A palm oil newsletter brought to you by IChemE Palm Oil Processing Special Interest Group

July - December 2020

POPSIG

IChemE

In the News

IChemE ADVANCING CHEMICAL ENGINEERING WORLDWIDE

Palm Oil Processing Special Interest Group

Editor's Message

This year 2020, which marks the 5th anniversary of POPSIG, has been a highly successful year for us. The highlight was the first collaboration with Malaysian Oil Scientists' and Technologists' Association (MOSTA) in organizing a webinar workshop with the theme Mitigation of 3-MCPDE & GE: Industry Perspective on 15 October 2020. This event attracted over 150 participants. We are proud that the very first MOSTA-POPSIG collaboration exceeds expectations.

Inside we feature three evening talks that discuss the latest technology development within palm oil processing industry. Nik Suhaimi from Sime Darby Plantation shared few technologies development within palm oil milling operation. He is also the winner for Sustainability and Palm Oil awards in IChemE Malaysia Award 2019. Tan Liok Min from Desmet Ballestra discussed the possibility to produce biodiesel using low grade feedstock, e.g. used cooking oils and animal fats. Dr Arshad Adam Salema, Senior Lecturer at Monash University Malaysia, shared his research work on the application of microwave technologies in the palm oil industry. This technology is currently at the preliminary stage, some have gone to pilot scale in optimization and process design.

Due to the COVID-19 pandemic, IChemE Malaysia Awards 2020 went virtual for the first time in its history on 19 October 2020. We are proud to see continual improvement and competitiveness of participants in this event. Sumwin Solutions triumphed in the Palm Oil category for their new patented technology and process to reduce the levels of a potentially harmful chemical compound from palm oil to fully meet European standards, enabling edible products to be marketed successfully in European countries.

Changes is the only constant. POPSIG also switched our university roadshow event from physical to virtual mode. Our three final university roadshow webinar events of the year had been a success, leaving behind virtual footsteps into lives of our future engineers. 316 participants joined the university roadshow webinar events. We will continue this meaningful event in the coming year.

In December our founder member Qua Kiat Seng presented in a webinar organized by the IChemE Subject Area Leads Food, Drink & Nutrition. Qua shared his perspective on the latest process innovations within vegetable oil processing industry. He also highlighted the role of chemical engineers play in the industry.

Knowledge sharing remains very relevant as the need to enable exchange of best practices and sharing experience to all that are interested in the palm oil processing industry. This time we featured an article written by our chair, Hong Wai Onn. He talks about the career prospects of chemical engineers in the palm oil processing industry. Our deputy chair, Prof. Dr. Chong Mei Fong, also shares her pre-commercialized Integrated Anaerobic-Aerobic Bioreactor for Palm Oil Mill Effluent Treatment & Biogas Generation journal in this issue.

Thank all our valued POPSIG members and POPSIG sponsors for their continuous support and dedication - we couldn't have been where we are now without such a tremendous level of endorsement from all of you. Best wishes and good fortune to you in 2021.

Chief Editor
Ausiera Rosland

Technology Development for Improving Palm Oil Milling Processing

The webinar on technology development for improving palm oil mill processing was held on 29th June 2020, delivered by Mr. Nik Suhaimi Mat Hassan who is currently the Chief Engineer at Sime Darby Plantation Research Sdn Bhd. Condensed in his introduction, Mr. Suhaimi tells the story of how today palm oil accounts for 34% of the worlds' vegetable oil production, with Malaysia contributing 39% of the world's palm oil production.

Being one of the major palm oil producers and exporters in the world, Malaysia plays an important role in fulfilling the needs of the growing global market as the world's population is growing rapidly. The oil palm tree is the most efficient crop as it produces 3.8 tonnes of palm oil per hectare of land as compared to rapeseed, sunflower and soybean oil with efficiency of 0.8, 0.7 and 0.5 tonnes of oil per hectare of land respectively. The oil palm utilizes the lowest harvesting area of 7% (20 million hectares) as compared to the total oilseed land area in the world of 289 million hectares. In terms of total world agricultural land, oil palm utilises only a meagre 0.5% of the land area as compared to 4.2 billion hectares used for agriculture in total. In addition to this, palm oil contains almost 50% unsaturated fatty acids and the remaining is saturated fatty acids where it is used as an alternative to trans-fats. This non-genetic modified oil is also rich in antioxidants and used widely in various food and non-food products.

Lately however, the oil palm industry has been accused to be unsustainable, causing major deforestation and killing of the Orang Utan and palm oil has also been linked to causing health related problems by certain quarters of the public, which led to banning of palm oil by the European Union. Hence, it is a crucial time now to spread the truth about palm oil by creating awareness to shift public's perception based on actual facts of palm oil.

Graduated in Chemical & Processing (B. Engineering and MSc) from Universiti Kebangsaan Malaysia and has been working for more than 16 years in Research and Development field. Mr. Nik Suhaimi's work focuses on oil mill process improvement, particularly on process improvement, product quality enhancement and new product development. He is tasked to provide technical supports for mills on technology evaluation, assessment, advisory and troubleshooting works.

Palm Oil Milling Initiatives

Oil Extraction Rate (OER) has hit a plateau in the oil palm industry due to several reasons such as inconsistency of fresh fruit bunches (FFB) quality received at the palm oil mills and due to the use of conventional machinery for production of crude palm oil which has reached its limit pertaining to oil recovery. Generally, majority of the oil is located in the vacuoles of the plant cells as free oil and dispersed into the cytoplasm within the mesocarp of the oil palm tissue. The current oil extraction process at mills is carried out by mechanically extracting it from sterilised and digested fruitlets. However, mechanical methods have reached the limitations on further improvement of the OER. Several technologies have been approached to enhance oil recovery via biological treatment, oil enhancer and process modification.

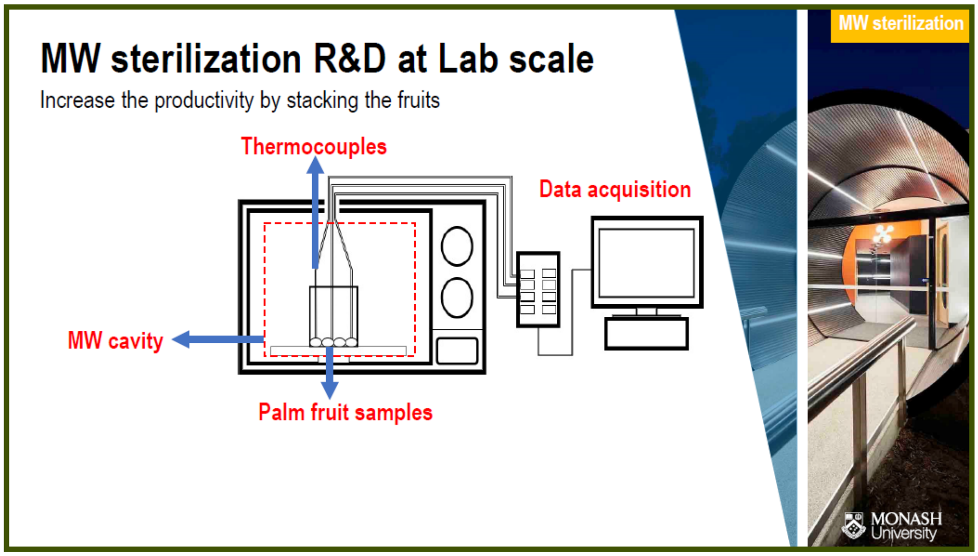
Sime Darby Plantation Research & Development department acting as the research arm of SDP, is continuously looking at technology leads to remain operational efficiency, sustainable and competitive. In between the year 2014 until 2017, there is a significant decline of Oil Extraction Rate (OER) observed which was mostly affected by vendor changes. To comply the policy regarding deforestation, handling the misleading claims and negative campaign, Primary Industries Minister (YB Teresa Kok) has issued a mandate for plantation industry to put a stop on land expansion. With no more land expansion, it is crucial to improve process efficiency to get higher yields.

The optimum extraction efficiency rate by mechanical technique with present means is in between 90 - 93% depending on the plant machinery and process control. The typical crude palm oil extraction rate (OER) during the milling process is ranged in between 18% (lowest) and 23% (maximum) by weight to FFB while palm kernel extraction rate (KER) ranged between 4 - 6%. Total oil loss in mill is between 1.4 - 1.6%. Another alternative technique of using solvent extraction which supposedly capable to provide higher yield of extraction has not been allowed for palm oil industry, thus leaving us with limited option but to compromise the conventional mechanical means of extraction.

The technology development for improving palm oil mill processing is mainly to address on safety issues, to reduce oil losses, increase the process efficiencies as well as to comply with the new regulation by Malaysia government along with the integration of IR 4.0 automation.

Basic palm oil milling process have remained unchanged for relatively so many years, there are a lot of technology developed and tested on improving the processing efficiency, to simplify the design, process safety, automation and environmental friendliness. In this talk, Mr. Nik Suhaimi shared the technology development focuses on five major section of mill processing; sterilization, empty bunch, fibre oil extraction for non-food processing, clarification and wastewater treatment.

Continue



The new technology application on FFB handling during the sterilization eliminates the need of using sterilisation cages, and replacing the batch process using high pressure vessel for safety preserve – hence the introduction of continuous sterilisation process at atmospheric steaming pressure. The evaluation is to improve in terms of fruit handling, simplify the design, safer operation, improved process efficiency and also to reduce the losses.

There is also a technology approach to extract the remaining 5% oils from fibres which are normally being used as boiler fuel at palm oil mill. Pressed fibre is transported to palm fibre extraction plant for oil recovery and the fibre after extraction is said to have 1% oil content remained. That fibre will still be used as boiler fuel to generate the energy for milling process while the extracted oil which is rich in carotene and palm Vit E is used for non-food application. Based on study, the caloric value in the fibre reduces about 10% after the extraction. Replying to question asked by a participant in Q&A session, the mills are using palm shells to top up the losses of 10% energy from the fibre extraction.

The more stringent discharge quality requirement imposed by the authority is pushing the industry with developing system with higher rate of biological treatment. This includes the use of anaerobic digester tank – some combined with biogas, mechanical system aerobic and introduction of polishing plant to meet the authority requirement for discharge standard.

The evolution of technology in palm oil milling industry which in this talk, Mr. Nik Suhaimi covers on the 3rd generation evolution which is the current development and is expected to be commercialised within the next 5-10 years. He focuses on the enzymatic assisted extraction process.

Enzymatic technology in palm oil mill processing.

With the past improvement focusing on mechanical machineries, Sime Darby has collaborated with Novozymes to explore and integrate biological means in current mechanical processing. Enzyme is substance produced by living organism which acts as a catalyst to bring about a specific biochemical reaction – is biodegradable, non-GMO and safe to use in food processing. Additional cocktails of hydrolytic enzyme to mesocarp fibre metric improves the digestion of the cell wall rupture. The combination of the digester and screw pressing step results in more oil being lacerated and at the same time reduces losses in the press fibre stage. This approach also helps to alleviate pollution to water quality, separation of oil and water phase during clarification process reduce water usage which results in reduce generation of oil in effluent.

Preliminary studies were conducted where they did maceration of fruitlets phase with enzyme – shows a very significant difference of oil release, with the condition of fibres indicating ease of oil separation with the help of enzyme. Several study was conducted with different methods; Soxhlet Extraction, Ultrasonic + Soxhlet Extraction and Supercritical Fluid Extraction (CO2). Mr. Nik Suhaimi highlighted that this application was already patented. He also shared the microscopic image of the fibre treated with enzyme in comparison to the ones in controlled condition, result shows that the enzyme treatment extracts more oil from the sample.

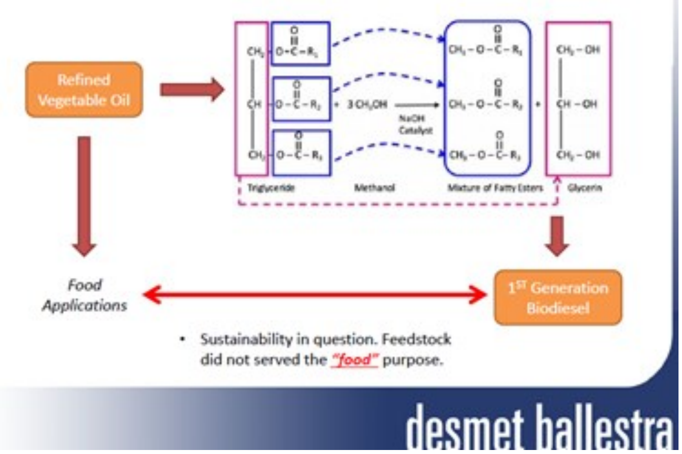
With the potential shown in lab trial, the development was then tested at mill which enzyme was introduced at MPD (mass passing through digester) and to ensure a better mixing of enzyme with fruitlet, pre-digester was also installed. This helps to increase retention time and allowing the biological process to take place. The commercial mill trial conducted in a 60MT FFB/hr mill has achieved > 1.0% OER increment with enzymatic treatment and installation of pre-digester. Result concluded based on a 6 months trial period with alternating sequences of enzyme cycles and control cycles. The conclusion is based on OER and enzyme vs. control runs, with a rigorous statistical analysis to confirm 95% statistical degree of confidence. Improvement has been made to this process later on by dosing the enzyme into diluted crude oil (DCO), which simplify the process as pre-digester (which is costly in the first place) will not be required and creates the opportunity for viable OER enhancement. This improvement is more effective thanks to the liquid-liquid fraction as compared to introducing the enzyme at MPD which mixing between liquid-solid is more challenging. The application of enzyme dosing into DCO, capital cost will be reduced (since pre-digester is costly), reduce power consumption as well as space utilization for the equipment installation in the current palm oil mill.

His vast experience and interdisciplinary skills in conducting researches and transforming laboratory test into pilot and commercial scales has resulted in few successful commercialisations of in-house developed processes where he is involved in the plant process design as well as mechanical design – Mr. Nik Suhaimi has contributed 6 patents on palm oil mill process improvement. In 2019, he won IChemE Malaysia Award 2019 for both categories Sustainability and Palm Oil for *Oil Recovery Enhancement using Cell Wall Degrading Enzymes in Palm Oil Extraction Process* and represent Malaysia for Global IChemE Award 2019 in Hull, UK. This year, he and his team received Best New Patent Filing for 2018 Award for Innovation Day 2019 by Sime Darby Plantation.

Biodiesel from Low Grade Feedstock

This talk was delivered on Monday 3rd August 2020 by Mr Tan Liok Min who is currently the Process Manager Oleochemicals at Desmet Ballestra (M) Sdn Bhd. Desmet Ballestra Group is a company involved in developing, engineering and supplying technologies, processing plants and proprietary equipment for various business divisions including Oils & Fats, Detergents, Surfactants Soap & Chemical Plants, Rosedowns Pressing, Stolz Animal Feed & Agro Food Equipment.

Biodiesel is mainly derived from edible oils which over the years has leads to an increasing criticism of its sustainability, set forth as a competition of usage between food versus fuel. The concern is can the industry produce enough biofuel without threatening food supplies and biodiversity? On top of that, using edible oils as the only feedstock for biodiesel production contributes to higher food price, deforestation, pricey taking into account of the total production cost and economical sustainability is very dependent on government grants and subsidies. Second generation biofuel technologies have been developed following to this disparagement. The second generation biodiesel includes nonedible vegetable oils, used cooking oils as well as animal fats. These are considered as promising substitute for edible oils as they neither compete with food purpose nor lead to land-clearing. Biodiesel produced from renewable energy sources have drawn much interest and are widely researched even to this day.



Transesterification – being the most efficient technique to produce Biodiesel require relatively clean feedstock. However, the low-grade feedstock is generally high in free fatty acids and other elements which make them not suitable to be processed directly in the conventional transesterification plant. Mr Tan shared the challenges faced in terms of properties and composition when dealing with non-refined feedstock, mainly on the wide range of quality that may vary truck after truck upon receiving at the plant as any waste available on market is possible to be processed. This demand a very tailor made process design and relevant operating unit to the plant.

Mr Tan Liok Min who has been working for almost 15 years in the Oils & Fats, Food Emulsifier and Oleo chemical field, has vast experience in laboratory testing, research and development, process design and engineering, plant operation, quality management, project management, plant commissioning, process issue troubleshooting and continuous improvement. In this session, Mr Tan focused the scope of low grade feedstock to the application of used cooking oils (UCO) and animal fats as these two are commonly available in market.

Common conversion processing techniques for biodiesel includes base-catalysed transesterification, acid-catalysed transesterification using H_2SO_4 / LC-MSA or cation exchange resin, and enzymatic transesterification (ETE). In processing low grade feedstock, base-catalysed transesterification offers the most suitable design. Mr Tan also shares the critical specification for low grade feedstock – the presence of certain elements, their impact on the process and final quality of product e.g. FFA when reacting with catalyst will cause soap formation, phosphorus creating emulsion problem, etc.

To produce in-spec biodiesel out of this extremely contaminated low grade feedstock, pre-treatment (degumming, adsorption, stripping) and post-treatment (post distillation) unit is introduced before and after the standard biodiesel plant respectively.

- Degumming: converts non-hydratable phospholipid into hydratable form that can be easily removed in subsequent washing/adsorption steps.
- Adsorption: by application of silica or bleaching earth combination with filtration, to remove impurities (soaps, phospholipids, oxidation agent, trace metals and other contaminants) prior to stripping step.
- Stripping: distillation at deep vacuum and high temperature to remove free fatty acids (FFA) which recovered as fatty acid distillate.
- Post distillation: purification process based on different boiling point.

The session ended with a very engaging Q&A and the questions posed has received a well-rounded answer by Mr Tan Liok Min.

Application of Microwave Technology in Oil Palm Industry

The palm oil industry has been slower in adopting new and alternative technologies since 1970s in the industry. Among this is the sterilization process, which consumes extensive amount of energy (in form of high-pressure steam) and takes longer processing time (~1 to 2 hours). Steam based sterilization process also produces palm oil mill effluents (POME). The type (batch vs. continuous) and heating method of sterilizer technology would greatly affect the performance and energy efficiency of the sterilization process. Another issue in the palm oil industry is the generation of huge amount of biomass. It should be noted that oil palm tree can only produce ~10% of crude palm oil and remaining is the biomass in the form of fronds, trunks, empty fruit bunches (EFB), oil palm shells (OPS), and oil palm fibres (OPF). Efforts have been done to convert these biomasses into value added products. However, most of the technologies either sterilize or valorise the biomass based on conventional heating method. Therefore, an alternative technology such as microwave heating was explored in recent years to sterilize the fresh palm fruits and valorise the biomass.

Visual representation of Dr Arshad's research focus

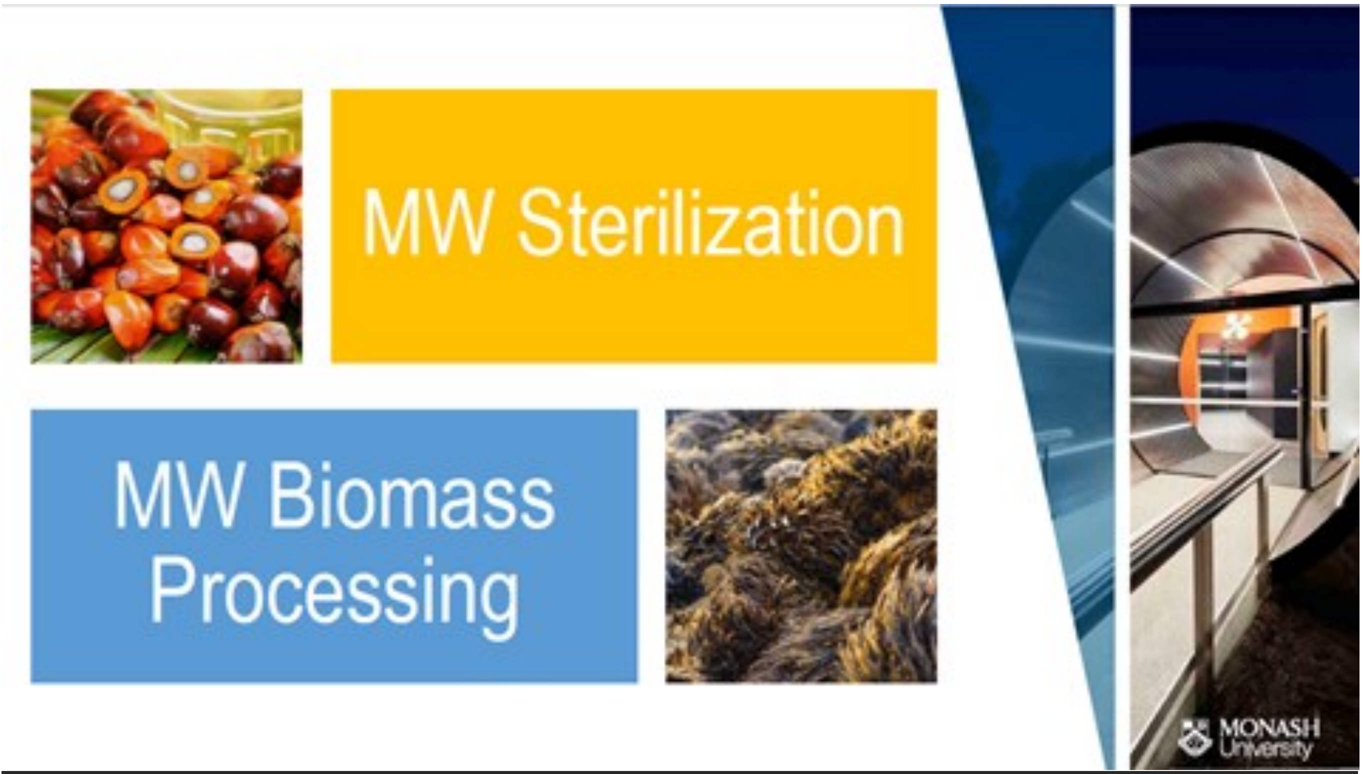
In this evening talk session held on 7th September 2020, Dr Arshad Adam Salema did a presentation on the application of microwave technology in palm industry. Dr. Arshad graduated his Bachelor's in Chemical Engineering from University of Pune, India, Master's in Chemical Engineering and PhD in Mechanical Engineering from Universiti Teknologi Malaysia. He did postdoctoral at University of New Brunswick, Canada and is currently working as a Senior Lecturer at Monash University Malaysia. He is a registered Chartered Engineer and Associate Member with Institution of Engineers, India, Life member of Indian Institute of Chemical Engineers, India and Graduate Engineer with Board of Engineers, Malaysia.

Being passionate in renewable energy, process design and development of thermo-chemical system, microwave processing, energy efficiency and sustainability. Dr Arshad has experience in design and development of bench scale fluidized bed reactor to produce high siliceous rice husk ash. He also developed both a lab scale and bench scale microwave pyrolysis system at UTM, Malaysia and UNB, Canada, respectively. One of his current projects is on "Microwave sterilization of palm fresh fruits", with Sime Darby Research Sdn. Bhd. and "Thermo-kinetic optimization of oil palm biomass pyrolysis products using hybrid Artificial Intelligent model" under FRGS grant, Ministry of Education.

The presentation focused on the fundamental, technical and application of microwave technologies in the palm oil industry. Although there are several benefits and advantages of Microwave technology over conventional heating method, it is still surrounded by critical technical challenges that hinder the scale-up and commercialization process of MW technology.

Note: Dr Arshad is also currently working on "Techno-economic feasibility of using solar energy for BRT Sunway electric buses", with Prasarana Bhd. and Sunway Group of Companies.

Continue



The challenges are divided into feedstock (biomass), process (technology), and product.

He started his presentation with introducing the comparison between microwave and conventional type of heating in radiation technology – explaining on the volumetric heating and of this technology contributing to energy saving among the other advantages before going into the limitations faced in the scale-up process which involves safety concern, scaling up and technical difficulties learned from his study on this technology. Few installation has been done on few grounds on lab scale, most have modified the domestic kitchen microwave including Dr Arshad himself, which is the most cost effective way to study this technology further. At the moment, they are still working hard on their research to determine whether this technology is techno-economically feasible or not.

In microwave sterilisation pilot scale, they are only using loose fruits as there can only be one layer on the conveyor belt that goes into the microwave cavity. The design dimension – mainly the inlet opening limits the material to be no larger than loose fruits, hence the difficulty in testing the technology with fruit bunch which leads to restriction of study on productivity. Study on the design is in work, to make do with the current design, Dr Arshad explained in depth on their experiment with stacking of the fruit bunch, its effects to the process including the heat transfer distribution inside the microwave cavity.

In most experiment done using domestic microwave, the temperature was observed from the outside of microwave. On the contrary, in his study, the exact temperature is being observed during the microwave heating sterilisation by placing thermocouple selected areas of the biomass used. Dr Arshad also shared the result from one of his experiment relating between the power and the temperature profile.

In explaining on the biomass processing topic, Dr Arshad has introduced the fundamental behind using microwave technology to produce bio-oil and biochar. Since the changes to the microwave technology are limited to the design, power and frequency which does not have much flexibility, biomass plays a major role in learning the heating and processing of microwave technology. In the case where biomass has low microwave absorption, a hybrid or a mix of that particular biomass with another substance that possess good absorption characteristic is done. Dr Arshad shared an interesting anecdote during his PhD which taught him the selection of material for the hybrid too is important so the temperature does not rise above the desired point and in his case involves melting incident of his experiment set up. Other than palm fruits, he has also studied this technology with various biomass i.e. coconut shell, palm leaves, barley and found that interestingly most biomass have a very common characteristic of loss tangent.

Before ending the session, Dr Arshad highlighted that this technology is currently at preliminary stage, some have gone to pilot scale in optimization and process design. The plan in the coming years is to explore and successively solve the limitations – eventually commercializing this technology.

IChemE Malaysia Palm Oil Award

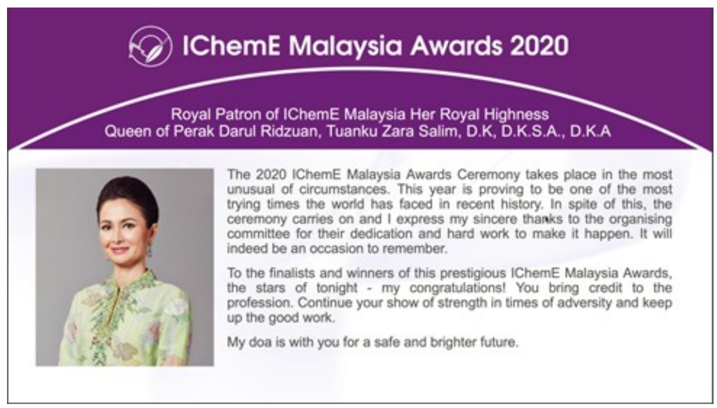
Flashback: IChemE Malaysia Awards 2019 in full splendor

IChemE Malaysia Awards 2020 goes virtual

Due to the current Covid-19 pandemic IChemE Malaysia Awards 2020 went virtual for the first time in its history from 6 to 6.30pm on Monday 19th October 2020.

A message from the Royal Patron of IChemE Malaysia, Her Royal Highness Queen of Perak Darul Ridzuan, Tuanku Zara Salim, was shown to finalists during the online ceremony.

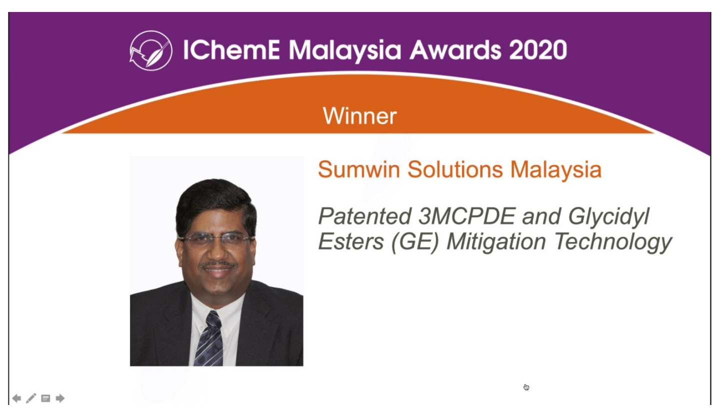
PETRONAS were victorious in four of eight categories and also secured four highly commended entries.



Message from the Royal Patron of IChemE Malaysia

The eight categories for IChemE Malaysia Awards 2020

Sumwin Solutions triumphed in the Palm Oil category for their new patented technology and process to reduce the levels of a potentially harmful chemical compound from palm oil to fully meet European standards, enabling edible products to be marketed successfully in European countries.



Winner Palm Oil Category represented by Mr. U.R. Unnithan, Founder and CEO of Sumwin Solutions Malaysia Sdn. Bhd.

Continue

Palm Oil Award

Winner: Sumwin Solutions Malaysia - *Patented 3MCPDE and Glycidyl Esters (GE) Mitigation Technology*

Summary of winning entry:

European regulatory body European Food Safety Authority (EFSA) has already set the standard for the level of 3 monochloropropane 1-2 diol esters (3MCPDE) and glycidyl esters (GE) in vegetable oils, including palm oil. These components have been proven to be carcinogenic and are harmful for human consumption. Not meeting the EFSA guideline makes marketing of palm oil for edible applications extremely difficult. All alternate technologies have huge capital expenditure (CAPEX), operational expenditure (OPEX), maintenance cost and are not environment friendly. Sumwin's patented breakthrough technology overcomes all these problems by offering low CAPEX, low OPEX and avoiding emulsification virtually eliminates oil loss in wash water thereby making it an environmentally friendly process. The global vegetable oil industry would benefit greatly from this innovation.

Commenting on his achievement Mr. Unnithan said:

"Humbled & honoured to win the IChemE Palm Oil Award 2020 and to be included as a finalist in the IChemE Global Awards. Sumwin would like to thank all customers, suppliers, employees, MPOB (Malaysian Palm Oil Board) and other stakeholders who have contributed to this success. As a practitioner in the Palm Oil industry for 28 years and as a Fellow of IChemE, I am pleased that Sumwin's Patented 3 MCPDE & GE mitigation technology can be adopted by the industry at the lowest CAPEX & OPEX"

Ir. Qua Kiat Seng, IChemE's Malaysian board member and POPSIG founder, in congratulating Mr. Unnithan said:

"I have been following the developments on this matter over the past decade and we are really proud that a chartered chemical engineer in Malaysia is able to offer a technological solution to the vegetable oil industry."

Highly commended: Universiti Kebangsaan Malaysia, Sime Darby Research and Yayasan Sime Darby - *Zero Waste Technology*

Prof. Ir. Dr. Law Chung Lim, Chair of IChemE's Malaysian Board, said:

"Congratulations to all of our winners tonight. This is recognition by your peers of the work you are doing day in, day out that demonstrates how you are helping to solve worldwide issues to advance chemical engineering's contribution for the benefit of society.

"Since its inception in July 2006, we have seen a growing participation from various industries in the IChemE Malaysia Awards. We hope to see that trend continue in the coming years to showcase and encourage more joined up thinking and collaboration between STEM professionals so that chemical engineers and the profession remain at the forefront of innovation as the world evolves."

Winners of the IChemE Malaysia Awards will automatically be entered into corresponding categories at the IChemE Global Awards, which will be delivered virtually through a series of webinars in November. Winners of the Global Awards are eligible for the overall award for *Outstanding Achievement in Chemical and Process Engineering.*

Highly commended Palm Oil Category : The UKM team with their Deputy Vice-Chancellor (Research and Innovation) Prof. Dato' Ir. Dr. Abdul Wahab bin Moham-

First MOSTA-POPSIG Collaboration Exceeds Expectations

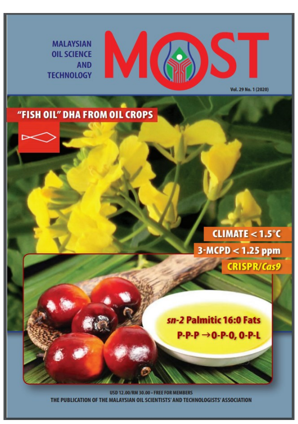
The webinar workshop with the theme Mitigation of 3-MCPDE & GE : Industry Perspective was held on Thursday, 15 October 2020 from 10.00 am to 12.30 pm. There were more than 150 participants.

Academician Tan Sri Emeritus Prof Datuk Dr Augustine S.H. Ong, President, MOSTA about to deliver his welcoming address.

MOSTA (Malaysian Oil Scientists' & Technologists' Association) has, since the topic surfaced in the last decade, been in the forefront seeking answers to the issue of 3-MCPDE (3-MonoChloroPropaneDiol Esters) and GE (Glycidyl Esters).

3-MCPDE is found in processed meats, sauces, gravies, biscuits and most vegetable oil where it is highest in palm oil. 3-MCPDE could pose risks to kidneys and testes and are formed unintentionally during oil refining processes at high temperatures in the presence of chloride ions.

GE are probably genotoxic and carcinogenic and increases during high temperature deodorisation. In both cases diacylglyerol (DAG) present in crude palm oil are precursors.



MOSTA's latest effort was published in MOST issue 2020 July Vol 29(1) where its editor Dr Goh Swee Hock has made an excellent summary of the MOSTA Workshop on Mitigation of 3-MCPDE on 19 February 2020.

The European Food Safety Authority (EFSA) has set from 2021 maximum limits for GE at 1 ppm and 3-MCPDE at 1.25 ppm for oils including palm kernel oil and 2.5ppm for other oils including palm oil.

At the workshop at Universiti Alumni Hall, Desmet Ballestra, Alfa Laval, Lurgi and Novozymes presented while Sumwin Malaysia Solutions made a first appearance at a MOSTA event. Mr. Unnithan presented Sumwin's patented technology to mitigate 3-MCPDE & GE in crude palm oil.

When MOSTA approached POPSIG about the next workshop we decided to invite chemical engineers from the industry to present so that participants can learn what a couple of industry players are doing. We are grateful that Sime Darby Plantations and IOI Edible Oils have come forward.

The moderator Ir Qua Kiat Seng, speakers Ir Shyam Lakshmanan and Ir Mervin Chew Chien Lye are chartered chemical engineers and members of POPSIG.

Ir Mervin from Sime Darby Plantations Research Sdn Bhd spoke first. His presentation was titled "Mitigation of 3-MCPDE & GE Precursors in Palm Oil Mill." The mitigation strategies adopted are chloride mitigation and improvement of oil quality to reduce DAG.

Chloride mitigation could broadly be through reduction of chloride in crude palm oil (CPO) by CPO washing or CPO dechlorination by the application of sodium metabisulfite. Also reduction of chloride at source can be done by palm fruits cleaning and secondary oil segregation. Palm fruits cleaning is effective and the reason is under investigation.

Continue

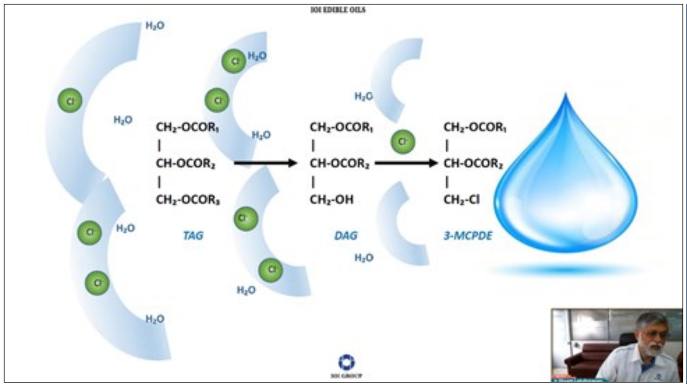
IChemE = Institution of Chemical Engineers

POPSIG = Palm Oil Processing Special Interest Group

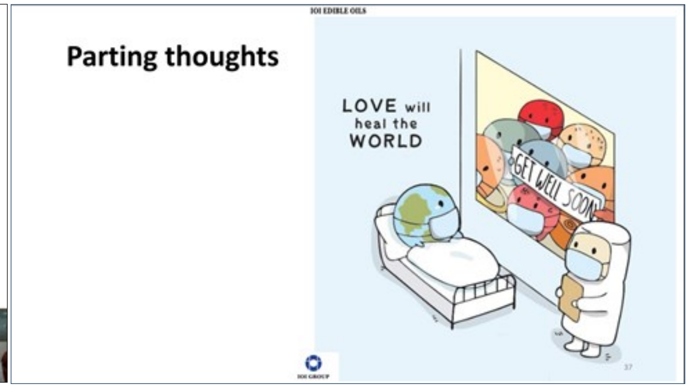
Oil quality improvement is through the reduction of free fatty acid (ffa). Fruit quality is enhanced by reducing enzymatic action through better fruits handling and management of harvesting interval. Autocatalytic action is reduced during processing by managing the time and moisture content as well as segregation of different oil qualities.

On GE he demonstrated a co-relationship between 3-MCPDE and GE. As GE formation during refining is less at lower temperatures it appears that GE should be removed by a post refining/deodoriation stage to meet RBD colour. As 3-MCPDE and GE tends to concentrate in olein fraction, it is needed to target lower levels at the refining stage.

Ir Shyam explored the numerous pathways of 3-MCPDE formation



Ir Shyam's last slide



Ir Shyam presented "IOI Edible Oils' 3-MCPDE & GE Mitigation Initiative." Ir Shyam started with a detailed examination of the pathways of 3-MCPDE formation. He then shared the effect of washing to remove chloride in crude palm oil. Organochloride was more difficult to remove than inorganic chloride and Ir Mervin also alluded to organochloride eg. sphingolipid organochloride in his presentation.

As the 3-MCPDE tests took about a day he made correlations between total chloride content in washed PO and 3-MCPDE in RBDPO for his operations to help him manage his processing. He confirms organochloride does matter.

In conclusion Ir Shyam likened the issue to the current Covid-19 pandemic and urged all sectors in the industry to work together to resolve the issue. Ir Mervin had also earlier concluded with a similar message.

Many questions were received and the Q & A session was over an hour long. Questions that could not fit into the time frame will be done through email. POPSIG looks forward to further collaboration with MOSTA in 2021.

A virtual group photo with the staff at MOSTA office at the end of the webinar workshop

Feedback from participants was very encouraging

- Excellent presentation
- Very good session and very informative
- It was a good quality webinar
- The papers by the presenters were good, the presenters set out their points clearly and presented well, and the moderator was excellent. Well done MOSTA for organising a webinar of such high quality.

Asia Pacific Region Update

- Food Oils and Dairy

The Learned Society Committee has identified 7 Subject Area Leads (SAL) viz Resource & Manufacturing, Energy, Water, Food, Drink & Nutrition, Major Hazards, Education, Innovation & Research and Health & Wellbeing. The SAL Food, Drink & Nutrition is led by David Platts from New Zealand and POPSIG is in his committee. SAL Food, Drink & Nutrition is organising a series of webinars in the Asia Pacific to share developments from the region in this subject area.

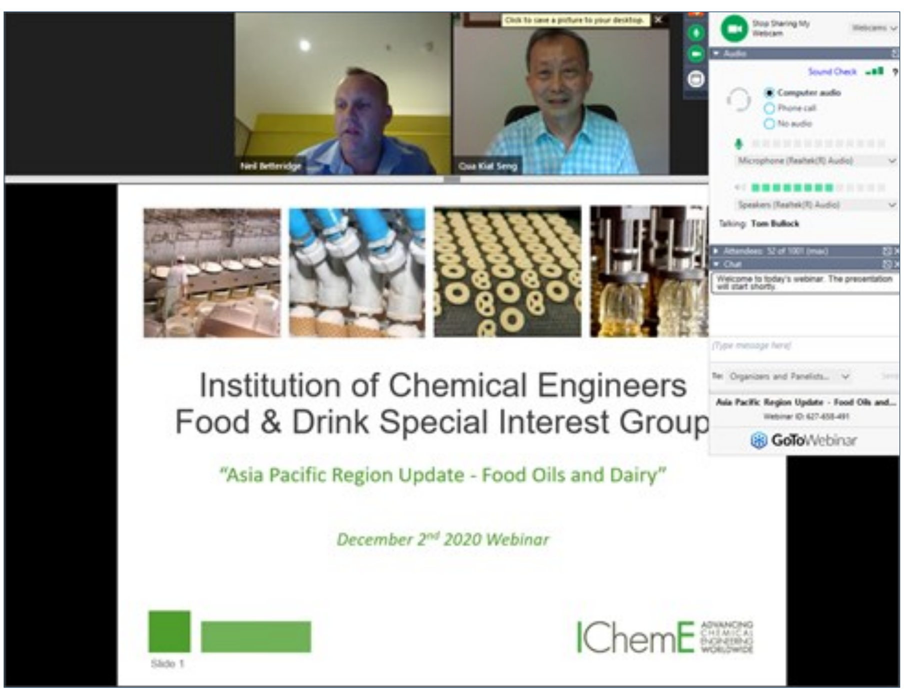
The first webinar was held at 4pm on 2nd December 2020 with the time chosen to cater for UK, Singapore, Malaysia, Australia and New Zealand participants. The webinar presented a snapshot of activities from two regions within the Asia Pacific. Qua Kiat Seng from Malaysia presented a perspective on Vegetable Oils (Palm and Soy etc.) focusing on innovations and the important role chemical engineers play. Neil Betterage from New Zealand compared the production of milk and milk products from the standpoint of two differing approaches, that of New Zealand and The United States of America, including commercial, technical and sustainability aspects.

The webinar was attended by 147 participants from 20 countries including Colombia, Canada and the USA. There was a good mix of participants from industry and academia including undergraduates. The webinar was hosted by Tom Bullock from the Food & Drink Special Interest Group.

The first speaker Ir.Qua Kiat Seng from Malaysia is semi-retired and contributes to University Programmes at Monash and is the founder of the POPSIG. Qua Kiat Seng is a chartered chemical engineer with a 32-year career in operations in the palm oil industry covering oil refining, foods, oleochemicals, soap and toiletries. He worked for Unilever, ICI and KLK in Malaysia and overseas. Before he retired, he was GM of Uniqema Malaysia Sdn Bhd.

Ir. Qua spoke on "Process Innovations in the Vegetable Oils Industry to keep you fed, healthy and safe." He started by giving some background on vegetable oils and their role in our diet, nutrition and health, the global vegetable oils market, sustainability issues and the challenges to keep the world fed in the future. Qua also highlighted the role chemical engineers play in the industry along with other engineers and scientists. He then went on to cover process innovations in protecting nutritional value, increasing oil extraction rates, value from waste, mitigation of contaminants and packaging reform.

The next speaker was Neil Betteridge from New Zealand. He is currently Senior Vice President Global Manufacturing for Fairlife in USA. Fairlife is the fastest growing consumer milk brand in North America which has patented innovative protein concentrating technology. Neil grew up in New Zealand on a dairy farm and studied Chemical Engineering at the University of Canterbury. Neil has more than 20 years in the dairy industry in a range of roles from Operations Leadership, Maintenance & Technology Leadership through to Capital Project management in a wide array of dairy products from infant formula, aseptic drinks, lipids and whey-based ethanol.



POPSIG University Roadshow Webinar — Year 2020 Footsteps

On 19th November and 1st of December 2020, POPSIG's last two final university roadshow webinar event of the year had been a success, leaving behind virtual footsteps into lives of our future engineers. POPSIG was glad to be able to continuously spread the mission of educating the community with palm oil sector's rightful knowledge all thanks to the cooperation from Universiti Teknologi Petronas (UTP), Universiti Malaysia Pahang (UMP), SEGi University (Selangor), Universiti Putra Malaysia (UPM) & Universiti Teknologi Malaysia (UTM). The total number of attendees on 19th November and 1st December were 91 and 102 participants while the first university roadshow webinar event on 21st October 2020 by Swinburne University (Sarawak), Curtin University Sarawak, Malaysia & Universiti Malaysia Sabah, was having 123 participants giving a total of 316 university roadshow webinar attendees.

POPSIG is grateful to have many wonderful and knowledgeable speakers volunteering their time and effort to share their experiences with the students though the university roadshow webinar. They are Pn. Sarafhana Dollah, Ms. Nursabrina Mohd Hayat and Ms. Anna Zulkifli who were representatives from Malaysia Palm Oil Council (MPOC), Ms. Liu Sin Lu and Mr. Chia Ing Chuk from Desmet Ballestra Sdn.Bhd, Mr. Galau Melayong from Sarawak Oil Palm Sdn. Bhd, Ms. Niza Zainuddin from IChemE Malaysia, Ir. Qua Liat Seng and Ir. Hong Wai Onn from IChemE POPSIG. Lastly, not to forget the event organizer Dr. Viknesh Andiappan and Mr. Vincent Tiang.

POPSIG will be working with more universities in Malaysia for the upcoming 2021 University Roadshow. Stay updated with the event on the IChemE POPSIG website.

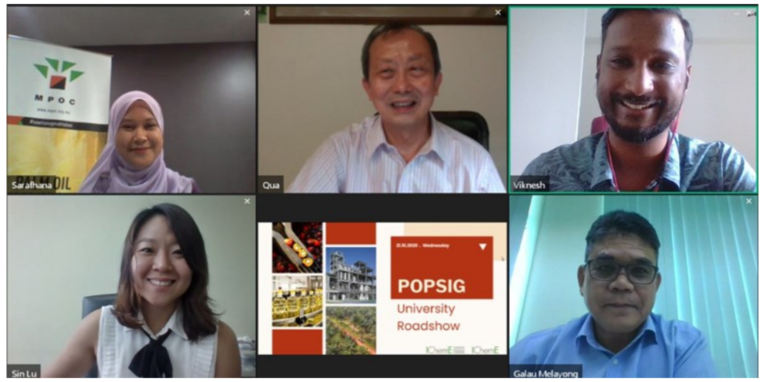


Figure 1: University Roadshow on 21st October 2020
Starting top left with Pn. Sarafhana Dollah, Ir. Qua Kiat Seng and Dr. Viknesh Andiappan. Bottom left with Ms. Liew Sin Lu. Bottom right with Mr. Galau Melayong.

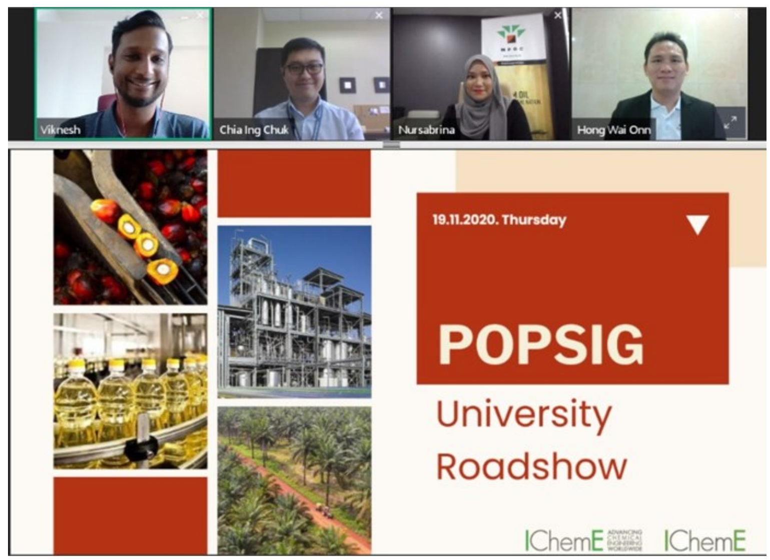


Figure 2: University Roadshow on 19th November 2020
Starting from left with ***Dr. Viknesh Andiappan, Mr. Chia Ing Chuk, Ms. Nursabrina, and Ir. Hong Wai Onn.***

Figure 3: Universiti Roadshow on 1st December 2020
Starting from left with Mr. Chia Ing Chuk, Ir. Qua Kiat Seng, Dr. Viknesh Andiappan, and Ms. Anna Zulkifli.

Palm Oil Processing —The Forgotten Career Path for Chemical Engineers

by Ir. Hong Wai Onn

First featured in: Focus Malaysia (focusmalaysia.my) October 1, 2020

It does not take a long to notice the unpopularity of the chemical engineering and palm oil industry, ask around. In reality, Malaysia is currently the second largest producer and exporter of palm oil worldwide, after Indonesia.

From its humble beginnings, palm oil has evolved to be among Malaysia's most important commodities, and has remained as one of the top ten largest export earners for Malaysia in the past decade.

The advancement of the palm oil industry is a testament to the nation's achievement in terms of its contribution to the gross domestic product (GDP), employment opportunities, poverty eradication, and narrowing the income divide between urban and rural communities.

Much of what made a good chemical engineer, including changing raw materials into useful products, easily transferred into a job that would bring success in a rapidly growing, globally important industry.

If the palm oil processing is such a good industry, you may wonder why so many people are turning away from this industry.

Well, let me offer some thoughts.

Unawareness of Today's Youth

When thinking about career options, very little of today;s youth is choosing to pursue the palm oil processing industry. This could be because they do not understand this industry and have no clue as to how they can contribute to it.

In the period of the 1960s, especially with the establishment of FELDA, many mechanicalengineers were employed to work in the milling sector. To this day, the palm oil millingsector is still heavily populated by them. Why not chemical engineers?

Till the late 1990s, there were only seven universities in Malaysia offered chemicalengineering undergraduate programme. Even then, many chemical engineering graduatespreferred to work in the oil and gas industry as there was lack of understanding on the roleand contribution of chemical engineers in the palm oil milling sector.

We then witnessed chemical engineers started to work in the refining and oleochemicalsectors as career opportunities arose with the boost of these sectors in the 1970s and 1980s.The number is still relatively small compared to petrochemicals sector, though.

Maybe the industry has not reached out to make the palm oil processing highly relevant tochemical engineers, or maybe, dare I say, these careers are not attractive enough for today'syouth since this industry is perceived by them as remote, dangerous, and difficult.

Whatever it is, this needs a paradigm shift if the talent shortage we all face is to be solved.

Unawareness Needs to End

We could argue all day about the industry is not doing enough to attract today's youth, buthave you ever asked undergraduates what they sense from their universities?

While there are engineering degrees offered to address specific industries' needs, they hardlysee degrees focused on palm oil processing.

The underlying message is then echoed at home, because while parents may agree that thepalm oil processing offer a good career path, they will quickly qualify that statement with,"well, but not for my kid." As a result, today's youth fall back on what they know. They are making career decisionsbased on unawareness of what the palm oil processing industry offers.

They are taking the paths most available and recognisable to them. I think it is in everyone'sbest interest—parents, educators and industry players—that the palm oil processing industrybecomes a viable option for as many young people as possible.

Continue

There are some professional institutions dedicated to making the palm oil processingindustry more accessible for young people.

The Institution of Chemical Engineers (IChemE) Palm Oil Processing Special InterestGroup's University Roadshow 2019-2020 has sessions that will present the truth about palmoil to undergraduates and talk about the career prospects in this industry.

There will also be a field trip to one sector of the industry after the half-day event (not in thetime of pandemic).

This Malaysian Palm Oil Council supported event is a straightforward way to introduce theindustry to young people.

In “A Chemical Engineer in the Palm Oil Milling Industry”, a fascinating array of facts andstatistics about the palm oil milling industry are discussed. The book also uncovers theopportunities chemical engineers have in this industry.

It is believed that this is the first memoir that has come out with stories from the palm oilmills. Imagine the impact such a simple reading could have on the career path of a youngperson.

Chemical Engineers Have A Significant Role to Play

Much of the work undertaken by a chemical engineer is applied based on cross-cuttingtechnical knowledge and competencies, such as process technologies, thermodynamics, heattransfer, mass transfer, and the like.

The need for process safety and sustainability underpin all of this across the palm oilprocessing industry, alongside operating with the highest ethical standards and acting inpublic interest at all times.

Chemical engineers in the palm oil processing industry, like in other industries, rely on the knowledge of mathematics and science, particularly chemistry and physics, to maximise process efficiency as well as overcome technical problems safely and economically.

Nonetheless, working with process operation is not the only career option the industry can offer. Chemical engineers also have a significant role to play in plant design.

Chemical engineers can apply technical knowledge to not only perform basic engineering to figure out technical issues and estimate rough investment costs, but also to oversee the building of a project from procurement and construction to commissioning.

For those chemical engineers like research and development, the palm oil processing industry always needs fresh minds to invent and develop new technologies to further enhance the competitiveness and resilience of the industry on a global scale.

Chemical engineers can also work as quality assurance or process improvement professionals. This not only helps plants avoids legal problems like selling finished products that do not meet the standards, but also helps to identify gaps and future opportunities to improve operations and make them more sustainable and safer.

For those chemical engineers like working with people, a number of engineering companies and suppliers of products and solutions employ technical professionals.

They will become a trusted advisor to their customers. They will provide not only technical support but also onsite training to users.

So, chemical engineers have a wide range of career options in the palm oil milling industry. It is unfortunate that today's youth are unaware of the opportunities that the industry can offer.

It does not have to remain that way. Start taking advantage of the many available resources to spark a newfound interest in the palm oil processing industry within your community today. – Oct 1, 2020

PRE-COMMERCIALIZED INTEGRATED ANAEROBIC-AEROBIC BIOREACTOR (IAAB) FOR PALM OIL MILL EFFLUENT (POME) TREATMENT & BIOGAS GENERATION

Yi Jing Chan, Foo Seng Hue, Mei Fong Chong, Denny K.S. Ng, David Lian Keong Lim

Journal of Oil Palm, Environment & Health 2020, 11:57-66 doi:10.5366/jope.2020.06

Abstract

Integrated anaerobic-aerobic bioreactor (IAAB) is a bioreactor technology which operates as a single treatment unit for the removal of organic matter and generation of biogas from Palm Oil Mill Effluent (POME). It is a single reactor configuration with compartmentalization in which the first, second and last compartments are designed for anaerobic, aerobic and settling processes respectively. A precommercialized IAAB (3000 m^3) was built at Havys Oil Mill Sdn Bhd which is located at Palong, Malaysia, with the objective of investigating its long-term performance under variable organic loads and environmental conditions with respect to effluent quality and methane yield. The pre-commercialized IAAB system was directly fed with raw POME from the palm oil mill. Based on the results, at the steady state operation of over five months, the IAAB achieved a total removal efficiency which was up to 99% for chemical oxygen demand (COD), and biochemical oxygen demand (BOD) and methane yield up to 0.26 L CH_4/g COD at organic loading rate (OLR) of 2.0 – 20.0 kg COD/m^3 day. The achievement of BOD <100 mg/L throughout the 150 operational days with 45% of compliance was reported. The system could significantly reduce 70% of footprint and 78% of hydraulic retention time (HRT) compared with current conventional treatment systems. Further work on optimization for the recirculation flow rate in the anaerobic zone with consideration of fluid dynamics and microbiology is required to achieve 100% compliance of BOD <100 mg/L.

1. Introduction

The palm oil industry in Malaysia has become one of the main contributors to the economic growth of the country. Malaysia's tropical climate facilitates these successful agricultural activities. To date, Malaysia accounts for 28% of world palm oil production and 33% of world exports[1]. However, the production of crude palm oil (CPO) has also generated significant agro waste, namely palm oil mill effluent (POME). POME is recognized as an underutilized agro-output that exhibits high acidity with average values of 50,000 mg/L chemical oxygen demand (COD) and 25,000 mg/L biochemical oxygen demand (BOD)[2]. The high amount of such wastewater produced is due to the high utilization of water in processing the fresh fruit bunches (FFBs) during oil extraction, washing and cleaning processes. It was reported that most palm oil mills in Malaysia operate at a capacity of 45 T/h of fresh fruit bunch (FFB) while producing 29.25 T/h POME[3]. Undoubtedly, this has triggered the need for better agricultural, industrial and sustainability practices to be implemented in palm oil mills.

Generally, POME treatment involves both anaerobic and aerobic degradation, as applying former method alone is insufficient to meet current effluent discharge legislation. Chan et al. (2009) reviewed that the organic matter in anaerobic effluent is not completely stabilized and an additional post treatment step is required to treat the ammonium ion and hydrogen sulphide found in effluent[4]. Hence, aerobic degradation is implemented to further treat the anaerobic effluent to meet the stringent discharge standard. Moreover, the anaerobic-aerobic process is capable of providing higher overall treatment efficiency, while effectively reducing energy consumption, as well as sludge disposal[5,6]. The anaerobic-aerobic system using high-rate bioreactors have been extensively studied to identify better options in treating POME. For instance, the upflow anaerobic sludge blanket (UASB) reactor has demonstrated various positive features such as its capability in treating high organic loadings with short hydraulic retention time (HRT) while consuming less energy[7]. Various novel designs which incorporate the features of UASB have been proposed to enhance bioreactor performance in treating POME. Najafpour et al. (2006) suggested to couple upflow fixed film (UFF) with an UASB reactor to shorten the start-up period at low HRT[8]. The hybrid reactor, i.e. upflow anaerobic sludge-fixed film (UASFF) bioreactor was proven to be able to remove 97% COD at HRT of 3 days with organic loading rate (OLR) of 11.58 kg COD/m3 day[8]. Poh and Chong (2014) also demonstrated that an upflow anaerobic sludge blanket-hollow centered packed bed (UASB-HCPB) reactor could remove 90% COD and BOD, and 80% suspended solid, while producing 60% methane[9].

In recent years, the idea of utilizing compact high-rate bioreactors has garnered attention in overcoming space limitations, odour problems and biosolids production[4]. The high rate integrated anaerobic-aerobic bioreactors (IAAB) have been developed to replace the conventional treatment methods mentioned above. IAAB can be defined as a breakthrough in innovation as it exploits the benefits of both the anaerobic and aerobic degradation processes while providing better biodegradation. The capability of IAAB in treating POME within a short hydraulic retention time at reduced space utility has been demonstrated in a previous study. The overall COD, BOD and total suspended solids (TSS) removal efficiencies greater than 99% were attained for OLR up to 18.5 kg COD/m^3 day, with methane yield of 0.32 L CH_4 / g COD removed[10].

Continue

The study showed encouraging results; and hence, the current study focuses on utilizing the similar IAAB design at a pre-commercialized scale to further evaluate the efficiency of the unit in treating POME. The present study was undertaken to investigate the performance of the precommercialized scale IAAB at different OLRs under the mesophilic condition as the determined maximum sustainable OLR would indicate whether the proposed novel design is practical for industrial utilization.

2. Materials and methods

2.1. Wastewater preparation

POME was sourced from Havys Oil Mill Sdn Bhd, Malaysia and its characteristics are presented in Table 1.

Table 1: Characteristics of POME based on the data over five months (from 21 Dec 2017 to 21 May 2018)

Parameter	Units	Average	Range
pH	-	4.5±0.10	4.18 - 4.7
BOD	mg/L	35,100±10,391	4,100 – 86,700
COD	mg/L	74,016±37,738	8,500 – 176,400
TSS	mg/L	31,611±15,531	31,200 – 34,300

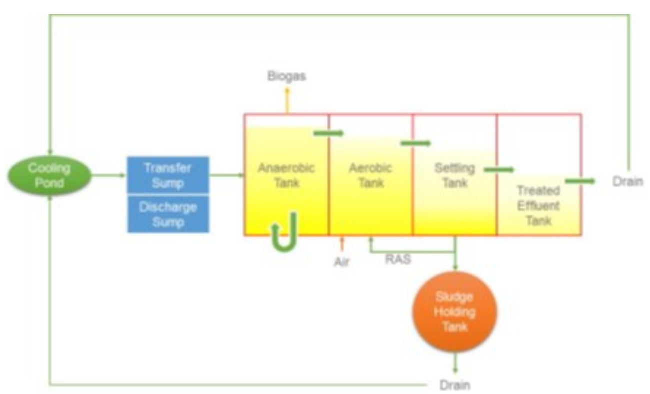
2.2. Reactor configuration and operating Procedures

The schematic of the IAAB is shown in Figure 1, while the photo for the unit is shown in Figure 2. This IAAB unit has a capacity of 10 m^3/h (maximum inlet flowrate) which is about 20% of the full-scale plant based on a 60 t/h of FFB mill capacity. As shown in Figure 1, the IAAB system consists of a transfer sump, an IAAB unit, a treated effluent tank and a sludge holding tank. Raw POME is fed to the transfer sump where a grip trap with bar screens is installed to filter out coarse solids and debris. The raw POME is stored in the transfer sump to ensure a constant supply of POME into the-anaerobic compartment, in which the degradation of complex organic matter without oxygen occurs. The feeding system is designed with an upflow manner and the POME is fed into a liquid distribution system through an inverter-controlled feed pump. This anaerobic compartment with an effective volume of 1125 m^3 is the major equipment in the biogas plant. The anaerobic compartment is inoculated with the anaerobic sludge obtained from the ponding system in the same palm oil mill. The anaerobic bacteria activity, mixed liquor suspended solids (MLSS), pH profile and upflow velocity are maintained for an efficient performance. Recirculation system in the anaerobic compartment ensures homogenous and uniform distribution of the POME. For the purpose of sampling and removing scum, POME can be released from the side of the anaerobic compartment to the drain sump. Biogas is collected from the geomembrane installed at the top of the anaerobic compartment (Figure 2) and is sent to a moisture separator (MS) for moisture removal. A flame separator (FS) is also used to prevent fire or explosion before releasing the biogas from the blower at 40˚C and 1 atm. The pressure of biogas in the geo-membrane is controlled by using the blowers at 0.4 mbar. The safety of the biogas geo-membrane is ensured with manual relief valve. After being treated anaerobically, POME overflows into the aerobic compartment (977 m^3) where the waste is further digested in the presence of oxygen. A blower is used to supply air to the aerobic compartment from the surroundings, with a dissolved oxygen (DO) concentration of 3 ppm. This is mainly to allow complete sludge mixing in the reactor and to supply adequate dissolved oxygen for biological processes.

From aerobic compartment, the POME overflows into the settling tank where the sedimentation process occurs, allowing the sludge to settle by gravity. The sludge is then transferred to the returned activated sludge (RAS) pump system, where a portion of the solids is returned to the aerobic compartment to maintain the desired biomass concentration in the aerobic compartment. The remaining portion of the sludge is transferred to a sludge holding tank where the sludge is kept in storage. The sludge can either be pumped into the effluent overflow drain by the sludge pumps or be transferred to the transfer sump. Finally, the treated POME flows into the treatment effluent tank from settling tank and is discharged as clear water.

The treatment performance of the IAAB system was monitored and analysed. The stability of the reactor was assessed in terms of pH, MLSS concentration and food-tomicroorganism (F/M) ratio. Samples were collected at different sampling points along the anaerobic and aerobic compartments. The achievement of more than 65% of CODremoval efficiency for three consecutive days was taken as stable performance of the IAAB.

Figure 1: The simplified IAAB system for the treatment of POME



Continue

Figure 2: Pre-commercialized scale of IAAB system (Courtesy of Havys Oil Mill Sdn. Bhd.)

2.3. Analytical methods

For anaerobic process, several monitoring parameters were evaluated during the entire operation. The parameters included COD, BOD, TSS concentrations of the effluent, pH, temperature, $MLSS_{an}$ of the anaerobic compartment, methane yield and composition. Whereas for aerobic process, the COD, BOD, TSS concentrations, pH of the treated effluent, temperature, DO, and $MLSS_a$ of the aerobic compartment were analyzed. Analytical determinations of BOD, COD, and TSS were carried out in accordance with the Standard Methods for the Examination of Water and Wastewater[11]. BOD_3 was analyzed on samples which had been incubated for 3 days at 30°C according to the EQA 1974 Second Schedule. COD was analyzed by using the colorimetric method with a HACH spectrophotometer (DR2000, Loveland, CO). TSS and MLSS were determined by filtering a sample through a glass fiber filter (Whatman grade GF/A, 1.6µm, UK) and the residue retained on the filter was dried in an oven (Memmert, Germany) at 105°C. On the other hand, VSS and MLVSS were determined by ashing the dry sample in a 550°C muffled furnace (Carbolite, UK) for 15 min. The composition of biogas was measured using a biogas analyzer (GFM 416 series, UK).

3. Results and discussion

3.1. Steady state performance of IAAB at different OLRs

The performance of the anaerobic-aerobic system for POME treatment was monitored to evaluate its performance from the aspect of COD and BOD removal efficiencies at anaerobic and aerobic compartments respectively, as well as methane composition and yield at various loading rates. The stability of the IAAB was evaluated from the aspect of pH, MLSS concentration and F/M ratio. The optimum operating conditions for IAAB were determined within the range implemented in this study as presented in Table 2. It is expected that the most appropriate OLR and MLSS concentrations will neither be too low or too high, as both conditions will deteriorate the performance of IAAB. Generally, the IAAB achieved high treatment efficiency with overall COD, BOD and TSS removals of up to 99%, at average OLR of 6.3±4.7 kg COD/m^3 day and total HRT of 10.0±5.9 days. The outcomes of the current study are presented and discussed in the following sections.

Table 2: Operating conditions for the anaerobic and aerobic compartment of the IAAB

Operating conditions	Anaerobic	Aerobic
OLR (kg COD/m^3 day)	0 – 20	0 – 9.5
HRT (days)	4.59 – 27.7	4.1 – 22.7
MLSS (mg/L)	9000 – 49,600	9000 – 40,500
DO (mg/L)	-	≥2
pH	6.5 – 7.4	7.5 – 8.5

3.1.1. COD removal efficiencies

Figure 3 shows the performance of anaerobic compartment in terms of COD removal efficiencies at various OLRs. The anaerobic COD removal efficiency was stable and consistent over 71.70 – 77.30% as OLR range increases until OLR of 10 – 12 kg COD/m^3 day. Thereafter, the anaerobic COD removal efficiency experienced a drastic fall to 65.89% at OLR range of 18 – 20 kg COD/m^3 day. The trend of the results was expected as similar results were portrayed by previous work, where a drastic decreasing trend in anaerobic COD removal efficiency was observed at approximately OLR of 19.6 kg COD/m^3 day onwards[12]. Conversely, the COD removal efficiency in the aerobic compartment was relatively higher and more stable, with an average value of 91±6.1% at OLR ranging between 0.48 – 9.53 kg COD/m^3 day. Similarly, the overall COD removal efficiency of the entire IAAB remained stable, averaged at 95.6 ± 6.6% regardless of the various OLR applied. The effect of OLR on the overall COD removal efficiency was not as straight forward. The overall COD removal efficiency provided by the IAAB system was contributed by the anaerobic and aerobic compartment of the bioreactor respectively. As reported previously, the increment of OLR resulted in lower contribution from anaerobic compartment to the overall COD removal efficiency [10,12]. On the contrary, COD removal efficiency in the aerobic compartment was compensated for the reduction in efficiency posed by the anaerobic zone at high OLR, as the aerobic microorganism activity was promoted. In short, the COD removal efficiencies in the anaerobic and aerobic zones were inversely related.

It was also noticeable that the anaerobic COD removal efficiency was not as high as reported previously[10,12]. This was expected as the present study had not been optimized to cater to the scaled-up volume of the bioreactor. Furthermore, the recirculation flow rate drawn from IAAB by the external

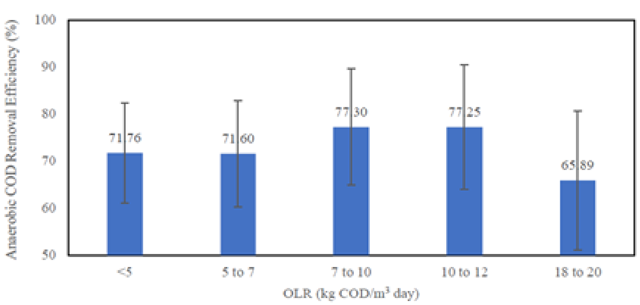
Continue

centrifugal pump was not high enough to provide adequate mixing within the system. This caused solids accumulation at the base of the anaerobic compartment with MLSS, which was as high as 31,637 mg/L.

Generally, mixing in the anaerobic zone is essential as it promotes the distribution of substrates and microorganisms thoroughly within the digester in achieving homogeneity. Mixing can also overcome the rheological behaviour of the nature of slurry which poses complications in attaining turbulence while also forming dead zones inside the digester[13]. According to Singh et al. (2020), approximately 44% failures of the biogas plants occur due to mixing flaws. Therefore, further work can be done in determining the optimum recirculation flow rate in the anaerobic zone through a multidisciplinary approach; this involves the expertise in fluid dynamics and microbiology.

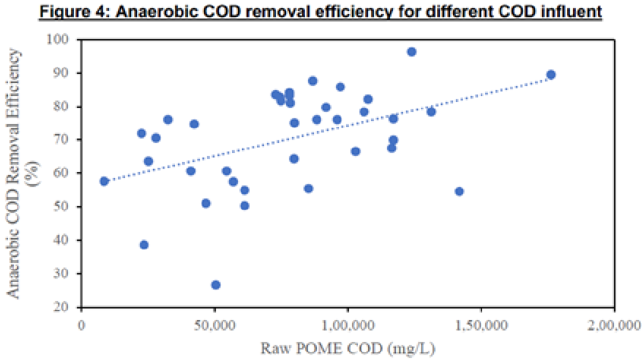
Figure 4 depicts the capability of IAAB in treating POME that

Figure 3: The anaerobic COD removal efficiency of IAAB at different range of OLR



exhibits a large range of COD. It can be observed that the anaerobic COD removal efficiency somewhat increases as the strength of the wastewater increases. This shows that this technology is effective in treating POME which usually exhibits COD at the range of 85,000 – 100,000 mg/L[14].

Figure 4: Anaerobic COD removal efficiency for different COD influent



Undoubtedly, the IAAB technology holds potential for treating a large quantity of high strength wastewater as it is known as a valuable feedstock for anaerobic-aerobic treatment to harness its high COD content for energy generation. Moreover, the present innovation greatly reduces sludge production when it is treated at the anaerobic section of the system[4]. Subsequently, the aerobic section will counter the fluctuations in the quality of the anaerobically treated effluent. The integration and optimization of both biological treatments are indeed a reliable innovation in overcoming the wastewater produced in this industry.

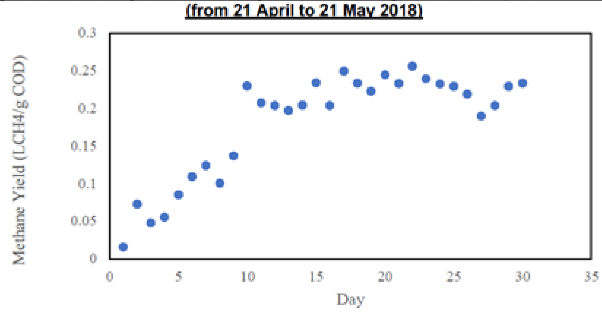
3.1.2. Methane gas composition and yield

The composition of biogas produced by the IAAB is presented in Table 3. The average methane composition of biogas ranges between 60.2 – 64.4%, compared to those obtained by Malakahmad et al. (2014), where the methane content was found to be 54 – 75%; the rest was carbon dioxide[15]. Poh and Chong (2014) also reported that UASB-HCPB reactor successfully produced biogas with methane content of 42.5 – 76.1 %, and the remaining was carbon dioxide when POME was treated under thermophilic condition. The high methane content was desirable as it represented the heating value of the gas. It is noticeable that <1 vol% of oxygen was picked up by the sensor. The oxygen content may be due to the exposure of the instrument to the atmosphere when the biogas was analyzed. Another possible cause was the leakage of oxygen into the anaerobic compartment from the aerobic section of the bioreactor. Nonetheless, the trace of oxygen content is negligible. Hydrogen sulphide generated is expected to be low when methane production is high. This phenomenon is explained by referring to the competition between the sulphate-reducing bacteria and methane producing bacteria for available hydrogen during anaerobic degradation[16]. However, traces of hydrogen sulphide in biogas is still unfavourable as it brings about corrosiveness and odour potential of the biogas, which may consequently lead to hazardous situation when it is ignited. Hence, it is essential to remove the acidic gas from biogas before utilization.

Table 3: The composition of biogas generated by the IAAB

Component	Average	Range
CH_4 (%)	63.2	60.2 – 64.4
CO_2 (%)	31.3	30.2 – 35.1
O_2 (%)	0.35	0.2 – 4.0
H_2S (ppm)	852	814 – 1902

Figure 5: Methane yield obtained by the IAAB throughout the 30 operational days (from 21 April to 21 May 2018)



Continue

Figure 5 indicates that the IAAB exhibited a stable methane yield which fell into the range of 0.190 – 0.257 L CH_4/g COD upon operating since the 10^{th} day onwards. The increase in methane yield also corresponded with the increasing MLSS concentration as the operational day continued until the 30^{th} day.

This shows that the operational condition of the IAAB was conducive for the bacterial activity of methanogens. The methane yield obtained in the present study is similar to the methane yield of 0.22 – 0.24 L CH_4/g COD obtained in mesophilic system at laboratory scale as reported in the previous study[17]. The alignment of the results achieved by the precommercialized scale IAAB with laboratory scale shows the potential of the proposed technology in providing higher treatment efficiency, once optimized.

3.1.3. Recommended operating conditions for IAAB

The operating conditions suggested for the anaerobic and aerobic compartments in IAAB are summarized in Tables 4 and 5 respectively. Referring to the outcome of the present work, OLR of 7 – 12 kg COD/m^3 day is the most appropriate range in attaining stable and consistent overall COD removal efficiency. The lower range of OLR is not selected as higher loading capacity is necessary in reducing the bioreactor volume, which leads to reduced capital costs. It was observed that consistent methane yield was attained over the MLSS range of 18,000 – 19,000 mg/L. In the previous work, low MLSS concentration was reported to be incapable in sustaining high bioactivity in the bioreactor[17]. On the other hand, excessively high MLSS concentration will cause low COD removal, long sludge settling time and high concentration of suspended solid in the effluent[17]. Hence, the MLSS concentration is proposed to be fixed at 19,000 mg/L. Mixing features are also incorporated to the anaerobic zone to promote intimate contact between the microorganisms with the substrate within the system. However, over mixing can lead to reduction of solution surface tension, inversion of digester contents and foaming problems. Therefore, it is suggested to provide intermittent recirculation rate of 140 m^3/h for every interval of 30 minutes and continuous recirculation rate. Nonetheless, it has to be at a lower rate of 70 m^3/h every hour. The COD removal efficiency set for the anaerobic zone is approximately 70 – 85% to ensure that the anaerobic effluent has adequate nutrients for the aerobes to carry out its biodegradation under the presence of oxygen. Hence, COD removal is set to be sufficient but not excessively high to ensure effective aerobic function in the next subsequent stage. Methane yield is expected to be 0.22 L CH_4/g COD with biogas production of 63% methane content. IAAB is expected to be generating power of 390 kW by utilizing methane production of 6 m^3/h.

The F/M ratio in the aerobic compartment is suggested to operate below 0.17 kg COD/kg MLSS day as the treatment efficiency decreases the value mentioned. The present work outcome has also proven that the IAAB is able to achieve a final BOD effluent below 100 mg/L with 45% of compliance. As mentioned in Section 3.1.2, higher COD removal efficiency was attained when operating at lower F/M ratio. In addition, the MLSS concentration is recommended to be within the range of 19,000 – 26,000 mg/L in ensuring that very high aeration is not required in the aerobic compartment because such implementation will increase the operating cost.

Table 4: Recommended operating conditions for anaerobic compartment

Anaerobic	Recommended Range
OLR (kg COD/m^3 day)	7 – 12
MLSS Concentration (mg/L)	19,000
Recirculation Rate	140 m^3/h intermittent mixing for 30 min every hour 70 m^3/h continuous mixing
COD Removal (%)	70 – 85
Methane Yield (LCH_4/g COD)	0.22
Methane Purity (%)	63%
Power Generation	6 m^3/h, COD 80,000 mg/L, 390 kW @40% gas engine efficiency

Table 5: Recommended operating conditions for aerobic compartment

Aerobic	Recommended Range
F/M (kg COD/kg MLSS day)	≤0.17
MLSS (mg/L)	19,000 – 26,000
DO (mg/L)	≥2
COD Removal (%)	85 – 99.6
Energy Consumption (kW/day)	35

DO is supplied at a minimum value of 2 mg/L to sustain the bacterial population of aerobes to provide decent biodegradation of the wastewater. With the suggestions above, final COD removal of 85.0 – 99.6% is targeted to be achieved by this pre-commercialized IAAB. The energy consumption of the aerobic zone is estimated to be 35 kW/d. The presented operating conditions are proposed to be the baseline of the operation of IAAB in attaining high treatment efficiency (overall COD removal efficiency >99%) as well as high methane generation (>0.22 L CH_4/g COD).

4. Conclusion

Efficient performance of the IAAB up to an OLR of 20.0 kg COD/m^3 day was demonstrated; where overall COD, BOD and TSS removals were reported up to 99%, while biogas production was achieved at 63% methane content. It was concluded that the IAAB is a very competitive technology compared to the conventional treatment systems. It can enhance the treatment performance to an appreciable extent and high methane yield. Undoubtedly, the present study has proven that various factors including OLR and MLSS concentration impose significant effects on the performance of IAAB. With consideration of the effects brought upon by different factors discussed in this paper, the anaerobic zone of the

Continue

IAAB is suggested to operate at OLR of 7 – 12 kg COD/m^3 day under MLSS concentration of 19,000 mg/L, and with intermittent and continuous mixing through recirculation flowrate of 140 m^3/h at interval of 30 minutes and 30 m^3/h. The aerobic zone is proposed to run below F/M ratio of 0.17 kg COD/kg MLSS day, under MLSS concentration of 19,000 – 26,000 mg/L and DO supply of more than 2 mg/L. Further work is required in enhancing the performance of the IAAB such as focusing in the optimization of the recirculation rate in providing adequate mixing within the anaerobic zone with consideration of microbiology and fluid dynamics. Positive outcomes of this research will enable a step closer to achieve industrial revolution in the wastewater treatment industry. Hence, this will allow the palm oil industry to play their role in conserving water quality and combating the climate change brought by the conventional treatment systems, which greatly depletes the carbon budget of the Earth. Undoubtedly, this promising innovation will be significant in ensuring safe water and sanitation for mankind while providing access to clean and modern energy.

5. Acknowledgement

The authors gratefully acknowledge the financial support of University of Nottingham Malaysia and Havys Oil Mill Sdn Bhd via an industrial grant.

Abbreviations

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
MLSS	Mixed Liquor Suspended Solid
MLVSS	Mixed Liquor Volatile Suspended Solid
RAS	Returned activated sludge
OLR	Organic Loading Rate
TSS	Total Suspended Solids
UASB	Upflow Anaerobic Sludge Blanket
UASFF	Upflow Anaerobic Sludge Blanket
POME	Palm Oil Mill Effluent

References

1. MPOC. MPOC Overview: About Palm Oil [Internet]. 2020. Available from:http://mpoc.org.my/about-palm-oil/
2. Yacob S, Hassan MA, Shirai Y, Wakisaka M, Subash S. Baseline study of methane emission from open digesting tanks of palm oil mill effluent treatment. Chemosphere. 2005;59(11):1575–81.
3. Akhbari A, Kutty PK, Onn CC, Ibrahim S. A study of palm oil mill processing and environmental assessment of palm oil mill effluent treatment. Environ Eng Res. 2019;25(2):212–21.
4. Chan YJ, Chong MF, Law CL, Hassell DG. A review on anaerobic-aerobic treatment of industrial and municipal wastewater. Chem Eng J. 2009;155(1–2):1–18.
5. B. Frostell. Anaerobic-Aerobic Biological Treatment of Starch Industry Waste Waters. Starch - Starke. 1983;35 (6):185-189.
6. F.J. Cervantes, S.G. Pavlostathis, A.C.van Haandel. Advanced Biological Treatment Processes for Industrial Wastewaters - Principles & Applications. Water Intell Online. 2006.
7. Metcalf and Eddy. Wastewater Engineering: Treatment and Reuse. 4th Ed. McGraw Hill New York, NY. 2003;10.
8. Najafpour G, Zinatizadeh AA, MohamedAR, Isa MH, Nasrollahzadeh HS. High-rate anaerobic digestion of palm oil mill effluent in an upflow anaerobic sludge-fixed film bioreactor. 2006;41(2):370-379.
9. Poh PE, Chong MF. Upflow anaerobic sludge blanket-hollow centered packed bed (UASB-HCPB) reactor for thermophilic palm oil mill effluent (POME) treatment. Biomass and Bioenergy [Internet]. 2014;67:231–42. Available from:http://dx.doi.org/10.1016/j.biombioe.2014.05.007
10. Chan YJ, Chong MF, Law CL. Bioresource Technology Start-up, steady state performance and kinetic evaluation of a thermophilic integrated anaerobic – aerobic bioreactor (IAAB). Bioresour Technol [Internet]. 2012;125:145–57. Available from:http://dx.doi.org/10.1016/j.biortech.2012.08.118
11. APHA. Standard Methods for the Examination of Water and Wastewater. Washington, DC: American Public Health Association. 1989.
12. Chan YJ, Chong MF, Law CL. Performance and kinetic evaluation of an integrated anaerobic–aerobic bioreactor in the treatment of palm oil mill effluent. Environ Technol (United Kingdom) [Internet]. 2016;38(8):1005–21. Available from: http://dx.doi.org/10.1080/09593330.2016.1217053
13. Singh B, Szamosi Z, Simenfalvi Z. Impact of mixing intensity and duration on biogas production in an anaerobic digester: a review. Crit Rev Biotechnol [Internet]. 2020;40(4):508–21. Available from: https://doi.org/10.1080/07388551.2020.1731413
14. Yap CC, Chan YJ, Loh SK, Vimala SC, Soh AC, Chong MF, et al. Comparison of different industrial scale palm oil mill ef fluent anaerobic systems in degradation of organic contaminants and kinetic performance. J Clean Prod [Internet]. 2020;262:121361. Available from: https://doi.org/10.1016/j.jclepro.2020.121361
15. Malakahmad A, Lahin FA, Yee W. Biodegradation of high-strength palm oil mill effluent (POME) through anaerobes partitioning in an integrated baffled reactor inoculated with anaerobic pond sludge. Water Air Soil Pollut. 2014;225(3).
16. Eriksen J, Andersen AJ, Poulsen H V., Adamsen APS, Petersen SO. Sulfur Turnover and Emissions during Storage of Cattle Slurry: Effects of Acidification and Sulfur Addition. J Environ Qual. 2012;41(5):1633-1641.
17. Chan YJ, Chong MF, Law CL. Optimization of palm oil mill effluent treatment in an integrated anaerobic-aerobic bioreactor. Sustain Environ Res. 2013;23(3):153–70.

IChemE offices

Global headquarters

UK

Tel: +44(0) 1788 578214

Email: membersupport@icheme.org

Australia

Tel: +61(0) 3 9642 4494

Email: austmembers@icheme.org

Malaysia

Tel: +603 2283 1381

Email: malaysianmembers@icheme.org

New Zealand

Tel: +64 (4) 473 4398

Email: nzmembers@icheme.org

Singapore

Tel: +65 6250 0385

Email: singaporemembers@icheme.org

www.icheme.org