UNIVERSITI MALAYA

INAUGURAL LECTURE

"Research In Polymer Chemistry Using Local Raw Materials"

11 February 2004

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by:

Professor Gan Seng Neon
(Ph.D., C.Chem, MRSC.,AMIC)
Department of Chemistry, Faculty of Science
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"RESEARCH IN POLYMER CHEMISTRY USING LOCAL RAW MATERIALS"

KOLEKSI ARKIB

by:

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Department of Chemistry, Faculty of Science
U.M., 50603 Kuala Lumpur

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Perpustakaan Universiti Malaya
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Syarahan Perdana ini diadakan sebagai pengiktirafan jawatan profesor di Universiti Malaya

University of Malaya

Professor Dr. Gan Seng Neon
(Ph.D.,C.Chem, MRSC.,AMIC)

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BIODATA

Dr Gan Seng Neon is the Professor of Polymer Chemistry in the Department of Chemistry, Faculty Science, University of Malaya. He started as a student in the Science Faculty of the University of Malaya in 1969, with the initial intention of majoring in Mathematics. Two years later, he was so intrigued by chemistry that he decided to pursue a career in chemistry. He obtained his B.Sc.Hons. in 1973, and went on to complete his Ph.D. in 1976, researching on the storage hardening problems of natural rubber. He obtained a French Government Fellowship for post doctorate training in anionic polymerization at the Centre des Researches sur les Macromolecules in Strasbourg for 1 year. He then returned to University of Malaya in 1978 to serve as a lecturer at the Centre of Foundation Studies in Science (Pusat Asasi Sains) for twelve years. He was appointed Associate Professor in 1986 and was transferred to the Department of Chemistry in 1990. He has spent one sabbatical leave at the Tokyo Institute of Technology, Japan, to do research in Ziegler-Natta catalysts in 1983, and another sabbatical leave in State College, U.S.A., at the Pennstate University, to work on pressure sensitive adhesives in 1989. He was appointed Professor in January 2000

In academic pursuit, Professor Gan has published more than 37 papers in international journals, and presented over 90 papers in both local and international seminars and conferences. He has co-authored "Pengenalan Kimia Fizik untuk STP dan Kursus- kursus Matrikulasi" in Bahasa Malaysia, which was published by UMCB Publication in 1982. He has also authored one book, "Buku Darjah Kimia Moden", published by the Preston Corporation in 1983 (second reprint 1985). He had collaborated with Yutaka Murata to compile a dictionary, "Chemical terminologies: Malay-Japanese-English", published by Mizutani Publ., Aichi, Japan, in January 1988.

Besides teaching undergraduate courses in Physical, Solid State, Industrial Organic and Polymer Chemistry, he has supervised and co-supervised many postgraduate students. Among those who have completed were 2 Ph.D and 12 M.Sc. He is currently supervising another 2 Ph.D and 7 M.Sc. students.

In application research, he has developed and patented a "Method of Curing Epoxy-Polymers" (British Patent Application No.47988/76) in 1976 and "Olefin polymerization catalysts and process for the polymerization of

olefins" (Malaysia patent, PI 9700042) in 1997. Recently he has developed some new water-reducible resins, which could be used in coatings and adhesives, and also as binders to convert waste fiber materials such as old newspapers, oil palm fibers and saw dust into boards. This invention has won a bronze medal at the I Tex 2000 Invention and Design Competition organized by the Malaysian Invention and Design Society on 29th Sept.2000. Realizing the need to develop and diversify the uses of local raw materials, he is currently working on polymer coating for natural rubber gloves, chemical modification of rubber latex, and new polymeric materials from palm oil and its derivatives.

Prof.Gan has been serving as consultant to a number of local companies in solving a wide range of chemical problems. He has worked with Guthrie Chemara, Seremban, on analysis of epoxidized natural rubber from March 91- Feb 92, and May 94 - April 95 and also with Ridgemonde Chemicals & Resins Sdn.Bhd., Shah Alam, on analysis, formulation and R&D problems of emulsion products from March 92- Sept 96. He worked for FACB in solving production problems of expanded LDPE foams from Jun 95-May 96. He investigated some paint problems for Nippon Paint(M) Sdn Bhd, from August 97-Feb 98. He was enggaged as a collaborator to Maskimi Polyol Sdn Bhd in developing new reagents for converting palm oil into polyurethane under an IGS Grant from November 2000 to August 2002. In between these projects, he has also solved numerous industrial problems of short duration ranging from 1 - 2 weeks to about a month. Some of the clients he has served were: Mattel (K.L.)Sdn.Bhd., Motorola, 3M (M) Seremban Sdn Bhd., Tenaga Nasional Berhad, Ansell(M) Sdn Bhd, Kulim, and Funabashi Uchida Manufacturing(M) Sdn Bhd, just to name a few.

In terms of extra curricular activities, he has been a member of various professional societies such as the Malaysia Institute of Chemistry (IKM, Instituit Kimia Malaysia), Malaysia Scientific Association and the Royal Society of Chemistry, and has held various committee posts. He nas served as the Hon. Secretary of the IKM Polymer Section in 1986-89, Hon. Treasurer of Academic Staff Association in 1986, Hon. Secretary and Treasurer for the Royal Society of Chemistry Malaysia Local Section in 1981-83, 1988-89, and 1991-93. He was a member of the Board of Governors of Catholic High School from Nov 1985-Nov 1996. He has represented University of Malaya in the Technical Committee of ISO/TC45 for Rubber & Rubber Products from 1996-2002.

He has received the "Certificate of Service" in Jun 1992 from the Royal Society of Chemistry,London, in recognition of his services as the

Honorary Secretary/ Treasurer for many years to the Malaysian Local Section and organizing various society activities.

He has also received the Award for Excellence in Service 1998 from the Vice-Chancellor, University of Malaya.

PAST PATENTS

1. Method of Curing Epoxy-Polymers, British Patent Application No.47988/76 first filed on 17-11-1976.
   (Inventors: D.R.Burfield, S.N.Gan and R.H.Smithers)
2. Olefin polymerization catalysts and process for the polymerization of olefins. Malaysia patent, PI 9700042, Application filed on Jan 7, 1997. (Inventors : Gan Seng Neon, Aishah Mohd Jelan and Lim Meng Chay).

RESEARCH PROJECTS COMPLETED IN LAST 10 YEARS

1. Polymer & petrochemicals - IRPA (Ref: 02/20/01) RM 182,000, 1988 - 1996
   Major outputs: 12 seminar/conference papers,2 journal papers, 1 Ph.D. thesis,1 M.Sc. thesis, 1 Patent (currently in process of commercialization)
2. Natural rubber chemistry - Vote F, RM3,000. Jan 1995 - Dec 1998, Major outputs: 3 Journal Papers, 1 Conference paper, 1 Workshop Paper, 1 M.Sc.student.
3. Biodegradable polymers - Vote F RM5,000, IRPA RM30,000, Co-researcher to Dr Irene Tan; Jan 1995 - Dec 1997, Major outputs: 4 seminar/conference papers, 2 journal papers, 3 M.Biotech. students.
4. Synthesis and characterization of water-reducible acrylics - Vote F RM2,000, Donation from Ridgemond Chem(M) Sdn Bhd. RM15,000, Jan 1996 - Dec 1998
5. Development of New Polymeric Materials - (IRPA No. 09-02-03-0365), RM 120,000, July 1997- Dec 2000 Major outputs: 2 journal papers, 2 M.Sc. students (final stage),1 Commercialization of improved catalysts (on-going)
6. Biodegradable & bio-compatible polymers - IRPA RM 100,000, Co-researcher to Dr Irene Tan. July 1997-Dec 2000, Major output:1 journal paper, 2 conference papers, 2 M.Biotech students.
7. Development of palm oil polyols for the production of rigid

polyurethane foams -IGP Fund, in collaboration with MASKIMI Polyols (M)Sdn Bhd., RM500,000 being paid in stages, November 2000 - 2002.

ON-GOING RESEARCH PROJECTS

1. Basic research on the production of polyhydroxyalkanoates (PHAs) with a view to commercialization, Supported by Sumirubber Industry Kedah (a subsidiary of Summitomorubber Industry, Japan), Co-researcher to Dr Irene Tan and Prof. Ramachandran. MOA between UM and SRIK was signed on 9-3-2002.
2. Development of polyester polyols from palm oil for the production of flexible polyurethane foams - IGP Fund, in collaboration with MASKIMI Polyols (M)Sdn Bhd., MOA between UM and Maskimi was signed in August 2003.
3. Development of UV-curable polymers from local raw materials - (IRPA No. 03-02-03-0133-EA133), RM148,000, started in December 2002.

University of Malaya

Professor Dr. Gan Seng Neon
(Ph.D.,C.Chem, MRSC.,AMIC)
Jabatan Kimia, Fakulti Sains, U.M., 50603 Kuala Lumpur

Synopsis

Malaysia has abundant natural resources, yet the chemical industry remains virtually insignificant. Most of the chemical products used in the country are imported. Natural rubber, petroleum and palm oil are among the important local resources.

This lecture highlighted some of the research projects, on local raw materials, that the author has carried out at the University of Malaya. The first project on natural rubber was on the fundamental chemistry related to storage hardening phenomenon. The subsequent aspects were more related to applications via chemical modifications. For the petrochemical area, the first project was related to the synthesis of a series of chromium based catalysts for the polymerization of ethylene and propylene. It was then expanded to cover kinetic studies, structural determination of polypropylene, thermal analysis, as well as finding the activation energies and looking at additives that affected the catalyst activities.

Malaysia is the largest producer of palm oil in the world. Almost 90% of palm oil and its products are used for edible purposes. About 10% of the total palm oil production is used for soaps, detergents and oleochemicals. In the initial research projects, the main objective was to make polymeric materials from palm oil. The earlier attempts were to produce water-reducible alkyds from palm stearin, and made them into baking enamels. By variation of reaction conditions, palm olein and crude palm oil were also convertible to alkyds with interesting properties. In an attempt to combine palm oil and natural rubber, a recent postgraduate project was formulated where the alkyd was blended with natural rubber to produce pressure sensitive adhesives. Certain acrylic monomers were incorporated into the alkyds to make the resins UV-curable.

The local palm oil industry has generated over 38 million tons of waste annually, in the form of empty fruit branches(EFB), oil palm fronds (OPF), and oil palm trunks (OPT). One possible use is to make the palm fibers into boards. A water-reducible acrylic resin was developed to bind the fiber into boards of good mechanical properties and without the liberation of formaldehyde.

PERPUSTAKAAN UNIVERSITI MALAYA

The works at the University of Malaya have attracted the attention of the private sectors. The Summirubber Industry of Japan has signed a MOA with the University in March of 2001 to collaborate in a project to produce bacterial bioplastic from palm oil derivatives.

A collaborative research project was carried out with the Maskimi Polyol Sdn Bhd, a local Company from Kajang, to develop new reagent for converting palm kernel oil into polyols for the production of rigid polyurethane foams. New grades of palm oil polyols were developed and already being produced at the factory. As an extension to the R & D project, by increasing the molecular weight through polycondensation, flexible foams could be made as well. Chemical modifications appear to have widened the scope of palm oil for many other interesting applications.

This lecture is aimed at the general audience.

University of Malaya

RESEARCH IN POLYMER CHEMISTRY USING LOCAL RAW MATERIALS
PENYELIDIKAN POLIMER MENGGUNAKAN BAHAN MENTAH TEMPATAN

Professor Dr. Gan Seng Neon
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INTRODUCTION

Malaysia has petroleum, natural gases and other primary resources, yet the chemical industry remains virtually an insignificant industry. We could have factories producing items ranging from tooth-pastes, air fresheners, polyurethane foams, adhesives to automotive paints, but much of the chemicals used are imported. Many items carrying the label of "made in Malaysia" are actually being made from processing the imported materials.

It is the more intermediate level of chemical and process engineering, backed by chemical research, which is required for upgrading our own raw materials to higher value-added products and which could contribute substantially to industrial development and to foreign exchange earnings. Undoubtedly, the Malaysian chemical industry is one with great potential for development. This lecture discusses some of my research projects on local raw materials carried out at the University of Malaya.

Among the various local raw materials of our country, three of the most important are: (i) natural rubber, (ii) petroleum & natural gases and (iii) palm oil. Allow me to briefly recollect some of my earlier projects on natural rubber and petrochemical catalysts before I talk about my recent work on palm oil and its derivatives.

PROJECTS ON NATURAL RUBBER

My Ph.D. project carried out in the 1973-1976 period was entitled "Epoxide Groups in Natural Rubber and Their Role in Storage Hardening" [1].

We discovered that natural rubber molecules, as produced in the rubber trees, already contain certain number of epoxide groups. These groups can then react with the amino acids in the latex, and subsequently cause progressive hardening of natural rubber during storage, a phenomenon referred to as "storage hardening"[2-6]. In the course of establishing the reaction mechanisms through the use of model compounds [7], certain weak b-substituted groups could accelerate the crosslinking of epoxy resin. In practical terms, the setting time of epoxy resins could be reduced. This has led us to file a patent in 1976 [8].

I obtained my Ph.D. in June 1976, and went to the Centre des Recherches sur les Macromolecules (CRM) in Strasbourg, France, for one year of Post-doctorate training, working on anionic polymerization of isoprene. I became a lecturer at the Pusat Asasi Sains in June 1978.

While in Pusat Asasi Sains, I was not able to utilize what I have acquired from France due to the lack of facilities. I presented my findings during the post-doctorate training at a local polymer seminar [9]. I concentrated on teaching duties and also involved myself in writing academic books in Bahasa Malaysia [10-13].

To keep up my interest in research, I maintained collaboration with some staff members at the Chemistry Department. By the time I was transferred to Jabatan Kimia in 1990, after serving 12 years at Pusat Asasi Sains, I already have established a number of research areas in natural rubber. These included: (i) Study on storage hardening mechanisms by radio-active tracers, (ii) Pressure sensitive adhesives from natural rubber blended with acrylic polymer, (iii) Silicone carbon black filled rubber compounds, (iv) Liquid natural rubber and epoxidised rubber, (v) Reactions of epoxidized natural rubber and (vi) Grafting of natural rubber with selected monomers through emulsion polymerization in latex.

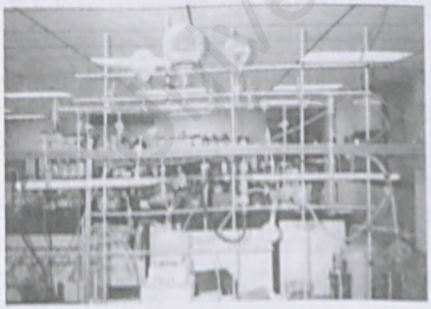
I have produced five M.Sc/M.Technology students [14-18], some undergraduate projects [19, 20], seminar/ conference [21-32] and journal papers [33-41] in natural rubber. In particular, I have collaborated with some lecturers at the Dental Faculty to investigate the use of NR in denture materials, and have obtained useful preliminary results for a conference presentation at the 8th Annual Scientific Meeting, International Association for Dental Research [25] in 1993.

PROJECTS ON PETROLEUM AND NATURAL GAS

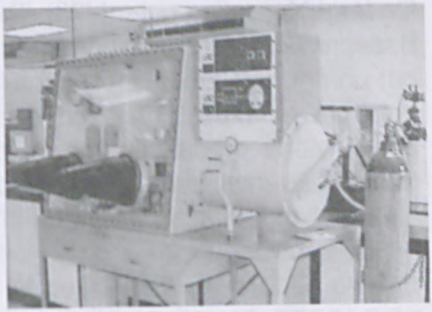
My works on petroleum and natural gas have been restricted to catalysts and polymerization of ethylene and propylene. It all started with my sabbatical leave at the research laboratory of Professor Kazuo Soga at the Tokyo Institute of Technology, Japan, during the period of July 1983 - February 1984.

One of the Ph.D. students at Prof.Soga's laboratory was having difficulty synthesizing a chromium catalyst reported in a patent literature [42]. I managed to help him in overcoming the problems within a few days. I also discovered that the same Cr catalyst could be made from different and simpler starting compounds by alternative routes. I spent the rest of my sabbatical on making polymers and copolymers of ethylene and propylene using the new catalyst. I brought back polymer samples for study by Differential Scanning Calorimeter at the Chemistry Department. My first few papers in this area were based mainly on the results from the sabbatical leave in Japan [43-46].

We were fortunate to get an IRPA Grant of $180,000 in 1988, to be shared with my other colleagues at Pusat Asasi Sains. We constructed a low pressure polymerization line with our own design, adapted from the setup of Prof Soga's laboratory, using locally available materials. We bought and installed a DryLab for handling air sensitive compounds.



The polymerization setup.

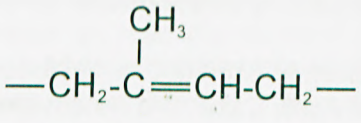


The DryLab

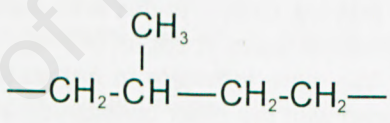
The scope of research has widened to include many other Cr complexes with substituted ligands. We were able to offer a number of postgraduate projects on topics like (i) Active sites determination of Ziegler-Natta catalysts, (ii) Tacticity of polypropylene, (iii) Synthesis of

new chromium complexes for polymerization of olefins, (iv) Effect of fillers on polypropylene, and (v) Kinetics of polymerizations [47-53].

The subsequent publications are based on works carried out using our own setup and facilities. We have participated actively in both local and overseas conferences/seminars [54-68]. Our wish to integrate the Ziegler-Natta catalysts with natural rubber can be seen in the following attempts: (i) We used a toluene solution of purified natural rubber as a medium for the polymerization of ethylene to modify both the kinetics of reaction as well as the thermal property of the polyethylene [57]. (ii) We used a Ziegler-Natta catalyst to carry out hydrogenation of natural rubber [61]. We have also published our findings in journals and academic texts [69-72]. In particular, the hydrogenation of natural rubber is a neat method of producing a perfect propylene-ethylene alternation polymer, which could not be achieved by any other method.



Repeating unit of natural rubber



Perfect propylene-ethylene alternating polimer

Our findings of the new series of chromium complexes have led us to file for a Malaysian patent [73]. The first IRPA Grant was finished in 1996. Based on our encouraging results, we put in another application in 1997 but unfortunately our application was not successful, and our team was not able to expand the scope of the project such as scaling up the polyethylene production for material characterizations. We maintained the fundamental studies and decided to diversify our scope and work with another "cheap local raw material" - the palm oil.

PROJECTS ON PALM OIL

Malaysia is currently the world's largest producer of palm oil. Malaysia has over 3.5 million hectares of oil palm plantation, producing more than 10 million tons of crude palm oil annually. Palm oil has become one of the world's leading vegetable oils in terms of both production and consumption. Almost 90% of palm oil and its products are used for edible

purposes such as cooking and frying oils/fats, shortenings (in breads, cakes and cookies), margarines and spreads, confectionery fats, vanaspati, non-diary products (such as ice cream, coffee whitener and whipped cream).

Examples of edible uses of palm oil.

About 10% of the total oil production is for non-food uses, mainly for soaps, detergents, and oleochemicals.

Our recent research activities at UM involving palm oils can be classified into six topics: (i) Development of biodegradable polymers. (ii) Water reducible alkyds from palm oil and its derivatives. (iii) Converting palm fibers into boards by using a water-based thermoset resin. (iv) Palm oil-based polyols for rigid polyurethane foams, (v) Palm oil-based polyester polyols for flexible foams, and (vi) UV-curable palm oil alkyds.

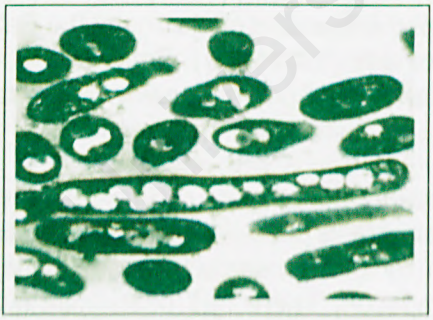
Development of biodegradable polymers

Like many other countries, Malaysia is also facing an escalating problem of environmental pollution by plastic waste. Generally these plastics are inert to microbial degradation. There has been increasing public concern over the harmful effects of petrochemical-derived plastic materials in the environment.

Several hundred thousand tons of discarded plastics find their ways into the waterways (rivers, streams, ponds, oceans) [74]. There is a world-wide interest to develop eco-friendly products such as bioplastics which can help us to overcome the problem of pollution caused by non-degradable plastics [75].

Local scenes of environmental pollution by plastics. Pictures clipped from newspaper.

We have developed a laboratory process to produce bacterial Polyhydroxyalkanoates (PHAs) using palm oil, palm kernel oil and their derivatives as primary carbon source. PHAs are polyesters accumulated in the cells under conditions of nutrient stress and act as a carbon and energy reserve.



Transmission electron microscopy of the bacteria grown on a palm oil derivative for 48 hours. PHAs appear as white granules at 13,000x

PHAs of different properties have been synthesized from saponified palm kernel oil, saponified crude palm oil, oleic acid, myristic acid as well as lauric acid. The bacterial polymers have average molecular weight ranging from 34,000 to 86,000. Characterizations by FTIR, FTNMR and DSC were carried out. The structures of repeating units were determined by an indirect gas chromatography technique. The biodegradability of the PHAs under various conditions were investigated. All these have formed

good subject matters for postgraduate studies. Dr Irene Tan and I have co-supervised seven M.Biotech/M.Sc. Projects [78-82] and produced some journal publications and conference papers [83-89].

Our research activities have attracted the attention of Sumitomo Rubber Industries, Japan. After a series of discussions, a Memorandum of Agreements was signed between UM & Summirubber Industries Kedah (a subsidiary of SRI) on 9-3-2002 to set up a collaborative project entitled : Basic Research on the Production of Polyhydroxyalkanoates (PHA) from Palm Oil and Palm Kernel Oil with a View to Commercialization. SRIK funded us for the purchase of a larger reactor and accessories, and employment of research assistants.

A picture during the MOA ceremony at Rumah Universiti on 9-3-02

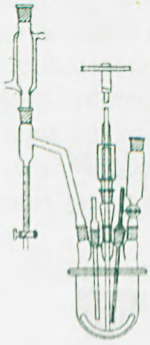
Through optimization of the conditions using the new reactor, the PHA yield has been increased by more than twenty folds per run [90, 91]. The project is on-going. We are now producing sufficient sample size and would be going into physical properties characterization, formulation of products, and investigating end-uses. We are expecting to produce more publications and postgraduate projects in the future.

This project is done In collaboration with Dr Irene Tan K.P. (ISB) & Prof. K, Ramachandran (Chem Eng.)

Water reducible alkyds from palm oil and its derivatives

Alkyds are formed by reacting polybasic organic acids with polyhydric alcohols (polyols). The notable difference between an alkyd and other polyesters is the presence of monofunctional fatty acids from vegetable

oils as a major part of its composition. Although various vegetable oils have been used in alkyd synthesis, there is no report (or rarely any) on the use of palm oil.



We have used palm stearin, crude palm oil and palm kernel oil as raw materials for the synthesis of alkyds, with 25-50% of the oil being used in the formulations [90-97].

Due to the low amounts of unsaturation in palm stearin and crude palm oil, these alkyds are not suitable for air-dry; they could be formulated into clear or colored enamels which could be cured at temperatures of 100° - 140°C.

Adjusting the composition and curing temperature can vary the gloss, hardness and adhesion properties of the coating. The new materials can be used for water-based environmentally friendly coating applications.

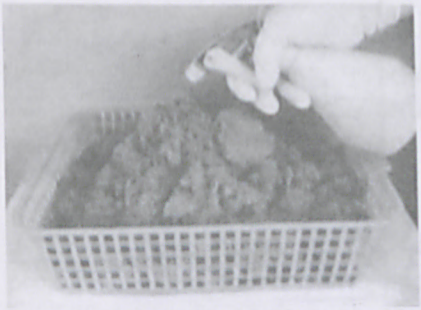
In terms of man-power training, this topic has generated five M.Sc. projects, two of which were already completed [98-99]. A number of papers have also been published in the international journals [100-102].

Converting palm fibers into boards by using a water reducible acrylic resin

The Malaysian palm oil industry generates over 38 million tons of biomass, in the form of lignocellulosic materials from empty fruit branches(EFB), extracted seeds, oil palm fronds (OPF), and oil palm trunks (OPT). These waste fibers should be exploited commercially to produce value-added products in order to benefit the industry and the country as a whole.

Waste produced by empty fruit branches and extracted seeds.

Fiber boards can be made from the waste materials. The empty fruit branches and extracted seeds can be mechanically ground to finer fibers. The simple process uses a newly invented water-based thermoset resin made in the University of Malaya



Treating the fibres with water based thermoset resin

Pressing the treated fibers into board

University of Malaya

The new resin uses water as solvent, and the advantages are quite obvious as water is cheap, non-toxic, and non-flammable. We discovered that the same resin system can be used to make boards out of other waste materials like saw dusts, wood fibers and old newspapers. Without disclosing details of the chemical compositions and processing parameters, we have participated in the ITEX 2000 exhibition and invention competition at the Putra World Trade Centre in September 2000 [103] and won a bronze medal. We have also presented the application, withholding critical details, at a workshop organized by the Malaysian Institute of Chemistry [104].

A postgraduate student was recruited to work on making fiber boards out of old newspaper [105,106]. The project was completed at the end of 2003.

Realizing the potential for commercial applications, a patent application for the water-based thermoset resins is currently in progress [107].

Palm oil based polyols for rigid polyurethane foams

Polyurethane (PU) is one of the most versatile advanced materials that could be used in many different industries. The production of polyurethane is based on the basic reaction between a polyol and a polyisocyanate. n HO-R'-OH + n OCN-R-CNO ➤ -[-OCONH-R-NH-COOR'-]n-

Rigid PU foams are being produced in varying densities and hardness and are widely used in many industries. The most important usage is as insulation materials for refrigerators and cold rooms. They are also being made into picture and mirror frames, rosettes, cornices, imitation woods, steering wheels, rear spoilers and bumpers, armrests of chairs and even toys.

Examples of applications of PU rigid foams (from left to right) : insulation in freezer, artificial wood and steering wheel.

Generally, the polyisocyanate has a functionality of two and the polyol has functionality between 2 and 6. By altering the equivalent weight of each component, the polymer structure can be significantly modified, and the resulting materials could range from very hard to very soft, and from very stiff to rubbery like.

Currently, the common commercial polyols are petrochemical-based polyethers and polyesters. The polyether polyols are made from propylene oxide and ethylene oxide, while the polyester polyols are made from dicarboxylic acids such as adipic acid and diols such as ethylene glycol. They are derived from crude oil and coals, both of which are diminishing natural resources.

One viable and highly desirable alternative is to make use of plant resources. It is indeed exciting to know that palm oil can be chemically converted into polyols for making rigid PU foams.

This project was developed in collaboration with a local company, the Maskimi Polyol Sdn Bhd, Kajang, under an IGS grant from the Government [108]. The original process involved reacting palm kernel oil with an expensive proprietary reagent (around RM11/kg) imported from UK. It was found that the same reagent could not be used on other types of vegetable oils except the coconut oil which have the similar triglyceride composition as the palm kernel oil.

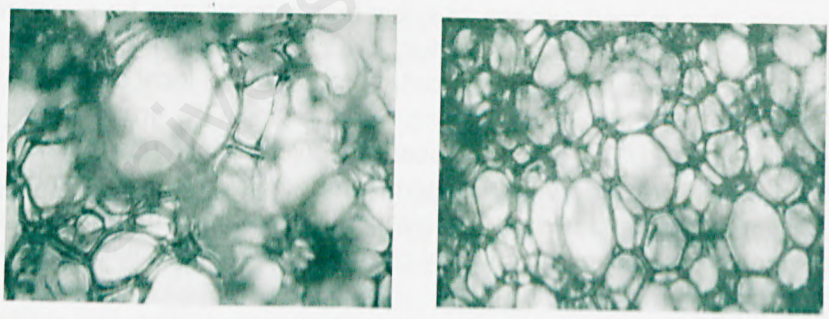
A number of new reagents were developed at the University of Malaya using a combination of organic compounds and catalyst at cheaper cost of around RM3-5 /kg. On a laboratory scale, the reagents were prepared and reacted with the different oils including the crude palm oil, palm stearin and palm olein under the same conditions. The products were analyzed and finally tested for foam formation with polyisocyanate [109,110]. The optimized reagent (in terms of cost and performance) was successfully scaled up for factory production.

The environmental friendly materials are fairly well received by the industry not only in Malaysia, but also overseas in countries like China, Australia, Vietnam, Philippines, Hong Kong, Brunei and Kuwait.

Palm oil based polyester polyols for flexible foams

Although diisocynates used for flexible PU foams are basically similar to those of the rigid foams, there are significant differences between the two systems. The polyols must be of higher molecular weight, typically in the range of 1000-6000. The rigid forms have close-cell structures, while the flexible foams are mostly consisting of open-cells.

Common polyester is produced by polycondensation of di- and tri-functional polyols with dicarboxylic acids. The palm oil-based polyester polyols are prepared by reacting palm oil (or its derivatives) with a mixture of dicarboxylic acid and ethylene glycol or 1,4-butanediol in the presence of a catalyst under control conditions. At this stage, we have succeeded in making four polyester polyols of average molecular weights of 850-2900, prepared by using 30-60% of palm kernel oil in the reaction mixtures. The palm oil-based polyols were new materials that were different from the current petroleum-based polyether polyols. We have managed to formulate a series of flexible foams with good properties, using the common PU additives and TDI.



The open-cell structures of two flexible foams of different densities.

The properties of the flexible PU foams are dependent on many variable parameters. These include: functionality of the polyol, the molecular weight of polyol, the type of isocyanate, blowing agent, catalyst, surfactant as well as the processing conditions [111]. Further works are being carried out to produce other palm oil-based polyester

polyols of higher molecular weights, and also with different oil contents. There is intention of applying a patent to protect the invention before we disclose the full details of our reagents and processes.

UV-curable palm oil alkyds

UV curing technology offers an alternative research effort towards reducing volatile organic compounds (VOC) particularly in the surface coatings industry in applications such as paints and printing inks. It is currently growing at the rate of about 9 to 10% annually.

This is an on-going Ph.D. project, started recently, but we already see some promising results. Palm oil alkyds with high hydroxyl content were first synthesized. Unsaturated monomer with suitable function groups, such as -COOH, is than attached onto the alkyd molecules, through the reactions with the -OH groups. The incorporated -C=C- group becomes the key functional group for UV curing process.

The UV machine was constructed by mounting a mercury vapor bulb on top of a conveyer. The bulb is able to produce an intensity of 225 mW cm^{-2} or 0.25J cm^{-2} at conveyer speed of 5 m min-1. The light output covered the range of 320-390 nm. The curing reactions could be monitored by FTIR measurements. The C=C bonds were seen at 810, 985, 1407, 1619 and 1635 cm-1. As the cross-linking reactions occur, the intensities of these peaks diminish. Comparing the absorbance at each of this wave number would enable us to estimate the rate and extent of the UV-curing reactions [112].

In an attempt to integrate palm oil and natural rubber, we have come up with another postgraduate project of using the palm oil alkyd as a tackifying agent to natural rubber for pressure sensitive adhesives [113-114].

CONCLUDING REMARKS

I would like to take this opportunity to thank all my research collaborators, postgraduate students, and undergraduate project students for their effort and hard work that we have gone through together. I hope they have enjoyed doing research on our local raw materials as much as I do. There is inevitably some unintentional

omissions as I have left out the long list of undergraduate projects, which were usually based on our earlier published works, and postgraduate projects not using local raw materials, for example one of my current Ph.D. students is working on core-shell emulsion polymerization of acrylic monomers [115-116].

Last but not least, I would like to record my gratitude to the University of Malaya for providing me the facilities and opportunities.

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