 kPa, 7 kPa, 8 kPa, 9 kPa and 10 kPa. The relevance of this research with previous research is to examine the effect of pressure on the permeability of water produced with different samples. As for the difference in this study, besides analyzing the effect of pressure on permeability, it also analyzed the effect of membrane filtration on long-term use without physical washing of the membrane. The purpose of this research is to determine the effect of ultra-low pressure filtration performance on the permeability of clean water and permeability of domestic waste.

2. Method

2.1 Research instruments

2.1.1 Research tools and material

The equipment used in this study is a series of filtration devices, stopwatches, glasses gauge, permeate container, water pump, water hose, and water trough as shown in Fig. 1.



(a) (b)

Fig. 1. (a) Series of filtration devices and (b) Hollow fiber membrane

The materials used in this study were clean water from the Farzaa Mataram Drinking Water Depot, domestic waste, and a U-shaped hollow fiber ultrafiltration membrane with a diameter of 4.6 cm and a length of 22.5 cm. This membrane has a contact area of 0.2417m^2 and has a pore diameter of 0.001µm. The advantage of using hollow fiber is that it has good ability in terms of back flushing. This is because the fiber material has self-supporting properties and makes it very easy to wash [20]. The membrane used can be seen in Figure 1.

2.1.2 Data collection technique

2.1.2.1 Preparation of domestic waste

Domestic waste is obtained from wastewater that exits directly through the sewer on the UNDIKMA campus by cisterns until it reaches the required volume. The campus domestic waste disposal channel can be seen in Figure 3 below.

Fig.3. The sewer inside campus yard.

2.1.2.2. Filtration

This filtration is carried out in three stages. The first stage is filtration with clean water which is used as standardization. At this stage the filtration is carried out with variations in pressure from 1 kPa to 10 kPa and then repeated from a pressure of 10 kPa to 1 kPa. At each pressure, filtration was carried out for 30 minutes and relaxation for 10 minutes before switching to the next pressure. Sampling was carried out for 3 minutes at each pressure and combined namely in the first minute, 10th minute, and 20th minute.

The second stage is filtration with domestic waste. At this stage given the same treatment as the first stage with differences in the samples used. After performing the second stage of filtration, the membrane is washed before being used for further filtration. This is done to improve the performance of the membrane. The third stage is long-term domestic sewage filtration. At this stage, filtration is carried out only at a pressure of 6 kPa. This filtration lasted for 35 days (5 weeks). Permeate was collected 3 times a day, namely at 7 am, 12 am and 5 pm. And carried out for 3 minutes. This stage is not carried out relaxation.

2.1.3 Data analysis technique

2.1.3.1 Filtration test

To calculate the transmembrane pressure use the hydrostatic pressure formula.

$$Ph = \rho \times g \times h \quad (1)$$

Than, Ph = hydrostatic pressure (Pa); ρ = density of substance (kg.m^3); g = speed of gravity (m/s^2); h = height (m).

2.1.3.2 Flux

Flux is the volume of permeate that passes through a unit area of the membrane in time certain with the presence of thrust (pressure). (Notodarmojo & Deniva, 2004). Systematically the flux is formulated as follows [21], [22].

$$(L/\ m^2.h) \quad (2)$$

Than, J = Flux (L/ m^2.h); V = Permeate Volume (ml); A = Surface area of the membrane (m^2); T = Time (hours)

2.1.3.3 Permeability

In quantity, membrane permeability is often expressed as flux or permeability coefficient. Permeability can be formulated as follows [21], [22].

$$(L/\ m^2.h.bar) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Than, L = Permeability (L/ m^2.h.bar) J = Flux (L/ m^2.h); Ph = Pressure (bar).

3. Results and discussion

3.1 Ultra-low pressure filtration performance on clean water permeability.

The permeability of a membrane is a measure of the speed at which a species penetrates the membrane. This permeability is affected by the number of pores, pore size, operating pressure and membrane thickness. In quantity, membrane permeability is often expressed as flux or permeability coefficient [12]. Flux is the volume produced from the feed solution through the membrane per unit time and the surface area of the membrane used (L/m2hour) [23], [24].

The working principle of this filtration is to use the concept of osmotic pressure to fight osmosis occurs. Osmotic pressure is the force required to be able to flow a solvent in a solution with a high concentration to a low concentration through a semipermeable membrane. Thus, the solvent can pass through the membrane while the solute or contaminant is retained on the surface of the membrane. In this study the pressure variations used were 1 kPa to 10 kPa. The following shows the permeability data of clean water.

This filtration process is divided into two, namely trend A and trend B. In trend A (colored green) filtration is carried out from a pressure of 1 kPa to 10 kPa and in trend B (colored blue) filtration is carried out from a pressure of 10 kPa to 1 kPa. In general, the permeability of clean water in trend A has decreased, while trend B has experienced a very significant increase. Based on Figure 4, it is known that in trend A there are two different phenomena, namely an increase in permeability in the pressure range of 1-3 kPa and a decrease in permeability in the pressure range of 4 -10 kPa. The increase in pressure occurs due to the activation of the pores in the membrane which is commonly referred to as pore activation.

Pore activation is a process of stretching the membrane pores so that facilitates the entry of feed water into the pores and can easily pass through the membrane [25] explains that an increase in transmembrane pressure can open new pores if the membrane is not completely

wetted (according to the Cantor equation, which says that the pressure required to open the pores is directly proportional to the pore radius). This pore activation can occur as the filtration time increases. At this stage the membrane used is still new, so it takes time to activate all the membrane pores. If the membrane is completely wetted, this effect should not be seen, because no new pores will open [25].

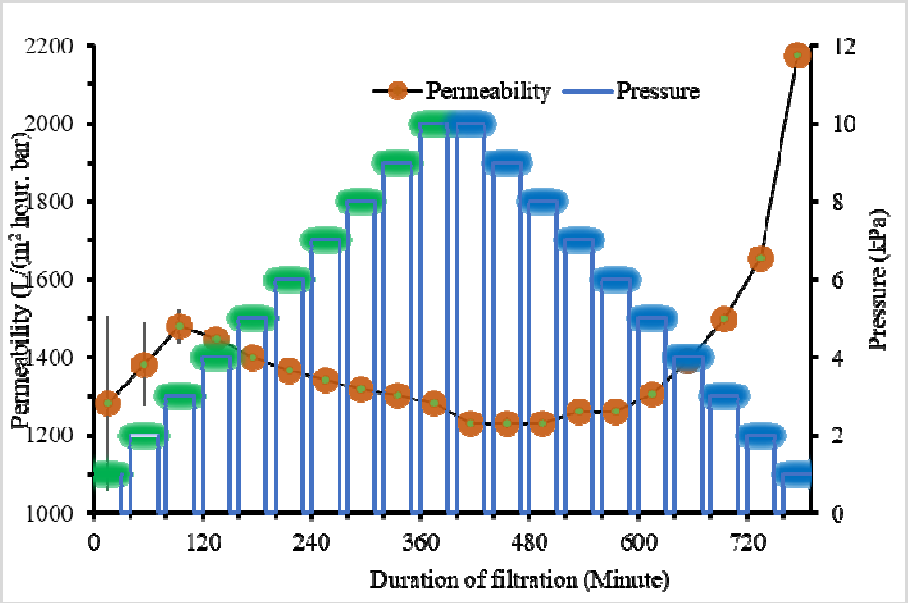


Fig.4. Clean water filtration

Furthermore, in the pressure range of 4-10 kPa there is a decrease in permeability. This is due to the event of membrane compaction (compaction). Compaction is a process of mechanical deformation of the constituent polymer matrix which causes the pore structure of the membrane to become denser and the flux decreases to a nearly constant value [23], [24]. The decrease in water permeability due to compaction requires higher operating pressures and higher energy consumption to maintain a constant water flux [26]. Compaction occurs when the membrane structure is compressed due to transmembrane pressure.

Membrane compaction refers to changes in the physical structure of membrane materials due to transmembrane exposure. Due to the flexible nature of the polymer in the matrix, it affects the hydraulic filtration performance [27]. Compaction can occur because the membrane material is made of polymeric material, which when pressure is applied, the pores will shrink. Thus, when greater pressure is applied, the pores of the membrane will shrink or condense so that the feed water is more difficult to pass through the membrane and results in a decrease in the permeability of the water produced.

Then in trend B the chart shows a significant increase. This is due to pore activation and decompaction. Thus, the water permeability will increase increases with decreasing pressure. With decreasing pressure then the pore of the membrane begins to stretch again, and the feed water can easily pass through the membrane causing an increase in permeability [9], [28], [29]. If a permeability comparison is made in trend A and trend B, the result is that the water permeability in trend B is greater than the water permeability in trend A. This difference occurs because in trend A the membrane pores used are not active, so it takes time to activate. throughout the membrane pores. Whereas in trend B the

membrane pores are already active so that the flux value obtained is higher than the flux in trend A.

3.2 Ultra-low pressure filtration performance on campus domestic waste permeability

Filtration with campus domestic waste resulted in permeability in trend A experienced a significant decrease with increasing pressure while the permeability in trend B increased with decreasing pressure. The phenomenon that occurs in trend A indicates compaction. With the occurrence of compaction, the permeability obtained decreases with increasing pressure received by the membrane [21], [25], [27]. At a pressure of 1 kPa the permeability of water reaches 4,090.5 (L/m^2.hour.bar) while at a pressure of 2 kPa the permeability of water reaches 3.001 (L/m^2.hour.bar). This proves that there is compaction in the membrane. The permeability of water begins to reach its stability at a pressure of 6 kPa which is indicated by a gradual decrease in permeability which can be seen in Figure 5.

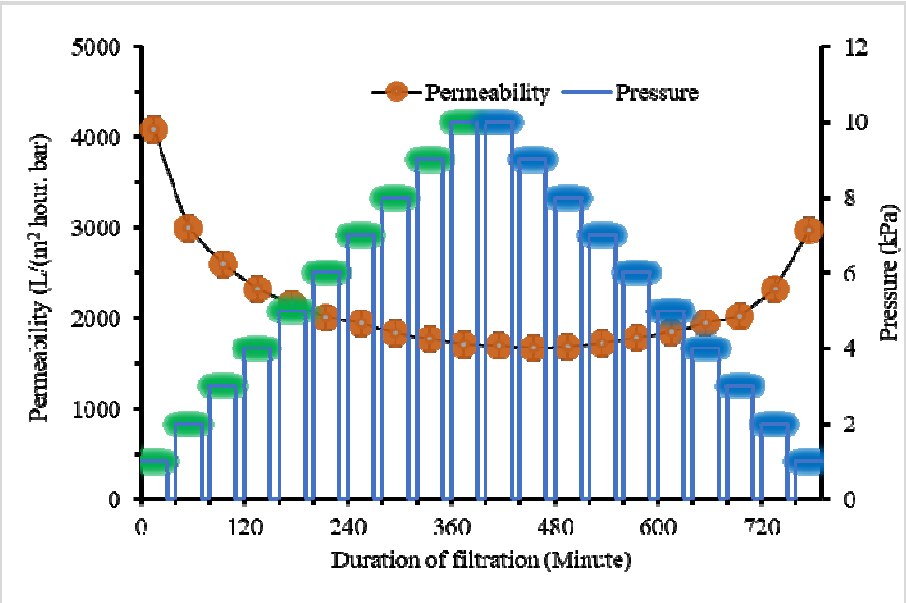


Fig. 5. Campus domestic waste filtration

Meanwhile, in trend B there was no significant increase in permeability. This caused by a blockage in the pores of the membrane (fouling). Fouling can be defined as the irreversible deposition of suspended particles, colloids, macromolecules, salts, etc. on the surface of the membrane or in the pore walls of the membrane causing a continuous decrease in flux. Fouling on the membrane results in a decrease in productivity during operation, namely a decrease in flux with respect to time, when all other parameters such as pressure, flow rate, temperature and feed concentration are kept constant [12], [30].

Biologically induced structural changes in the impurity layer lead to a heterogeneous structure and network of channels and lead to a decrease in the specific resistance of this layer over time [31]. The development of voids, channel networks and heterogeneous structures leads to a decrease in the impurity layer resistance, counteracts its increase in thickness and leads to stabilization of the flux. Similar structural changes in the impurity layer can be observed in membrane bioreactors (MBR) [31]–[34].

At a pressure of 1 kPa trend B experiences a greater increase when compared to other pressures on trend B. This is caused by decompaction. Decompaction is the event of stretching back the membrane pores that have been closed during compaction[27]. Basically, the decompaction that occurs should show the same permeability value as trend A for 1 kPa pressure. However, the data above shows that the decompaction that occurs produces a permeability value of trend B that is smaller than the permeability value of trend A. This shows that fouling occurs reversibly as the pressure decreases. This statement is supported by [27] who stated that when the applied pressure is removed, the membrane thickness can increase rapidly and is time dependent, which is a recovery process.

If we observe the difference in permeability in Figure 4.1 trend B and Figure 5 trend B, it is found that the permeability of domestic waste (2978.9 L/m^2.hour.bar) is higher than that of clean water (2176.3 L/m^2.hour.bar). This shows that pore activation can occur as a whole and takes a long time. The substances that can be filtered by the hollow fiber membrane is the contaminants have a larger size compared to the pore size of the membrane so as to produce a quality filtrate [22], [35]. Long-term filtration is carried out to observe the performance of the membrane when it is used regularly for a long time. The filtration result data can be seen in Figure 6.

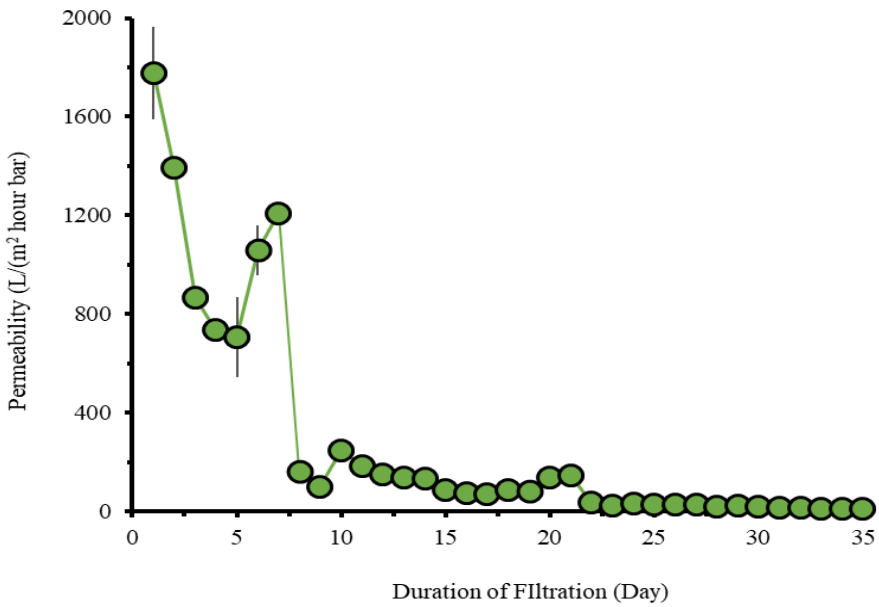


Fig. 6. Figure 6 Long-term filtration performance

This filtration was carried out for 35 days at a constant pressure of 6 kPa and without washing the membrane. The sample used is replaced every week. The flux or permeability value is calculated 3 times a day for 3 minutes with a time span of 5 hours. From the data above it can be seen that the filtration yield decreased significantly in the range from day 2 to day 5. Then it increased on the 6th and 7th day. Then it decreased again on the 8th day drastically. This decrease occurs due to fouling which inhibits the rate of water permeability [33], [36], [37]. This fouling occurred reversibly which resulted in an increase in permeability on the 6th and 7th day. Fouling is accompanied by compaction of the membrane [21], [36], [37]. Then on the 8th day there was a drastic decrease, this was caused by compaction accompanied by pore blockage.

According to [27], pore blockage results in the formation of a cake layer, which is dominated by inorganic molecules or natural organic matter, depending on the pore size of

the feed and membrane. During the filtration process, microorganisms, organic aggregate colloidal material, as well as organic matter and inorganic particulates in the feed water can be rejected by the membrane which then accumulates on the surface of the membrane. Substances retained on these membranes tend to form biofilm layers, which are considered "mini-ecological systems" [28], [38]. After the initial colonization of the membrane surface by bacteria, biofilm development will also increase with increasing pressure. As stated by [31], [33], [34], [36], [39] decreased flux and increased impurity layer resistance are generally assumed to be related to the deposition of the biopolymer on the membrane surface and the formation of a gel layer.

Several studies have shown that soluble microbial products, which are low molecular weight organic compounds, released into solution from substrate metabolism and decay of biomass, were found to have a large impact on fouling [31], [40]. Biofilms increase membrane resistance, which causes a decrease in ULPM (Ultra Low Nenbrane Filtration) flux [27], [41] . The longer the filtration time, the more biofilms that form and fill the surface of the membrane. Along with this, the resulting filtration permeability reaches a level of balance or stability. From the picture above, the stability of the flux is obtained on the 22nd day and so on. Flux values stabilize after about a week of operation and remain constant over long periods of time (several months). Many approaches have been studied to reduce the occurrence of fouling on the membrane, including pre-treating the feed water, high velocity cross-flow hydrodynamic washing, backwashing, optimization of chemical/operational conditions such as pH and recovery ratio, and modification of membrane surfaces [12], [23], [42].

4. Conclusion

The permeability of clean water has decreased due to compaction that occurs concomitantly by increasing the pressure. While the permeability of domestic waste has decreased due to compaction that occurs with increasing pressure and accompanied by clogging of the membrane pores (fouling).

5. Suggestion

For further research, it is necessary to carry out filtration with the addition of media as a filter for microorganisms contained in domestic waste to reduce the formation of biofilm layers and increase permeability. Besides that, before doing filtration with a membrane it would be nice if the membrane pores were activated first to obtain high permeability. Then it is necessary to carry out further research to determine the effect of molecules/ions on the filtration performance of ultra-low pressure membranes.

Acknowledgment

The authors would like to express their sincere gratitude to the Ministry of Education, Culture, Research and Technology of the Republic of Indonesia, Directorate of Research, Technology, and Development (DRTPM), for providing funding support for this research project. We are grateful for the financial assistance received under contract number 078/E5/PG.02.00.PL/2023. This support has been instrumental in enabling the successful execution of this study and the generation of valuable findings.

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