The role of $g$-$C_3N_4$ in round-the-clock photocatalysis for POME

N A M Razali$^{1,2}$, W N W Salleh$^{1,2,}$*, N Rosman$^{1,2}$, H Ismail$^{1,2}$, S Z N Ahmad$^{1,2}$, F Aziz$^{1,2}$, W J Lau$^{1,2}$, A F Ismail$^{1,2}$

$^1$Advanced Membrane Technology Research Centre (AMTEC), Universiti Teknologi Malaysia, 81310, Skudai, Johor, Malaysia
$^2$School of Chemical and Energy Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310, Skudai, Johor

*Corresponding author: hayati@petroleum.utm.my

Abstract. The main drawback of conventional palm oil mill effluent (POME) treatment is that the process is time and space-consuming. Besides, the treatment produces highly polluted wastewater that pollutes the environment if discharged directly. Photocatalytic process has significant potential to degrade recalcitrant organic pollutants and has recently attracted tremendous attention. However, current approaches mainly focus on visible light condition, which is still an ineffective treatment for POME. In this study, POME was successfully degraded using graphitic carbon nitride ($g$-$C_3N_4$) photocatalyst synthesised by calcination. The prepared photocatalyst was characterised by ultraviolet-visible diffuse reflectance (UV-Vis DRS) spectroscopy and scanning electron microscopy (SEM). The SEM results revealed the morphology of $g$-$C_3N_4$ photocatalyst. $g$-$C_3N_4$ could act as a visible-light-driven (VLD) photocatalyst with the highest photocatalytic efficiency of 71% under visible light. The present work highlights the potential of $g$-$C_3N_4$ towards the degradation of POME under visible light and dark condition. The highly enhanced photocatalytic performance is attributed to $g$-$C_3N_4$, but it does not work well in round-the-clock photocatalysis. However, $g$-$C_3N_4$ can work as the band alignment to drive separate photogenerated charge carriers, leading to effective photocatalytic degradation. $g$-$C_3N_4$ photocatalyst may be considered as an ideal candidate for treating POME.

Keywords: $g$-$C_3N_4$, energy-storage material, palm oil mill effluent, photocatalysis, visible-light-driven

1. Introduction
In the past several decades, water pollution has become a worldwide concern, including wastewater from industries. Palm oil mill effluent (POME) is released from palm oil mills and it is the main source of water pollution [1,2]. Moreover, acidic and viscous POME can harm the aquatic ecosystem [3]. POME contains a high amount of water and suspended solids consisting of carbohydrates, amino acids, fibres, and some inorganic nutrients, such as iron, copper, potassium, magnesium, nitrogen, chromium, and cadmium [4]. POME is categorised based on its strength, which is influenced by the number and concentration of contaminants. For example, low-strength POME contains high biochemical oxygen
demand/chemical oxygen demand (BOD/COD) ratio and is biodegradable [5]. POME treatment must be conducted as the effluent has a high tendency of polluting the environment [6].

Various conventional wastewater treatment methods have been used, such as biodegradation through microorganisms, and physical and chemical processes, including adsorption, filtration, and flocculation. However, the shortcomings of most of these methods are low efficiency, expensive, time-consuming, high post-treatment costs of generated secondary pollutants, and only phase transformation of contaminants occurred instead of complete mineralisation to obtain non-toxic products, such as carbon dioxide, water, and inorganic salts [7–9]. Among these methods, advanced oxidation processes (AOPs) have emerged as promising methods for removing contaminants of emerging concern from wastewater effluent [10]. Compared to other complex methods in AOPs, photocatalysis is the safest method because mild condition is used, and neither high temperatures nor hazardous materials are applied. Photocatalysis offers several advantages: environmentally friendly, high performance, low energy consumption, and no secondary pollution [11,12]. However, photocatalysis is not satisfactory owing to their low solar energy utilisation efficiency, poor selective adsorption, poor stability, and high recombination rate of electron-hole pairs [13].

Several excellent materials like titania (TiO$_2$), tungsten trioxide (WO$_3$), zinc oxide (ZnO), and ferric oxide (Fe$_2$O$_3$) have been explored as photocatalytic nanomaterials. Among the explored materials, TiO$_2$-based photocatalysts (3.2 eV) have excellent photoactivity and high stability but still have limitations in terms of easy recombination of photogenerated electron-hole pairs, low quantum efficiency, and the photocatalysts can be activated only by ultraviolet (UV) light [14,15]. Accordingly, numerous studies on visible-light-driven (VLD) photocatalysts have focused on air pollutants, photocatalytic hydrogen production, and wastewater treatment and disinfection [16,17]. Among the emerging VLD photocatalysts, graphitic carbon nitride (g-$C_3$N$_4$) is an important catalyst due to its appropriate band gap and unique light-harvesting ability that absorbs visible light less than 450 nm [19]. g-$C_3$N$_4$ has been demonstrated as an excellent visible light responsive photocatalyst that is inexpensive, easy to synthesise, highly stable, suitable electronic structure, and outstanding photocatalytic performance [20]. Moreover, it should be noted that g-$C_3$N$_4$ has the advantages of hydrophilicity, large specific surface area, inert, and environmentally friendly [21]. Unfortunately, g-$C_3$N$_4$ also exhibits a series of undesirable disadvantages, like low specific surface area, irregular morphology, and a hydrophobic surface that often limits photocatalytic performance [22]. Furthermore, the extensive application of g-$C_3$N$_4$ is limited due to poor utilisation of long-wavelength light, low quantum efficiency, and high recombination of photoexcited electrons-hole pairs [23,24].

Jiang and his team reviewed several doping techniques for g-$C_3$N$_4$ with metal, non-metal, co-doping, and heterojunction to enhance the light absorption, facilitate the charge separation and transportation, and prolong the charge carrier lifetime [25]. However, another limitation prevents the industrialisation innovation of photocatalysis due to light restriction. According to Lu and his co-worker, the decomposition of contaminants only occurs after light excitation, photoelectron/hole pair generation and migration, and oxidising and reductive species formation. Therefore, darkness would disrupt the catalytic reaction for most photocatalysts, as well as their photocatalytic efficiency and applications [26]. In order to achieve the catalyst with high photocatalytic activity, some efforts have been made to investigate the potential of energy-storage material (ESM) and VLD photocatalyst towards various pollutants, for example, ZnWO$_4$, BiFeWO$_6$/WO$_3$, Pt/TiO$_2$/WO$_3$, and Ag-MoS$_2$ [27–30].

In this work, the enhancement of visible light and round-the-clock photocatalysis for g-$C_3$N$_4$ photocatalyst prepared by calcination was investigated. The photocatalytic activity of g-$C_3$N$_4$ was assessed by the degradation of POME under visible light irradiation. The synthesis of material, properties, and structure of g-$C_3$N$_4$ are briefly discussed. The progress in improving the degradation efficiency of POME by g-$C_3$N$_4$-based photocatalysis is discussed. The feasibility of g-$C_3$N$_4$
photocatalyst for the degradation of organic pollutants is also summarised.

2. Experimental methodology

2.1. Chemicals and reagents
Melamine (2,4,6-triamino-s-triazine) was obtained from Acros Organics. All solutions were prepared using deionised water and all chemicals chosen in this study were of analytical grade and used without further purification.

2.2. Preparation of g-C₃N₄
For the preparation of g-C₃N₄, 10 g of melamine was heated in a muffle furnace at 100, 200, 300, 400, and 500 °C for 1.5 h using a heating rate of 2 °C min⁻¹ and then naturally cooled. The resulting powder was slightly crushed with a mortar and pestle to obtain fine powder of photocatalysts. The samples were labelled as G1 (g-C₃N₄ prepared at 100 °C), G2 (g-C₃N₄ prepared at 200 °C), G3 (g-C₃N₄ prepared at 300 °C), G4 (g-C₃N₄ prepared at 400 °C), and G5 (g-C₃N₄ prepared at 500 °C).

2.3. Characterization of photocatalysts
For morphological examination, the samples were characterised using scanning electron microscopy (SEM). The ultraviolet-visible-near infrared (UV-Vis-NIR) spectrophotometer (UV-3600 Plus, Shimadzu) was used in the wavelength of 300-800 nm to construct the Tauc plot for band gap determination, and colour was measured using the 8025 APHA platinum-cobalt standard method at 455 nm using a UV-Vis spectrophotometer (DR5000, Hach).

2.4. Adsorption and photocatalytic degradation of POME
Fresh POME was collected from an aeration pond of Felda Taib Andak palm oil mill in Kulai, Johor, Malaysia. Subsequently, the POME waste was stored in an airtight container and transported to the laboratory. The effluent was filtered to eliminate suspended solids and preserved in a freezer for storage (maximum of 3 months) to prevent microbial biodegradation of the effluent [31]. The adsorption using g-C₃N₄ was conducted by following dark absorption. All the experiments were conducted under the following conditions: 200 ml of POME (200 ml, 0.2 g L⁻¹) was magnetically stirred for 60 min at room temperature in the dark to obtain an adsorption-desorption equilibrium. In a typical photocatalytic experiment, 0.2 g of the photocatalyst was suspended in 200 ml of POME and the degradation was observed under visible light irradiation (100 W), as shown in Figure 1.

During photodegradation, 5 ml of aqueous solution was sampled and filtered using a syringe filter every 60 min, and POME colour was measured using the platinum-cobalt (Pt-Co) standard method. The photocatalytic activity of the samples was evaluated throughout 7 h of the experiment using two sets of procedures (1 h adsorption, 7 h of light irradiation, and 1 h adsorption, 2 h of light irradiation, 1 h of dark condition) to investigate their photocatalytic activity and energy storage ability, respectively. The removal efficiency was calculated using the following Eq. (1):

Removal efficiency (%) = [(C₀ - C) / C₀] × 100%  \hspace{1cm} (1)

where C₀ and C are the colour of the POME in water before irradiation and the colour after a certain irradiation time (t), respectively.
3. Results and discussion

3.1. Characterisation of photocatalysts

3.1.1 SEM micrographs

The morphology and superficial microstructure of g-C₃N₄ were investigated by SEM. The SEM images recorded at high magnification clearly showed different structures for the samples prepared at 200 and 400 °C. Figure 1(A) and (B) illustrate the SEM images with different magnification factors ranging from 50 to 100 µm. It is noteworthy that the SEM image of g-C₃N₄ prepared at 200 °C displays the formation of smaller surface, contributing to favourable photogenerated charge transfer at the interface (Figure 1(B)). As illustrated in Figure 1(A) and (B), the synthesised g-C₃N₄ samples showed irregular granular structure with a size of several micrometres [32,33]. The magnification of SEM images is distributed from 30 to 100 µm, as shown in Figure 1(C) and (D). There is no estimated size of both samples in Figure 1(A) and 1(C), which clearly showed irregular shapes that could be identified only by field-emission scanning electron microscopy (FESEM). As can be seen in Figure 1(C) and (D), the G4 sample is predominantly composed of mixed aggregate morphology, which is rod-like structures and short rods adhered to the irregular and small scattered particles at the surface [34,35]. The results indicate that the morphologies of the samples possess a structure composed of perforated plates due to the gases discharged from thermal treatment that partially affected the material [34,36].

![SEM images of g-C₃N₄](image)

Figure 1. SEM image of the g-C₃N₄, calcined at different calcination temperature (A), (B) for (g-C₃N₄ at 200°C: G2), (C) and (D) for (g-C₃N₄ at 400°C: G4).

3.1.2 UV-Vis diffuse absorption spectra

According to Kuznetsova and his co-worker, the electronic structure based on optical absorbance can determine the photocatalytic activity through optical diffused reflectance spectra [37]. Figure 2 presents the obtained spectra for G2. The photocatalyst was chosen as it exhibits the highest decolourisation for
photocatalytic activity and the best energy storage performance. The band gap of the as-prepared sample was estimated from the UV-Vis DRS spectra via the Tauc plot in Eq. (2):

\[(\alpha h_v)^n = A (h_v - E_g)\]  

(2)

where \(\alpha\) is the absorption coefficient, \(h_v\) is the incident photon energy, \(A\) is a constant and \(E_g\) is the band gap energy (eV).

As shown in Figure 2, the sample exhibits an absorption edge in the visible light region. The band gap energy value was obtained by tracing a tendency line using the maximum inclination region of the graph. The band gap of g-C\(_3\)N\(_4\) is approximately 3.05 eV.

![Tauc plot of g-C\(_3\)N\(_4\) synthesized under different calcination treatment at 400 °C and 200 °C.](image)

**Figure 2.** Tauc plot of g-C\(_3\)N\(_4\) synthesized under different calcination treatment at 400 °C and 200 °C.

3.2. Photocatalysis

The effect of the calcination temperature applied in the preparation of g-C\(_3\)N\(_4\) on the photocatalytic activity for two conditions was studied to determine the photocatalyst that contributes towards visible light and energy-storage factor. The adsorption-desorption equilibrium of the photocatalysts was established by stirring the catalyst with respective pollutants for 60 min in dark condition. The experiments were carried out under light irradiation for 6 h (visible light) and also 2 h of light irradiation and 1 h of dark condition (energy storage). For this objective, these results were also compared to the measured results for g-C\(_3\)N\(_4\) prepared at different temperatures of 100-500 °C labelled as G1, G2, G3, G4, and G5, as shown in Figure 3.

Upon further increment of calcination temperature, a fluctuating trend of catalytic activity was observed, whereby G1, G2, G3, G4, and G5 exhibited about 14%, 71%, 16%, 62%, and 57%, respectively. According to the results in Figure 3, the calcination temperature of g-C\(_3\)N\(_4\) below 550 °C would achieve a great rate of photocatalytic reaction. This is because the effectiveness of VLD below 550 °C contributes to greater photogenerated electrons, leading to more efficient separation of charge and better photocatalytic activity [38]. From the results, G2 demonstrated the highest decolourisation that increased and decreased significantly as the calcination temperature increased. This is due to the reduced accessibility of many vacant active surface sites on g-C\(_3\)N\(_4\) compared to the initial stage. There will be competition for excess vacant surface sites due to the significant repulsion between the pollutants and photocatalyst [39].
Based on Figure 4, g-C₃N₄ did not demonstrate the potential of energy storage. The decolourisation of POME only reached 12%, 39%, 14%, 32%, and 14% for G1, G2, G3, G4, and G5, respectively. The findings showed that the as-prepared g-C₃N₄ exhibited insignificant round-the-clock photocatalysis for POME, where the photocatalytic efficiency only exceeded 30% within 420 min.

Figure 3. The photocatalytic degradation of POME (VLD scheme) (100 mL, 0.2g A) g-C₃N₄ photocatalyst.

Figure 4. The photocatalytic degradation of POME (ESM scheme) (100 mL, 0.2g A) g-C3N4 photocatalyst.

4. Conclusion
This study evaluated the morphological, adsorption, and photocatalytic performance of g-C₃N₄. g-C₃N₄ photocatalysts were prepared at different calcination temperatures via calcination to study the potential of ESM and VLD photocatalysts. Improved POME degradation under visible light irradiation was observed among the g-C₃N₄ photocatalysts, with the best photocatalytic activity of 71%. The enhanced photocatalysis is ascribed to the strong light absorption intensity of g-C₃N₄, although there is not much improvement in round-the-clock photocatalysis.
5. References

[1] Poh P E and Chong M F 2009 Development of anaerobic digestion methods for palm oil mill effluent (POME) treatment *Bioresour. Technol.* **100** 1–9

[2] Tan Y D and Lim J S 2019 Feasibility of palm oil mill effluent elimination towards sustainable Malaysian palm oil industry *Renew. Sustain. Energy Rev.* **111** 507–22

[3] Abrams J F, Hohn S, Rixen T, Baum A and Merico A 2016 The impact of Indonesian peatland degradation on downstream marine ecosystems and the global carbon cycle *Glob. Chang. Biol.* **22** 325–37

[4] Bello M M and Abdul Raman A A 2017 Trend and current practices of palm oil mill effluent polishing: application of advanced oxidation processes and their future perspectives. *J. Environ. Manag.* **198** 170–82

[5] Abdulsalam M, Man H C, Idris A I, Yunos K F and Abidin Z Z 2018 Treatment of palm oil mill effluent using membrane bioreactor: Novel processes and their major drawbacks *Water (Switzerland)* **10**

[6] Rupani P and Singh R 2010 Review of current palm oil mill effluent (POME) treatment methods: Vermicomposting as a sustainable practice *World Appl. Sci. ...* **11** 70–81

[7] Yunus I S, Kurniawan A, Adityawarman D, Sofian I, Kurniawan A and Adityawarman D 2012 Nanotechnologies in water and air pollution treatment *Environ. Technol. Rev.* **2515**

[8] Chi G T, Churchley J, Huddersman K D, Trent S, Road S M and Cv C 2013 Pilot-Scale Removal of Trace Steroid Hormones and Pharmaceuticals and Personal Care Products from Municipal Wastewater Using a Heterogeneous Fenton "s Catalytic Process *Int J Chem Eng* 1–10

[9] Oller I, Klamerth N, Agu A and Rodri E M 2012 Application of solar AOPs and ozonation for elimination of micropollutants in municipal wastewater treatment plant effluents *Water Res.* **7** 4–11

[10] Rueda-Marquez J J, Levchuk I, Fernández Ibañez P and Sillanpää M 2020 A critical review on application of photocatalysis for toxicity reduction of real wastewaters *J. Clean. Prod.* **258**

[11] Abderrazak Y 2020 Photocatalysis: A step closer to the perfect synthesis *J. Organomet. Chem. 920*

[12] Li X, Chen D, Li N, Xu Q, Li H, He J and Lu J 2020 Efficient reduction of Cr(VI) by a BMO/Bi2S3 heterojunction via synergistic adsorption and photocatalysis under visible light *J. Hazard. Mater.* **400** 123243

[13] Zhang J, Gao N, Chen F, Zhang T, Zhang G, Wang D, Xie X, Cai D, Ma X, Wu L and Wu Z 2019 Improvement of Cr (VI) photoreduction under visible-light by g-C3N4 modified by nano-network structured palygorskite *Chem. Eng. J.* **358** 398–407

[14] Fujishima, Rao and Tryk 2000 Titanium dioxide photocatalysis. *J Photochem Photobiol C* **1** 1–21
[15] Xie B, Xiong Y, Chen R, Chen J and Cai P 2005 Catalytic activities of Pd-TiO2 film towards the oxidation of formic acid Catal. Commun. 6 699–704

[16] Le Y, Qi L, Wang C and Song S 2020 Hierarchical Pt/WO3 nanoflakes assembled hollow microspheres for room-temperature formaldehyde oxidation activity Appl. Surf. Sci. 512 145763

[17] Zhang F, Wang X, Liu H, Liu C, Wan Y and Long Y 2019 Recent Advances and Applications of Semiconductor Photocatalytic Technology Appl. Sci. 9 2489

[18] Chen D, Li T, Chen Q, Gao J, Fan B, Li J, Li X, Zhang R, Sun J and Gao L 2012 Hierarchically plasmonic photocatalysts of Ag/AgCl nanocrystals coupled with single-crystalline WO3 nanoplates Nanoscale 4 5431–9

[19] Mamba G and Mishra A K 2016 Graphitic carbon nitride ( g-C 3 N 4 ) nanocomposites: A new and exciting generation of visible light driven photocatalysts for environmental pollution remediation Appl. Catal. B Environ. 198 347–77

[20] Reddy K R, Reddy C V, Nagadoula M N, Shetti N P, Jaesool S and Aminabhavi T M 2019 Polymeric graphitic carbon nitride (g-C 3 N 4 )-based semiconducting nanostructured materials: Synthesis methods, properties and photocatalytic applications J. Environ. Manage. 238 25–40

[21] Wu Y, Wang H, Tu W, Liu Y, Tan Y Z, Yuan X and Chew J W 2018 Quasi-polymeric construction of stable perovskite-type LaFeO3/g-C3N4 heterostructured photocatalyst for improved Z-scheme photocatalytic activity via solid p-n heterojunction interfacial effect J. Hazard. Mater. 347 412–22

[22] Wang W, Fang J, Shao S, Lai M and Lu C 2017 Compact and uniform TiO2@g-C3N4 core-shell quantum heterojunction for photocatalytic degradation of tetracycline antibiotics Appl. Catal. B Environ. 217 57–64

[23] Zhang M, Xu J, Zong R and Zhu Y 2014 Enhancement of visible light photocatalytic activities via porous structure of g-C 3 N 4 Appl. Catal. B, Env. 147 229–35

[24] Li S, Dong G, Hailili R, Yang L, Li Y, Wang F, Zeng Y and Wang C 2016 Effective photocatalytic H 2 O 2 production under visible light irradiation at g-C 3 N 4 modulated by carbon vacancies ‘Applied Catal. B, Environ. 190 26–35

[25] Jiang L, Yuan X, Pan Y, Liang J, Zeng G, Wu Z and Wang H 2017 Doping of graphitic carbon nitride for photocatalysis: A revieiw Appl. Catal. B Environ. 217 388–406

[26] Lu Y, Zhang X, Chu Y, Yu H, Huo M, Qu J, Crittenden J C, Huo H and Yuan X 2018 Cu2O nanocrystals/TiO2 microspheres film on a rotating disk containing long-afterglow phosphor for enhanced round-the-clock photocatalysis Appl. Catal. B Environ. 224 239–48

[27] Neto N F A, Nunes T B O, Li M, Longo E, Bomio M R D and Motta F V 2019 Influence of microwave-assisted hydrothermal treatment time on the crystallinity , morphology and optical properties of ZnWO 4 nanoparticles : Photocatalytic activity Ceram. Int.

[28] Priya A, Arunachalam P, Selvi A, Madhavan J and Al-mayouf A M 2018 Synthesis of BiFeWO 6 / WO 3 nanocomposite and its enhanced photocatalytic activity towards degradation of dye under irradiation of light Colloids Surfaces A 559 83–91
[29] Khan H, Rigamonti M G and Boffito D C 2019 Enhanced photocatalytic activity of Pt-TiO2/WO3 hybrid material with energy storage ability Appl. Catal. B Environ. 252 77–85

[30] Sun K, Jia F, Yang B, Lin C, Li X and Song S 2020 Synergistic effect in the reduction of Cr(VI) with Ag-MoS2 as photocatalyst Appl. Mater. Today 18 100453

[31] Cheng C K, Rizauddi Derahman M and Khan M R 2015 Evaluation of the photocatalytic degradation of pre-treated palm oil mill effluent (POME) over Pt-loaded titania J. Environ. Chem. Eng. 3 261–70

[32] Han X, Tian L, Jiang H, Kong L, Lv J, Shan J, Wang J and Fan X 2017 Facile transformation of low cost melamine-oxalic acid into porous graphitic carbon nitride nanosheets with high visible-light photocatalytic performance RSC Adv. 7 14372–81

[33] Xu Y H, Xu G, Sun M Y and Wang K 2020 Low-temperature solvothermal–calcination preparation and enhanced photocatalytic performance of polymeric graphitic carbon nitride with disordered–ordered hybrid plane Chem. Pap. 74 4067–74

[34] Zhu H L and Zheng Y Q 2018 Mesoporous Co3O4 anchored on the graphitic carbon nitride for enhanced performance supercapacitor Electrochim. Acta 265 372–8

[35] Yu Z, Li F, Yang Q, Shi H, Chen Q and Xu M 2017 Nature-Mimic Method to Fabricate Polydopamine/Graphitic Carbon Nitride for Enhancing Photocatalytic Degradation Performance vol 5

[36] Shcherban N D, Mäki-Arvela P, Aho A, Sergienko S A, Yaremov P S, Eränen K and Murzin D Y 2018 Melamine-derived graphitic carbon nitride as a new effective metal-free catalyst for Knoevenagel condensation of benzaldehyde with ethylcyanoacetate Catal. Sci. Technol. 8 2928–37

[37] Kuznetsova M, Oliveira S A A, Rodrigues B S and Souza J S 2020 Microwave - Assisted Synthesis of Bismuth Niobate / Tungsten Oxide Photoanodes for Water Splitting Top. Catal.

[38] Paul D R, Sharma R, Nehra S P and Sharma A 2019 Effect of calcination temperature, pH and catalyst loading on photodegradation efficiency of urea derived graphitic carbon nitride towards methylene blue dye solution RSC Adv. 9 15381–91

[39] Sia Y Y, Tan I A W and Abdullah M O 2016 Adsorption of colour, TSS and COD from palm oil mill effluent (POME) using acid-washed coconut shell activated carbon: Kinetic and mechanism studies MATEC Web Conf. 87

Acknowledgments
The authors gratefully acknowledge the financial support from the Ministry of Education and Universiti Teknologi Malaysia under HICOE Research Grant (Project Number: R.J090301.7851.4J423) and UTM High Impact Research (Project Number: Q.J130000.2451.08G36). The authors would also like to acknowledge technical and management support from Research Management Centre (RMC), Universiti Teknologi Malaysia.