



Pertanika Journal of

**SCIENCE &  
TECHNOLOGY**

**JST**

**VOL. 23 (1) JAN. 2015**



PERTANIKA  
JOURNALS

A scientific journal published by Universiti Putra Malaysia Press

## About the Journal

*Pertanika* is an international peer-reviewed journal devoted to the publication of original papers, and it serves as a forum for practical approaches to improving quality in issues pertaining to tropical agriculture and its related fields. *Pertanika* began publication in 1978 as the Journal of Tropical Agricultural Science. In 1992, a decision was made to streamline *Pertanika* into three journals to meet the need for specialised journals in areas of study aligned with the interdisciplinary strengths of the university. The revamped Journal of Science & Technology (JST) aims to develop as a pioneer journal focusing on research in science and engineering, and its related fields. Other *Pertanika* series include Journal of Tropical Agricultural Science (JTAS); and Journal of Social Sciences and Humanities (JSSH).

JST is published in **English** and it is open to authors around the world regardless of the nationality. It is currently published two times a year, i.e. in **January** and **July**.

## Goal of *Pertanika*

Our goal is to bring the highest quality research to the widest possible audience.

## Quality

We aim for excellence, sustained by a responsible and professional approach to journal publishing. Submissions are guaranteed to receive a decision within 12 weeks. The elapsed time from submission to publication for the articles averages 5-6 months.

## Indexing of *Pertanika*

*Pertanika* is now over 33 years old; this accumulated knowledge has resulted in *Pertanika* JST being indexed in SCOPUS (Elsevier), EBSCO, Thomson (ISI) Web of Knowledge [CAB Abstracts], DOAJ, Google Scholar, ERA, ISC, Citefactor, Rubriq and MyAIS.

## Future vision

We are continuously improving access to our journal archives, content, and research services. We have the drive to realise exciting new horizons that will benefit not only the academic community, but society itself.

We also have views on the future of our journals. The emergence of the online medium as the predominant vehicle for the 'consumption' and distribution of much academic research will be the ultimate instrument in the dissemination of research news to our scientists and readers.

## Aims and scope

*Pertanika* Journal of Science and Technology aims to provide a forum for high quality research related to science and engineering research. Areas relevant to the scope of the journal include: *bioinformatics, bioscience, biotechnology and biomolecular sciences, chemistry, computer science, ecology, engineering, engineering design, environmental control and management, mathematics and statistics, medicine and health sciences, nanotechnology, physics, safety and emergency management*, and related fields of study.

## Editorial Statement

*Pertanika* is the official journal of Universiti Putra Malaysia. The abbreviation for *Pertanika* Journal of Science & Technology is *Pertanika J. Sci. Technol.*

## EDITOR-IN-CHIEF

**Mohd. Ali Hassan**

*Bioprocess engineering,  
Environmental Biotechnology*

## CHIEF EXECUTIVE EDITOR

**Nayan Deep S. Kanwal**

*Environmental Issues – Landscape  
Plant Modelling Applications*

## UNIVERSITY PUBLICATIONS COMMITTEE

**Mohd Azmi Mohd Lila, Chair**

## EDITORIAL STAFF

### Journal Officers:

Kwan Lee Yin, *ScholarOne*

Kanagamalar Silvarajoo, *ScholarOne*

### Editorial Assistants:

Siti Juridah Mat Arip  
Zulinaardawati Kamarudin  
Norhafizah Abd Rani

### COPY EDITORS

Doreen Dillah  
Crescentia Morais  
Ena Bhattacharyya

### PRODUCTION STAFF

#### Pre-press Officer:

Nik Khairul Azizi Nik Ibrahim

#### Layout & Typeset:

Sarwani Padzil  
Noor Sholihah Mohd Daud

### WEBMASTER

Mohd Nazri Othman

### PUBLICITY & PRESS RELEASE

Magdalene Pokar (*ResearchSEA*)

## EDITORIAL OFFICE

### JOURNAL DIVISION

Office of the Deputy Vice Chancellor (R&I)

1<sup>st</sup> Floor, IDEA Tower II

UPM-MTDC Technology Centre

Universiti Putra Malaysia

43400 Serdang, Selangor Malaysia.

Gen Enq.: +603 8947 1622 | 1619 | 1616

E-mail: [executive\\_editor.pertanika@upm.my](mailto:executive_editor.pertanika@upm.my)

URL: [www.journals-ij.upm.edu.my](http://www.journals-ij.upm.edu.my)

### PUBLISHER

Kamariah Mohd Saidin

UPM Press

Universiti Putra Malaysia

43400 UPM, Serdang, Selangor, Malaysia.

Tel: +603 8946 8855, 8946 8854

Fax: +603 8941 6172

E-mail: [penerbit@putra.upm.edu.my](mailto:penerbit@putra.upm.edu.my)

URL: <http://penerbit.upm.edu.my>



## EDITORIAL BOARD

2013-2015

### Abdul Halim Shaari

*Superconductivity and Magnetism,  
Universiti Putra Malaysia, Malaysia.*

### Adem Kilicman

*Mathematical Sciences,  
Universiti Putra Malaysia, Malaysia.*

### Ahmad Makmom Abdullah

*Ecophysiology and Air Pollution  
Modelling, Universiti Putra Malaysia,  
Malaysia.*

### Ali A. Moosavi-Movahedi

*Biophysical Chemistry,  
University of Tehran, Tehran, Iran.*

### Amu Therwath

*Oncology, Molecular Biology,  
Université Paris, France.*

### Angelina Chin

*Mathematics, Group Theory and  
Generalisations, Ring Theory,  
University of Malaya, Malaysia.*

### Bassim H. Hameed

*Chemical Engineering: Reaction  
Engineering, Environmental Catalysis  
& Adsorption,  
Universiti Sains Malaysia, Malaysia.*

### Biswa Mohan Biswal

*Medical, Clinical Oncology, Radiotherapy,  
Universiti Sains Malaysia, Malaysia.*

### Christopher G. Jesudason

*Mathematical Chemistry, Molecular  
Dynamics Simulations, Thermodynamics  
and General Physical Theory,  
University of Malaya, Malaysia.*

### Ivan D. Rukhlenko

*Nonlinear Optics, Silicon Photonics,  
Plasmonics and Nanotechnology,  
Monash University, Australia.*

### Kaniraj R. Shenbaga

*Geotechnical Engineering,  
Universiti Malaysia Sarawak, Malaysia.*

### Kanury Rao

*Senior Scientist & Head, Immunology  
Group, International Center for Genetic  
Engineering and Biotechnology,  
Immunology, Infectious Disease Biology  
and System Biology, International Centre  
for Genetic Engineering & Biotechnology,  
New Delhi, India.*

### Karen Ann Crouse

*Chemistry, Material Chemistry, Metal  
Complexes – Synthesis, Reactivity,  
Bioactivity, Universiti Putra Malaysia,  
Malaysia.*

### Ki-Hyung Kim

*Computer and Wireless Sensor Networks,  
AJOU University, Korea.*

### Kunnawee Kanitpong

*Transportation Engineering-Road  
Traffic Safety, Highway Materials  
and Construction, Asian Institute of  
Technology, Thailand.*

### Megat Mohd Hamdan

**Megat Ahmad**  
*Mechanical and Manufacturing  
Engineering, Universiti Pertahanan  
Nasional Malaysia, Malaysia.*

### Miralini Kandiah

*Public Health Nutrition, Nutritional  
Epidemiology, UCSI University, Malaysia.*

### Mohd Adzir Mahdi

*Physics, Optical Communications,  
Universiti Putra Malaysia, Malaysia.*

### Mohd Sapuan Salit

*Concurrent Engineering and Composite  
Materials, Universiti Putra Malaysia,  
Malaysia.*

### Narongrit Sombatsompop

*Engineering & Technology: Materials  
and Polymer Research, King Mongkut's  
University of Technology Thonburi  
(KMUTT), Thailand.*

### Prakash C. Sinha

*Physical Oceanography, Mathematical  
Modelling, Fluid Mechanics, Numerical  
Techniques, Universiti Malaysia  
Terengganu, Malaysia.*

### Rajinder Singh

*Biotechnology, Biomolecular Sciences,  
Molecular Markers/ Genetic Mapping,  
Malaysia Palm Oil Board, Kajang,  
Malaysia.*

### Renuganth Varatharajoo

*Engineering, Space System,  
Universiti Putra Malaysia, Malaysia.*

### Riyanto T. Bambang

*Electrical Engineering, Control, Intelligent  
Systems & Robotics, Bandung Institute of  
Technology, Indonesia.*

### Sabira Khatun

*Engineering, Computer Systems  
& Software Engineers, Applied  
Mathematics, Universiti Malaysia  
Pahang, Malaysia.*

### Shiv Dutt Gupta

*Director, IHMR, Health Management,  
Public Health, Epidemiology, Chronic  
and Non-communicable Diseases,  
Indian Institute of Health Management  
Research, India.*

### Suan-Choo Cheah

*Biotechnology, Plant Molecular Biology,  
Asiatic Centre for Genome Technology  
(ACGT), Kuala Lumpur, Malaysia.*

### Wagar Asrar

*Engineering, Computational Fluid  
Dynamics, Experimental Aerodynamics,  
International Islamic University,  
Malaysia.*

### Wing Keong Ng

*Aquaculture, Aquatic Animal Nutrition,  
Aqua Feed Technology, Universiti Sains  
Malaysia, Malaysia.*

### Yudi Samyudia

*Chemical Engineering, Advanced  
Process Engineering, Curtin University of  
Technology, Malaysia.*

## INTERNATIONAL ADVISORY BOARD

2013-2016

### Adarsh Sandhu

*Editorial Consultant for Nature  
Nanotechnology and Contributing  
Writer for Nature Photonics, Physics,  
Magnetoresistive Semiconducting  
Magnetic Field Sensors, Nano-Bio-  
Magnetism, Magnetic Particle Colloids,  
Point of Care Diagnostics, Medical  
Physics, Scanning Hall Probe Microscopy,  
Synthesis and Application of Graphene,  
Electronics-inspired Interdisciplinary  
Research Institute (EIIRIS), Toyohashi  
University of Technology, Japan.*

### Graham Megson

*Computer Science, The University of  
Westminster, U.K.*

### Kuan-Chong Ting

*Agricultural and Biological Engineering,  
University of Illinois at  
Urbana-Champaign, USA.*

### Malin Premaratne

*Advanced Computing and Simulation,  
Monash University, Australia.*

### Mohammed Ismail Elnaggar

*Electrical Engineering, Ohio State  
University, USA.*

### Peter G. Alderson

*Bioscience, The University of Nottingham,  
Malaysia Campus.*

### Peter J. Heggs

*Chemical Engineering,  
University of Leeds, U.K.*

### Ravi Prakash

*Vice Chancellor, JUIT, Mechanical  
Engineering, Machine Design, Biomedical  
and Materials Science, Jaypee University  
of Information Technology, India.*

### Said S.E.H. Elnashaie

*Environmental and Sustainable  
Engineering, Penn. State University at  
Harrisburg, USA.*

### Suhash Chandra Dutta Roy

*Electrical Engineering, Indian Institute of  
Technology (IIT) Delhi, India.*

### Vijay Arora

*Quantum and Nano-Engineering  
Processes, Wilkes University, USA.*

### Yi Li

*Chemistry, Photochemical Studies,  
Organic Compounds, Chemical  
Engineering, Chinese Academy of  
Sciences, Beijing, China.*

## ABSTRACTING/INDEXING

*Pertanika* is now over 35 years old; this accumulated knowledge has resulted the journals being indexed in SCOPUS (Elsevier), Thomson (ISI) Web of Knowledge [BIOSIS & CAB Abstracts], EBSCO, DOAJ, Google Scholar, AGRICOLA, ISC, Citefactor, Rubriq and MyAIS. JST is also indexed in ERA.

The publisher of *Pertanika* will not be responsible for the statements made by the authors in any articles published in the journal. Under no circumstances will the publisher of this publication be liable for any loss or damage caused by your reliance on the advice, opinion or information obtained either explicitly or implied through the contents of this publication.

All rights of reproduction are reserved in respect of all papers, articles, illustrations, etc., published in *Pertanika*. *Pertanika* provides free access to the full text of research articles for anyone, web-wide. It does not charge either its authors or author-institution for refereeing/publishing outgoing articles or user-institution for accessing incoming articles.

No material published in *Pertanika* may be reproduced or stored on microfilm or in electronic, optical or magnetic form without the written authorization of the Publisher.

Copyright © 2015 Universiti Putra Malaysia Press. All Rights Reserved.





**Pertanika Journal of Science & Technology**  
**Vol. 23 (1) Jan. 2015**

**Contents**

<b>Foreword</b>	i
<i>Nayan Deep S. Kanwal</i>	
<b>Editorial</b>	
Integration of Science, Technology and Entrepreneurship to Capture the Power of the Nanoengineering Wave	i
<i>Vijay K. Arora</i>	
<b>Review Article</b>	
Applications of <sup>18</sup> (F) FDG PET/CT in Oncology	1
<i>AS Fathinul Fikri, AJ Nordin, YK Cheah and FN Ahmad Saad</i>	
<b>Regular Articles</b>	
Smoking Behavior among Adolescents in Rural Schools in Malacca, Malaysia - A Case-Control Study	13
<i>Nor Afiah, M. Z., Rahmah M. A., Salmiah, M.S., Lye, M.S., Shamsul Azhar, S. and Fazilah, I.</i>	
Prevalence of Psychological Stress among Undergraduate Students Attending a Health Programme in a Malaysian University	29
<i>Phang, C. K., Sherina, M. S., Zubaidah, J. O., Noor Jan, K. O. N., Firdaus, M., Siti Irma, F. I. and Normala, I.</i>	
Analysing Elephant Habitat Parameters using GIS, Remote Sensing and Analytic Hierarchy Process in Peninsular Malaysia	37
<i>Suhaida Aini, Alias Mohd Sood and Salman Saaban</i>	
Removal of Dissolved Organic Carbon from Peat Swamp Runoff Using Assorted Tropical Agriculture Biomass	51
<i>Sim, F. S., Mohd Irwan Lu, N. A. L., Lee, Z. E. T. and Mohamed, M.</i>	
Optimization of Drilling Parameters for Delamination Associated with Pre-drill in Chopped Strand Mat Glass Fibre Reinforced Polymeric Material	61
<i>T. Panneerselvam and S. Raghuraman</i>	
RFID-Enabled Web-Based Interface for a Chemical Storage Management System	73
<i>Rosiah Osman, Abd. Rahman Ramli, Wan Azizun Wan Adnan and Intan Helina Hasan</i>	
Modelling of Carbon Dioxide Absorption into Aqueous Ammonia Solution in a Wetted Wall Column	89
<i>Ujjal Kumar Ghosh, Chiu Choon Hong, Jobrun Nandong and Shufeng Shen</i>	

**Selected Articles from CUTSE International Conference 2012  
(Engineering Goes Green)**

**Guest Editor:** Muhammad Ekhlaur Rahman

**Guest Editorial Board:** M. V. Prasanna, Hannah Ngu Ling Ngee, Zeya Oo and Rajamohan Ganesan

- T-DepExp: Simulating Transitive Dependence Based Coalition Formation 105  
*Billy Pik Lik Lau, Ashutosh Kumar Singh and Terence Peng Lian Tan*
- Synthesis of Nanoparticle-based Binary Oxide Electrode  $\text{TiO}_2\text{-ZrO}_2$  with Carrot-derived Natural Dye Extract for Dye Sensitized Solar Cell (DSSC) Application 119  
*S. Y. Win, T. T. Win, Y. M. Maung, K. K. K. Soe, T. T. Kyaw, C. K. Tan, S. Rajalingam and Z. Oo*
- Information Technology: Impacts on Environment and Sustainable Development 127  
*Adib Kabir Chowdhury and Veeramani Shanmugan*
- Experimental Study on Mixed Convection Heat Transfer in a Square Duct with Varying Inclination Angles 141  
*G. Rajamohan, R. Narayanaswamy and P. Kumar*
- Microstructure Analysis, Physical and Thermal Properties of  $\text{Al}_2\text{O}_3\text{-Al}_2\text{TiO}_5$  Functionally Graded Ceramics for the Application of Car Brake Rot 153  
*Rong Kimberly, F. P., Oo, Z. and Sujan, D.*

# Foreword

Welcome to the **First Issue 2015** of the Journal of Science and Technology (JST)!

JST is an open-access journal for studies in science and technology published by Universiti Putra Malaysia Press. It is independently owned and managed by the university and is run on a non-profit basis for the benefit of the world-wide science community.

In this issue, **13 articles** are published, **one** is review articles and **seven** are regular articles. **Five articles** are from Curtin University's Technology, Science and Engineering International Conference "Engineering Goes Green" (CUTSE 2012). The authors of these articles vary in country of origin, coming from **Malaysia, India, Nigeria, China, Myanmar and Australia**.

The review article in this issue discusses the applications of  $^{18}\text{F}$  FDG PET/CT in Oncology (*AS Fathinul Fikri, AJ Nordin, YK Cheah and FN Ahmad Saad*). The first regular article in this issue is on a case control study of smoking behavior among adolescents in rural schools in Malacca, Malaysia (*Nor Afiah, M. Z., Rahmah M. A., Salmiah, M.S., Lye, M.S., Shamsul Azhar, S. and Fazilah, I.*). The following article look at: prevalence of psychological stress among undergraduate students attending a health programme in a Malaysian university (*Phang, C. K., Sherina, M. S., Zubaidah, J. O., Noor Jan, K. O. N., Firdaus, M., Siti Irma, F. I. and Normala, I.*); analysing elephant habitat parameters using GIS, remote sensing and analytic hierarchy process in peninsular Malaysia (*Suhaida Aini, Alias Mohd Sood and Salman Saaban*); removal of dissolved organic carbon from peat swamp runoff using assorted tropical agriculture biomass (*Sim, F. S., Mohd Irwan Lu, N. A. L., Lee, Z. E. T. and Mohamed, M.*); optimization of drilling parameters for delamination associated with pre-drill in chopped strand mat glass fibre reinforced polymeric material (*T. Panneerselvam and S. Raghuraman*); RFID-enabled web-based interface for a chemical storage management system (*Rosiah Osman, Abd. Rahman Ramli, Wan Azizun Wan Adnan and Intan Helina Hasan*); and modelling of carbon dioxide absorption into aqueous ammonia solution in a wetted wall column (*Ujjal Kumar Ghosh, Chiu Choon Hong, Jobrun Nandong and Shufeng Shen*).

I conclude this issue with five articles arising from the CUTSE 2012 international conference: T-DepExp: simulating transitive dependence based coalition formation (*Billy Pik Lik Lau, Ashutosh Kumar Singh and Terence Peng Lian Tan*); synthesis of nanoparticle-based binary oxide electrode  $\text{TiO}_2\text{-ZrO}_2$  with carrot-derived natural dye extract for dye sensitized solar cell (DSSC) application (*S. Y. Win, T. T. Win, Y. M. Maung, K. K. K. Soe, T. T. Kyaw, C. K. Tan, S. Rajalingam and Z. Oo*); information technology: impacts on environment and sustainable development (*Adib Kabir Chowdhury and Veeramani Shanmugan*); experimental study on mixed convection heat transfer in a square duct with varying inclination angles (*G. Rajamohan, R. Narayanaswamy and P. Kumar*); and microstructure analysis, physical and thermal properties of  $\text{Al}_2\text{O}_3\text{-Al}_2\text{TiO}_5$  functionally graded ceramics for the application of car brake rot (*Rong Kimberly, F. P., Oo, Z. and Sujana, D.*)

I anticipate that you will find the evidence presented in this issue to be intriguing, thought-provoking, and, hopefully, useful in setting up new milestones. Please recommend the journal to your colleagues and students to make this endeavour meaningful.

I would also like to express my gratitude to all the contributors, namely, the authors, reviewers and editors for their professional contribution towards making this issue feasible. Last but not least, the editorial assistance of the journal division staff is fully appreciated.

JST is currently accepting manuscripts for upcoming issues based on original qualitative or quantitative research that opens new areas of inquiry and investigation.

**Chief Executive Editor**

Nayan Deep S. KANWAL, [FRSA](#), [ABIM](#), [AMIS](#), Ph.D.

[nayan@upm.my](mailto:nayan@upm.my)



*Editorial*

## **Integration of Science, Technology and Entrepreneurship to Capture the Power of the Nanoengineering Wave**

**Vijay K. Arora**

*UTM Distinguished Visiting Professor and IEEE-EDS Distinguished Lecturer, Wilkes University, U. S. A.*

Nano in its various formats (or allotropes to borrow the term from the chemistry of carbon) has changed the social landscape not only for electronics, but also for human enterprise in planning the future of a community, state, country and the planet Earth. Nanoscience, nanotechnology, nanoengineering and nanobusiness are all moving targets, creating new start-ups among unlikely partners. The complete nanoensemble, by its very nature, is a multi- and inter-disciplinary venture. Perhaps there is a need for engagement of not only scientists and engineers, but also of thinkers, ethicists, lawyers, theologians and politicians. Engineering, a process of synthesis, is an engine of innovation, invention and growth. To quote Theodore Von Kármán, the California Institute of Technology's Provost, who said during the formative years of the institute, "Scientists discover the world that exists; engineers create the world that never was." In other words, science is about being driven by curiosity to understand the world. Engineering is about using science to transform the world. A mature researcher must remain curious, adventurous and engaged to derive the joys arising from creating a new device, venture or educational paradigms, as ideas from disparate groups are synthesised and communicated through journal articles.

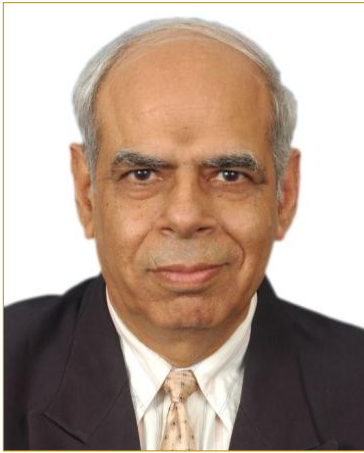
As Malaysia's neighbours India and Sri Lanka join the elite Washington Accord (WA), project- and problem-based learning will take increasing importance in training the workforce for tomorrow. Seventeen countries are now members of the WA (arranged alphabetically with year admitted in parenthesis): Australia - Represented by Engineers Australia (1989); Canada - Represented by Engineers Canada (1989); Chinese Taipei - Represented by Institute of Engineering Education Taiwan (2007); Hong Kong China - Represented by The Hong Kong Institution of Engineers (1995); India - Represented by National Board of Accreditation (2014); Ireland - Represented by Engineers Ireland (1989); Japan - Represented by Japan Accreditation Board for Engineering Education (2005); Korea - Represented by Accreditation Board for Engineering Education of Korea (2007); Malaysia - Represented by Board of Engineers Malaysia (2009); New Zealand - Represented by Institution of Professional Engineers NZ (1989); Russia - Represented by Association for Engineering Education of Russia (2012); Singapore - Represented by Institution of Engineers Singapore (2006); South

Africa - Represented by Engineering Council of South Africa (1999); Sri Lanka - Represented by Institution of Engineers Sri Lanka (2014); Turkey - Represented by MUDEK (2011); United Kingdom - Represented by Engineering Council UK (1989); and United States - Represented by ABET, the Accreditation Board for Engineering and Technology (1989). One aspect of this globalisation is that English is de facto the international language in which to publish new and noteworthy results. Some WA countries struggled with this issue and accepted the fact that the globalised humanity of planet Earth appreciates creativity and innovation (C&I) only through the medium of English. Good communication skills in the English language have become of paramount importance.

*Pertanika* journals diversified into three specialised journals as the *Journal of Tropical Agricultural Science (JTAS)*, *Journal of Science and Technology (JST)* and *Journal of Social Sciences & Humanities (JSSH)* to provide multidimensional strengths to put nanoengineering in broader perspective with focus on science and engineering in JST. JST is dedicated to the unification of science and engineering, covering a journey from quantum physics to nanoengineering, including peripheral topics of mind-body integration in training the mind to create brain conducive to integrative forces of nature for C&I to flourish. Science is adventure, a mix of curiosity and play. Only with curiosity about the unknown and exploration of the unfamiliar, can there be discovery. A researcher must remain steadfast in his/her adventure of discovery and ultimately, transformation. As new materials appear on the world stage, nanoengineering captures the attention of strategic planners in search of C&I for betterment of humanity. One aspect of this integration is that biology is an essential ingredient to derive the benefit of nanoengineering, in addition to physics, chemistry and mathematics. In general, nanoengineering arises from the vigour of curiosity, tempered by the rigour of reason. This interplay of curiosity and reason gives science its robustness, enhanced further by dynamism, imagination and the drive to understand the natural world.

Technology is science responding to life's necessities, and the many demands of the human conditions. Technology gives us devices and inventions to make our lives better. Curiosity interplaying with reason gives us science; science interplaying with necessity gives us technology. The interaction of science and technology is what helps bring about understanding of the world, connecting with the world, thereby contributing to the transformation of the world. By integrating curiosity, reason and necessity, *Pertanika* will play its part, hopefully a big part, in the global knowledge community, dedicating to transforming our world into a better place.

As we usher in the new year of 2015, I envision *Pertanika* becoming a powerhouse of transformative science and technology not only for Universiti Putra Malaysia (UPM), but also for Malaysia, the ASEAN region and beyond. *Pertanika* will be a place for the creative interplay of curiosity, reason and necessity. With the engagement of its readers, *Pertanika* will be a wellspring of ideas and innovation, overflowing with benefits for the global economy.



**Vijay K. Arora:**  
*Distinguished Professor & noted international educator and IEEE-EDS Distinguished Lecturer*

Professor Arora, noted international educator and IEEE-EDS Distinguished Lecturer, resurrects nanoengineering integration in his most recent book entitled *Nanoelectronics: Quantum Engineering of Low-Dimensional Nanoensembles*, soon to be released by CRC Press: Taylor and Francis Group. Professor Arora obtained his Ph.D from the University of Colorado. He has held distinguished appointments at the University of Tokyo, National University of Singapore, Nanyang Technological University, University of Western Australia and Universiti Teknologi Malaysia (UTM), in addition to several short-term visiting assignments around the world. Presently, he is a distinguished visiting professor at UTM on leave from Wilkes University, U. S. A. where he holds tenure as a Professor teaching electrical engineering, physics and engineering management. Professor Arora was accorded Leading Educators of the World 2005, Leading Scientists of the World 2005 and Man of Achievement 2005 by International Biographical Centre of Cambridge, England. He is listed in a number of Who's Who biographies. He has been invited to give keynote lectures and presentations internationally. His publications include more than 100 papers in reputed journals and many uncounted publications in conference proceedings and numerous invited/keynote lectures. Professor Arora serves on the editorial board of a number of journals. He was chair of NanoSingapore2006, NanotechMalaysia2010 and EscienceNano2012 conferences. He can be reached at [vijay.arora@wilkes.edu](mailto:vijay.arora@wilkes.edu).





*Review Article*

## **Applications of <sup>18</sup>(F) FDG PET/CT in Oncology**

**AS Fathinul Fikri<sup>1\*</sup>, AJ Nordin<sup>1</sup>, YK Cheah<sup>2</sup> and FN Ahmad Saad<sup>3</sup>**

<sup>1</sup>*Centre for Diagnostic Nuclear Imaging, Universiti Putra Malaysia, 43100 Selangor, Malaysia*

<sup>2</sup>*Department of Biomedical Science, Universiti Putra Malaysia, 43100 Selangor, Malaysia*

<sup>3</sup>*Faculty of Engineering, University Teknologi MARA, Pulau Pinang, Malaysia*

### **ABSTRACT**

The escalating costs of conventional diagnostic technology in oncology have yet to obviate futile surgery intervention and the spiralling treatment cost. The evolution in engineering technology which looks at the correlation of the anatomy and the function of tumours i.e. Positron Emission Tomography-Computed Tomography (PET-CT) have impacted on the improved diagnostic accuracy and treatment in oncology. Clinical data have demonstrated that the information provided by PET/CT often changes patient management. This review addresses the value of PET-CT as a surrogate molecular marker in tumours and to discuss some issues in adopting PET/CT in routine daily practice as supported by the numbers of literature reviews of its application in oncology since it was first commercialized in 2001. The description of the technology used in multimodality imaging has gained encouraging interest among physicians, policy makers and insurance companies on the importance of the PET-CT, for which roles are not limited to the staging, disease prognostication and treatment monitoring with potential impact on treatment cost and justification of radiation safety for the patient. PET/CT is a useful tool in cancer investigation as evidenced by its role as a surrogate marker in underpinning the cellular reprogramming of different pathological entities.

*Keywords:* Casemix, PET/CT, oncology, image fusion, technology

#### *Article history:*

Received: 6 August 2012

Accepted: 21 May 2014

#### *E-mail addresses:*

ahmadsaadff@gmail.com (AS Fathinul Fikri),

drimaging@yahoo.com (AJ Nordin),

ykcheah@upm.edu.my (YK Cheah),

najib4496@yahoo.com (FN Ahmad Saad)

\*Corresponding Author

### **INTRODUCTION**

Most radiologic procedures i.e. Computed Tomography (CT) or Magnetic Resonance Imaging (MRI) map the morphology of tumours with little or no information about their metabolism. Positron Emission Tomography (PET) employing 2-(fluorine-18)

fluoro-2-deoxy-D-glucose (FDG) is being gradually received as an important tool in providing qualitative and quantitative metabolic informations that is critical in influencing diagnosis and follow-up (Lau *et al.*, 2006; Czernin, 2007). Radio-labelling of the PET tracer, the Flourine-18 ( $^{18}\text{F}$ ) with FDG (glucose analogue) provides an accurate localisation of a cancerous biological target via signalling the intracellular glycolysis obtained by the co-registration of the PET and CT images (Antti, 2010). The value of combining the FDG-PET and the CT has improved the diagnostic accuracy in cancer at large (Fathinul, 2013a; Fathinul *et al.*, 2013b; Nordin, 2012; Pfannenber, 2007; Niikura *et al.*, 2011). For the purpose of this review, we address the utility of FDG-PET CT as a useful imaging tool by highlighting its use in the field of oncology imaging.

### *Scanning Procedure*

PET/CT equipped with a crystal detector arranged in a ring around the patient covering an extended 50cm to 70cm per field of view is the common prototype system in commercial use. Prior to undergoing a PET/CT examination, patients are required to fast for at least 6 hours and to avoid strenuous physical activities. After validating the desired venous glucose level ( $< 7.0\text{mmol/L}$ ), patients are injected with approximately 10mCi  $^{18}\text{F}$ -FDG and are instructed to lie completely still in the first 60 minutes in a designated injection room. A CT scan is performed for the purpose of an attenuation correction to rescale the 511kV PET data. The PET emission acquisition is performed at approximately 3.0 minutes per bed position. PET, CT and fusion PET/CT images are displayed on a dedicated PET-CT display system for qualitative and semi-quantitative analysis (Ronald *et al.*, 2010).

### *Flurodeoxyglucose (Fdg) as a Signaling Probe for PET/CT*

One of the primary metabolic changes associated with proliferating tumour cells is induction of aerobic glycolysis. Glucose is a critical nutrient for proliferating cells (Lee *et al.*, 2009). Malignant cells have increased facilitated glucose transport and up regulation of hexokinase activity; hence, tumours can be identified by regions of increased glucose utilisation (Gatenby & Gillies, 2004). FDG is used to signal altered glucose metabolism in patients with malignancy. The focal area of abnormally increased FDG uptake is considered suspicious for malignant disease, particularly as metabolic changes which often precede the morphological changes are associated with disease (Wahl, 1991). Whole-body PET/CT has become the standard of care for cancer staging because of its high diagnostic accuracy and ability to provide a rapid survey for both regional and distant forms of metastatic disease (Czernin, 2007).

### *Qualitative and Semi-quantification of FDG Uptake*

The uptake of  $^{18}\text{F}$ -FDG can be assessed by qualitative and semi-quantitative means; each has its advantages and limitations. Mannus *et al.* recommended a scheme on the visual interpretation of tumour response on PET (Fig.1, Table 1) (MacManus, 2003). Quantitative evaluation of FDG PET images provides quantitative data in the form of a standardised uptake value (SUV). This is an uptake measurement that provides a mean of comparison of FDG uptake between different lesions. Measurement of SUV requires attenuation correction to avoid the variability

in FDG uptake due to the differences in tumour habitus within the body. This value normalises the tumor FDG uptake with the FDG injected activity and the body weight (Kim, 1994)

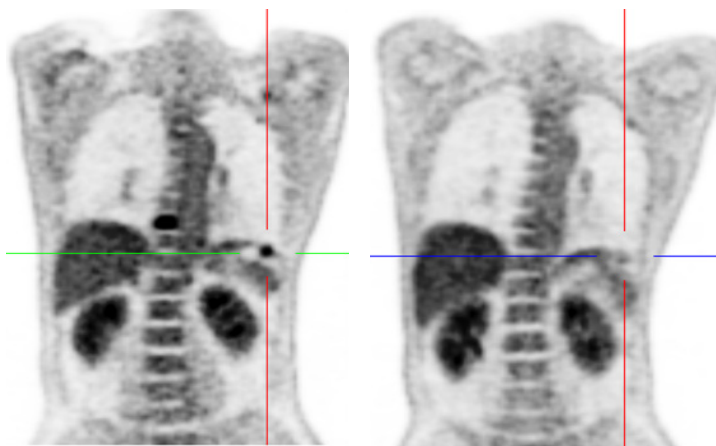


Fig. 1: PET/CT treatment monitoring of a 60-year-old patient with left basal non-small lung carcinoma (NSCLC). The left panel: A coronal baseline PET image showing a 3.0 mm left FDG-avid lesion (SUV max: 7.56). The right panel: A coronal post-treatment PET image showing partial metabolic response of the left NSCLC lesion (SUV max: 3.17)

TABLE 1: Scheme Defining the Different Qualitative Assessment of the Disease Response as Evaluated on PET-CT (Macmanus, 2003)

Type of response	Description
Complete metabolic response (CMR)	-return of 18F-FDG uptake in previously documented lesions to a level of equivalent to or lower than the activity in normal tissue
Partial metabolic response (PMR) (Fig. 1)	-a significant visual reduction in 18F-FDG PET uptake in tumour sites on the visual analysis of a tumour in question but residual abnormalities suggesting malignancy
Progressive metabolic disease (PMD)	-an increase in the extent of metabolic abnormality favouring tumour growth or evidence of new sites of disease
Stable metabolic disease (SMD)	- no change

*PET-CT and the Recist Criteria*

The standalone structural imaging modality assessment of a small cancer lesion is devoid of information on the functional changes. The actual metabolic activity of a cancer is thence deemed as under evaluated in important parameters that influence successful treatment as cancer healing is confounded by area or fibrosis which mimic the viable cancer tissue. The use

of Response Evaluation Criteria in Solid Tumours (RECIST 1.1) to criteria in the assessment of a lesion does not represent the actual intracellular changes which lead many limitations in preparing a patient for an appropriate treatment strategy (Eisenhauer *et al.*, 2009). An instance of this is a lymph node of size larger than 1 cm denoted as containing a tumour on the structural imaging, which always misleads the treating physician on the nodal staging on the TNM AJCC 6<sup>th</sup> edition (Yan-Ping *et al.*, 2009). The most favourable index of the 18F-FDG PET/CT is that it is capable of exhibiting more rapid change in cellular metabolism than in tumour size (Stroobants *et al.*, 2003). Functional information derived from PET is complementary to the high resolution structural imaging data available from such modalities as CT and MRI. Because of the limitations of CT scanning, PET/CT scanning may also have a role in response assessment after induction therapy prior to surgery, particularly for stage IIIA NSCLC. Choi *et al.* found that the residual metabolic rate of glucose (MRglc) as measured using FDG-PET was strongly correlated with response to preoperative chemoradiotherapy in locally advanced NSCLC as assessed by a pathological examination of a tumour obtained from a thoracotomy (Choi *et al.*, 2002). Currently, the American College of Radiology Imaging Network 6668/RTOG 0235 trial is prospectively evaluating whether the primary tumour 18F-FDG SUV<sub>max</sub> shortly after definitive chemoradiation can predict long-term survival in inoperable stage II or III NSCLC (Greene *et al.*, 2002). In GIST, Choi *et al.* confirmed their previous observation that RECIST significantly underestimated tumour response. They suggested that a more than 10% decrease in one dimension of a cancer lesion on CT at 2 months after treatment is adequate to identify good responders to FDG-PET, and predicts a longer long-term prognosis (Haesun *et al.*, 2007). The use of contrast-enhanced CT has enabled demonstration of tumour characteristics i.e. tumour density, enhancing tumour nodules and tumour vessels, in addition to tumour size. The additional information on the tumour enhancement on CT connotes that the outside dimensions of a tumour mass may not accurately reflect how active the tumour is and the decrease in tumour density of the responding tumours on CT is correlated with the development of tumour necrosis or cystic myxoid degeneration.

An evolving new guideline looking at the metabolic changes as a yardstick for post treatment evaluation of a solid tumour has been suggested i.e. PET assessment evaluation of a solid tumour (PERSIST). However, a lot more work on the factors that confound the parameters used before these new criteria are to be accepted given assessment on the metabolic changes require more parameters that need standardization (Richard *et al.*, 2009). PERSIST, however, offers the potential to characterise the nature of tumour cells on the understanding of the alteration of their normal biochemical and biologic features. Thus, the information obtained is basically different from that alluded by anatomic imaging.

### *FDG PET/CT in Tumor Staging*

Poor sensitivity of standalone CT, MRI and PET may lead to inaccurate staging of a tumour. Recent data, with regards to tumour staging, have shown that integrated PET/CT images are superior to PET images alone and PET and CT images viewed side by side (Kim, 1994). Contrast CT technique used for the evaluation of equivocal PET results promises higher achievable diagnostic results in many tumours (Nordin, 2012), for instance, the prevalence

of brown fat FDG-accumulation in patient neuroendocrine tumour. The contrasted CT has a greater sensitivity in distinguishing an occult lesion given the raised lesion-to-background noise ratio (Yon, 2006; Pottgen, 2006). The impact of PET in detecting diffuse involvement of other organ systems as part of the metastatic spread or delineation of the subcentimetre focus of FDG-avidity has averted futile surgery and unnecessary treatment costs (Pottgen, 2006). In this regards, we observed the change in the patient management as a result of the up-staging of tumour by the PET-CT modality (Fathinul, 2011). In addition, the metabolic information on the PET image would facilitate the biopsy localisation of a lesion. This is supported by many published data on the improved diagnostic yield of biopsy employing PET/CT as compared to the conventional approach (Fathinul, 2011; Caroline, 2008). Subcentimeter metastatic lesions are better visualised on the PET/CT as compared to CT given the benefit of signalling glycolytic metabolism that has improved lesion detection at large (Fig.2) (Yoon, 2011).

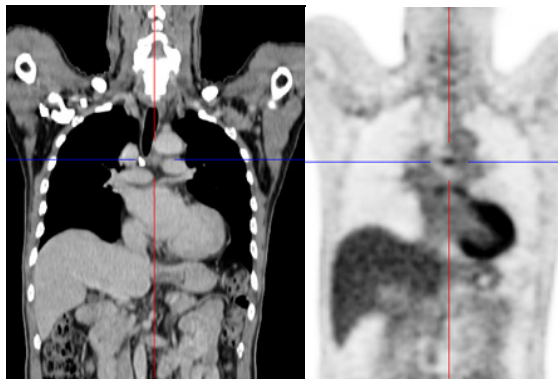


Fig.2: Example of discordant positron emission tomography (PET) and computed tomography (CT) results. CT (left) images of a mediastinal lymph node showing a subcentimeter lymph node. The corresponding PET image (right) exhibited an FDG-avid lymph node denoting the altered glucose metabolism suspicious for pathological lymph node. [Images courtesy of Pusat Pengimejan Diagnostik Nuklear]

The value of using PET/CT for patients undergoing restaging after treatment is equally apparent. It is now possible for this modality to distinguish between malignancy and post-therapeutic change (Van *et al.*, 2002). According to Selzner *et al.*, combined PET/CT over scored standalone CT and PET in restaging tumours after years of disease-free survival, when the distorted anatomy may not be easily distinguished from the site of a tumour recurrence (Selzner *et al.*, 2004). PET/CT has proven to be a very sensitive non-invasive staging technique and may even determine the exact location of a solitary lymph node particularly in evaluating the stage of non-small cell lung cancer (NSCLC), thus concluding the precise classification as N1 or N2 lymph node station based on classification by the American Joint Committee of Cancer (AJCC) (Asamura, 2000). Unsuspected extra thoracic soft tissue or skeletal metastases also may be revealed by PET/CT in cases where other imaging methods fail to demonstrate distant metastasis (Schoder, 2007).

### *FDG PET/CT Predicts Tumor Aggressiveness*

In addition, the degree of metabolic defect via semi-quantitative analysis, SUV could predict tumour aggressiveness and overall patient survival as high SUV values correlate with poor disease prognosis (Yamada *et al.*, 1992). We reported 23 patients with recurrent pheochromocytoma/paraganglioma, with regards to SUVmax evaluation on tumour aggressiveness; nine patients had local controls (34.1%) with mean progression-free survival (PFS) of  $19.35 \pm 3.34$  months with a significant number of patients with metastatic disease who had  $SUV > 9.2$  as compared to the local disease group ( $p < 0.05$ ) (Fathinul *et al.*, 2014). The prediction of tumour aggressiveness is important for tailoring a management plan obviating the risk of unnecessary treatment toxicity and to reduce the cost burden for patients. This is in line with many studies which demonstrated that the decrease of FDG uptake after a single infusion of chemotherapy was a predictor of eventual response to this regimen (Kostakoglu *et al.*, 2002). On the other hand, no decrease of tumour FDG uptake after the first infusion was a predictor of non-response.

### *FDG PET/CT Alters the Management Plan*

PET/CT changed the primary diagnosis in approximately 16% of cases, whereas PET/CT resulted in a change in staging and treatment plan in approximately 28% to 32% of the cases, respectively, and thus enabled the establishment of an appropriate scheme for disease response to treatment (Pottgen, 2006). Current procedures to monitor therapy using anatomical imaging modalities, such as CT, have a major setback given that functional changes often precede anatomical changes. A significant metabolic change can be established by comparing the standardised uptake values (SUV) from pre- and post-treatment scans, although such comparisons can only be made accurately on attenuation-corrected, quantitative PET images (Wahl, 1991). In our experience, we found that in a cohort of 23 patients with head and neck tumours, there were changes in the management plan in 58% of the patients being evaluated on the PET/CT as compared to CT-based staging (Fathinul, 2013a).

### *PET-CT in Radiation Oncology*

The new approach of radiation therapy and intensity modulated radiation therapy necessitates more precise target volume definitions for dose-sparing of normal tissues. Traditionally, CT has been popular as a tool of choice for radiation therapy planning. Nevertheless, CT has been shown to have relatively low sensitivity and specificity for detecting tumour tissue (Gregoire, 2007). In a meta analysis for solid tumours, PET/CT imaging was found to have a better sensitivity of 92% and a specificity of 93% compared to 85% and 88% for PET and 64% and 83% for CT alone, respectively, and hence for the radiation treatment (Antoch, 2004). Tumour biology has been identified as an essential factor for effective dose delivery (Ling *et al.*, 2000). With PET/CT imaging the biological tumour volume allows the radiation dose to be modulated according to the distribution of the PET signal intensity within the tumour volume specifically (Ling *et al.*, 2000; Schwartz *et al.*, 2005). In addition, the PET-CT provides a single reproducible session for highly precise patient positioning during the imaging and



treatment sessions rendering an accurate tumour delineation and effective dose delivery over standalone PET and CT systems (Gilman, 2007). The proliferating tissue has increased FDG avidity although the radiation inflammatory effect may at times be misinterpreted as a true positive lesion (Figure 3). A recent review of PET/CT utilisation for radiotherapy planning in lung cancer showed differences in the range of 30% to 60% between PET-derived contours versus CT-only target volumes (Greco, 2007).

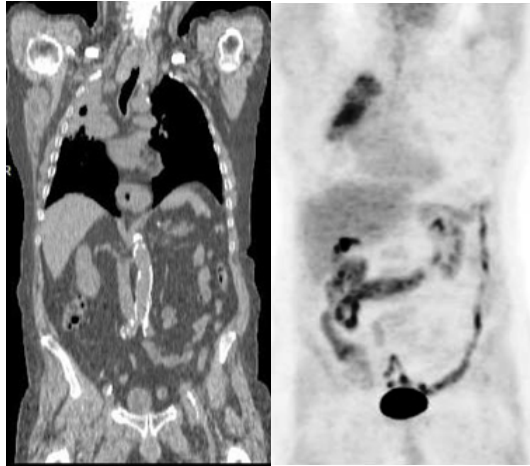


Fig.3: CT and PET coronal images; A 54-year-old man had completed radiotherapy of the right lung for recurrent NSCLC. The images show typical dome-shape consolidative changes with increased FDG accumulation in radiation pneumonitis. (Images courtesy of Peter Mac Callum Centre)

### *PET/CT and the Radiation Risk*

Most commonly, PET utilises  $^{18}\text{F}$ -FDG as a radiotracer; the short half-life of 110 min reduces radiation exposure compared with other commonly used radionuclides such as  $^{99\text{m}}\text{Tc}$  (6 hours) or  $^{201}\text{Tl}$  (72 hours). It carries a low absorbed dose to the patient estimated at approximately 7 mSv. The radiation (X-rays) from our diagnostic CT protocol ranged from 8mSv to 16 mSv for a two-dedicated low tube current dose (35mAs) and the CARE Dose 4D (120kV). The 64-multislice CT technique was equipped with the dual focal spot that ensured more image yields without increase in the total radiation dose and the CARE dose 4D is capable of modulating tube current adaptation tailoring to the patient's size, for which features render an efficient effective patient dose of up to 20% as compared to the lower 16 multislice of the same kind (Zito, 2009). In general, the benefits of subjecting patients for the PET-CT outweigh the radiation risk as most information required for the staging of a tumour is available in a single session study. In a study by Hishar *et al.*, the dose minimisation strategy on PET was adequate to yield a good PET-CT image without significant compromise (Hishar, 2014).

### *PET-CT and Economy*

Despite increasing evidence supporting the accuracy of standalone imaging i.e. CT, MRI or PET, high cost and limited cost-effectiveness data have militated against funding for routine clinical use in many countries (Gambhir, 1996). There is now substantial evidence that PET/CT is an exceedingly accurate multimodality imaging in detecting malignant tissue and provides a higher specificity than conventional imaging (Michael *et al.*, 2011; Ell, 2006). Precision in staging may avert futile surgery for which PET-CT has changed the management plan whilst providing additional clinical benefits to patients (Ell, 2006). Considering the median length of pre- and post-operative hospital stay, the cost of surgical resections and biopsies evaluated on PET-CT was found overall to be cost beneficial (Rohren, 2004). In Heinrich *et al.*'s trial on patients with pancreatic cancers who underwent PET-CT for disease staging, metastases were found in 16 patients with cancer initially deemed resectable, leading to different management and cost savings of USD 1,066 per patient (Heinrich *et al.*, 2005). In the United States, the use of FDG PET scanning has been shown to be a cost-effective alternative to conventional imaging methods in the evaluation of non-small-cell lung cancer, and this led MEDICARE, an insurance provider, to reimburse patients for those indications (Dewan, 1995). In our initial experience in working with patients with cancers referred for staging, a remarkable change in management strategy reflected a potential reduction in the total costs incurred to be borne by the patients.

### *PET-CT Potential Pitfalls*

As PET and CT are operated on a sequential basis, where co-registration of data obtained from both methods is deemed to some degradation artefacts. The use of contrasted CT in PET/CT; among other known artefacts the following were seen: banana lesion caused by diaphragmatic movement in the lower lung; breathing artefacts; patient motion; incidental metal device on the patient torso or FDG-RBC microembolus; leakage of FDG at the injection site or from the contaminated patient's gown after urine voiding; and pooling of intravenous contrast as source of false positive FDG-avidity were also observed as an attribute to the overestimation of the attenuation correction (Fathinul & Lau, 2009a; Fathinul & Lau, 2009b; William, 2007). Therefore, a careful instruction for PET/CT preparation and adoption of improved techniques during PET-CT i.e. gated respiration and improvement of the PET detector to facilitate image enhancement are urgently required.

## **CONCLUSION**

A combined PET and CT scanner is a practical and effective approach in acquiring co-registered anatomical and functional images in a single scanning session. It denotes the new era in molecular imaging whereby advancement in science and technology has impacted the way physicians personalise treatment plans with more effective strategy and a cost effective package for the patient. Combined contrasted PET/CT imaging facilitates the separation of normal physiologic uptake from pathological tissue with a more favourable accuracy and, hence, helps reduce the incidence of false-positive and false-negative incidence.



## ACKNOWLEDGEMENTS

This work was supported in part by the Research University Grant Scheme (RUGS), University Putra Malaysia.

## REFERENCES

- Antoch, G., Saoudi, N., Kuehl, H., Dahmen, G., Mueller, S. P., Beyer, T., Freudenberg, L. S. (2004). Accuracy of whole-body dual-modality fluorine-18-2-fluoro-2-deoxy-D-glucose positron emission tomography and computed tomography (FDG-PET/CT) for tumor staging in solid tumors: comparison with CT and PET. *J Clin Oncol*, 22(21), 4357-4368.
- Antti, S., Heikki, U., & Sami, K. (2010). Integrated anatomy and viability assessment PET/CT. *Euro Intervention Supplement*, 6(G), 132-137.
- Asamura, H., Suzuki, K., Kondo, H., Tsuchiya, R. (2000). Where is the boundary between N1 and N2 stations in lung cancer? *Ann Thorac Surg.*, 70, 1839-1845.
- Boellaard, R., O'Doherty, M. J., Weber, W. A., Mottaghy, F. M., Lonsdale, M. N., Stroobants, S. G., & Krause, B. J. (2010). FDG PET and PET/CT: EANM procedure guidelines for tumour PET imaging: version 1.0. *European Journal of Nuclear Medicine and Molecular Imaging*, 37(1), 181-200. doi: 10.1007/s00259-009-1297-4
- Caroline, B. M., Françoise, K. B., Philippe, M. L., Campion, B. D., & Steven, L. G. (2008). Investigation of FDG-PET/CT imaging to guide biopsies in the detection of histological transformation of indolent lymphoma. *Haematol*, 3(93), 471-472.
- Choi, H., Charnsangavej, C., Faria, S. C., Macapinlac, H. A., Burgess, M. A., Patel, S. R., Benjamin, R. S. (2007). Correlation of computed tomography and positron emission tomography in patients with metastatic gastrointestinal stromal tumor treated at a single institution with imatinib mesylate: proposal of new computed tomography response criteria. *J Clin Oncol*, 25(13), 1753-1759.
- Choi, N. C., Fischman, A. J., Niemierko, A., Ryu, J. S., Lynch, T., Wain, J., Mathisen, D. (2002). Dose-response relationship between probability of pathologic tumor control and glucose metabolic rate measured with FDG PET after preoperative chemoradiotherapy in locally advanced non-small-cell lung cancer. *Int J Radiat Oncol Biol Phys*, 54(4), 1024-1035.
- Czernin, J., Allen-Auerbach, M., & Schelbert, H. R. (2007). Improvements in cancer staging with PET/CT: Literature-based evidence as of September 2006. *J Nucl Med.*, 48(1), 78-88.
- Dewan, N. A., Reeb, S. D., & Gupta, N. (1995). PET-FDG imaging and transthoracic needle lung aspiration biopsy in evaluation of pulmonary lesions: A comparative risk-benefit analysis. *Chest*, 108, 441-446.
- Eisenhauer, E. A., Therasse, P., Bogaerts, P., Schwartz, L. H., & Verweij, J. (2009). New response evaluation criteria in solid tumors: Revised RECIST guideline (version 1.1). *Eur J Cancer*, 45, 228-247.
- Ell, P. J. (2006). The contribution of PET/CT to improved patient management. *Br J Radiol.*, 79, 32-36.
- Fathinul Fikri, A. S., Nordin, A. J., & Eddie Lau, E. F. (2013a). <sup>18</sup>(F) FDG-PET/CT is a useful molecular marker in evaluating tumor aggressiveness; A revised understanding of an in-vivo FDGPET imaging that alludes the alteration of cancer biology. *Cell Biochemistry and Biophysic*, 66, 37-43. DOI: 10.1007/s12013-012-9395-5.

- Fathinul Fikri, A. S., Nordin, A. J., Mohtarrudin, N., Hemalata, & Lau, W. F. E. (2011). 18[F] FDG-PET/CT is a useful molecular marker in evaluating thymoma aggressiveness. *European Journal of Radiology Extra*, 78(2), e89-e92. doi: <http://dx.doi.org/10.1016/j.ejrex.2011.02.006>
- Fathinul, F., & Lau, W. F. E. (2009a). An intense 18F- FDG pulmonary microfocus on PET without detectable abnormality on CT: A manifestation of an iatrogenic FDG pulmonary embolus. *Biomed Imaging Interv J*, 6(4):e37.
- Fathinul, F., & Lau, W. F. E. (2009b). Avid 18F-FDG uptake of pectoralis major muscle: An equivocal sequela of strenuous physical exercise. *Biomed Imaging Interv J*, 5(2), e7.
- Fikri, A. S., Kroiss, A., Ahmad, A. Z., Zanariah, H., Lau, W. F., Uprimny, C., Virgolini, I. J. (2014). Localization and prediction of malignant potential in recurrent pheochromocytoma/paraganglioma (PCC/PGL) using 18F-FDG PET/CT. *Acta Radiol*, 55(5), 631-640.
- Gambhir, S. S., Hoh, C. K., & Phelps, M. E. 1996. Decision tree sensitivity analysis for cost-effectiveness of FDG-PET in the staging and management of non-small-cell lung carcinoma. *J Nucl Med*, 37, 1428-1436
- Gatenby, R. A., & Gillies, R. J. (2004). Why do cancers have high aerobic glycolysis? *Nat Rev Cancer*, 4, 891-899.
- Gilman, M. D., Fischman, A. J., Krishnasetty V, Halpern EF, Aquino SL. 2007. Hybrid PET/CT of the thorax: when is computer registration necessary?. *J Comput Assist Tomogr*, 31, 395-401.
- Greco, C., Rosenzweig, K, Cascini, G. L., & Tamburrini, O. 2007. Current status of PET/CT for tumor volume definition in radiotherapy treatment planning for non-small cell lung cancer (NSCLC). *Lung Cancer*, 57, 125-34.
- Greene, F. L., Page, D. L., Fleming, I. D. *et al.* (Eds.) (2002). Lung. In: *AJCC cancer staging manual*, 6th ed. New York, NY: Springer.
- Gregoire, V., Haustermans, K., Geets, X., Roels, S., & Lonneux, M. (2007). PET based treatment planning in radiotherapy: A new standard? *J Nucl Med*, 48(Suppl 1), 68S-77S.
- Heinrich, S., Goerres, G. W., Schafer, M., Sagmeister, M., Bauerfeind, P., Pestalozzi, B. C., . . . Clavien, P. A. (2005). Positron emission tomography/computed tomography influences on the management of resectable pancreatic cancer and its cost-effectiveness. *Ann Surg*, 242(2), 235-243.
- Herbrik, M., Treffert, J., Geiger, B., Riegger, C., Hartung, V., Rosenbaum-Krumme, S. J., & Heusner, T. A. (2011). Diagnostic accuracy of virtual 18F-FDG PET/CT bronchoscopy for the detection of lymph node metastases in non-small cell lung cancer patients. *J Nucl Med*, 52(10), 1520-1525.
- Hishar, H., Fathinul Fikri, A. S., Salasiah, M., Noramaliza Mohd, N., & Abdul Jalil, N. (2014). Investigation on the influence of dose minimisation management on the PET image quality. *Radiography*, 20(1), 65-69. doi: <http://dx.doi.org/10.1016/j.radi.2013.10.005>
- Kim, C. K., Gupta, N. C., Chandramouli, B., & Alavi, A. (1994). Standardized uptake values of FDG: body surface area correction is preferable to body weight correction. *J Nucl Med*, 35(1), 164-167.
- Kostakoglu, L., Coleman, M., Leonard, J. P., Kuji, I., Zoe, H., & Goldsmith, S. J. (2002). PET predicts prognosis after 1 cycle of chemotherapy in aggressive lymphoma and Hodgkin's disease. *J Nucl Med*, 43(8), 1018-1027.

- Kubota, R., Yamada, S., Kubota, K., Ishiwata, K., Tamahashi, N., & Ido, T. (1992). Intratumoral distribution of fluorine-18-fluorodeoxyglucose in vivo: high accumulation in macrophages and granulation tissues studied by microautoradiography. *J Nucl Med*, *33*(11), 1972-1980.
- Lau, W. F., Binns, D. S., Ware, R. E., Ramdave, S., Cachin, F., Pitman, A. G., & Hicks, R. J. (2005). Clinical experience with the first combined positron emission tomography/computed tomography scanner in Australia. *Med J Aust*, *182*(4), 172-176.
- Lee, T. S., Ahn, S. H., Moon, B. S., Chun, K. S., Kang, J. H., Cheon, G. J., & Lim, S. M. Comparison of 18F-FDG, 18F-FET and 18F-FLT for differentiation between tumor and inflammation in rats. *Nuclear Medicine and Biology*, *36*(6), 681-686. doi: 10.1016/j.nucmedbio.2009.03.009
- Ling, C. C., Humm, J., Larson, S., Amols, H., Fuks, Z., Leibel, S., & Koutcher, J. A. (2000). Towards multidimensional radiotherapy (MD-CRT): biological imaging and biological conformality. *Int J Radiat Oncol Biol Phys*, *47*(3), 551-560.
- Mac Manus, M. P., Hicks, R. J., Matthews, J. P., McKenzie, A., Rischin, D., Salminen, E. K., & Ball, D. L. (2003). Positron Emission Tomography Is Superior to Computed Tomography Scanning for Response-Assessment After Radical Radiotherapy or Chemoradiotherapy in Patients With Non-Small-Cell Lung Cancer. *Journal of Clinical Oncology*, *21*(7), 1285-1292. doi: 10.1200/jco.2003.07.054
- Mao, Y. P., Xie, F. Y., Liu, L. Z., Sun, Y., Li, L., Tang, L. L., & Ma, J. (2009). Re-evaluation of 6th edition of AJCC staging system for nasopharyngeal carcinoma and proposed improvement based on magnetic resonance imaging. *Int J Radiat Oncol Biol Phys*, *73*(5), 1326-1334.
- Moses, W. W. (2007). Recent Advances and Future Advances in Time-of-Flight PET. *Nuclear Instruments & Methods in Physics Research. Section A, Accelerators, Spectrometers, Detectors and Associated Equipment*, *580*(2), 919-924. doi:10.1016/j.nima.2007.06.038
- Niikura, N., Costelloe, C. M., Madewell, J. E., Hayashi, N., Yu, T. K., Liu, J., & Ueno, N. T. (2011). FDG-PET/CT compared with conventional imaging in the detection of distant metastases of primary breast cancer. *Oncologist*, *16*(8), 1111-1119.
- Nordin, A. J., Noraini, I., Fathinul, F., Ahmad, Z. F. (2012). The role of contrast Enhanced CT in integrated PET/CT study CT Imaging Book. Computed Tomography- Clinical applications. *InTech*, 293-312.
- Pfannenber, A. C., Aschoff, P., & Brechtel, K. (2007). Value of contrast-enhanced multiphase CT in combined PET/CT protocols for oncological imaging. (2007). *The British Journal of Radiology*, *80*(954), 437-445. doi: doi:10.1259/bjr/34082277
- Pottgen, C., Levegrun, S., Theegarten, D., Marnitz, S., Grehl, S., Pink, R., & Stuschke, M. (2006). Value of 18F-fluoro-2-deoxy-D-glucose-positron emission tomography/computed tomography in non-small-cell lung cancer for prediction of pathologic response and times to relapse after neoadjuvant chemoradiotherapy. *Clin Cancer Res*, *12*(1), 97-106.
- Rohren, E. M., Turkington, T. G., & Coleman, R. E. (2004). Clinical Applications of PET in Oncology. *Radiology*, *231*(2), 305-332. doi: 10.1148/radiol.2312021185
- Schoder, H., & Gonen, M. (2007). Screening for cancer with PET and PET/CT: potential and limitations. *J Nucl Med*, *48*(1), 4S-18S.
- Schwartz, D. L., Ford, E. C., Rajendran, J., Yueh, B., Coltrera, M. D., Virgin, J., & Laramore, G. E. (2005). FDG-PET/CT-guided intensity modulated head and neck radiotherapy: a pilot investigation. *Head Neck*, *27*(6), 478-487.

- Selzner, M., Hany, T. F., Wildbrett, P., McCormack, L., Kadry, Z., & Clavien, P. A. (2004). Does the novel PET/CT imaging modality impact on the treatment of patients with metastatic colorectal cancer of the liver? *Ann Surg*, 240(6), 1027-1034.
- Stroobants, S., Goeminne, J., Seegers, M., Dimitrijevic, S., Dupont, P., Nuyts, J., van Oosterom, A. (2003). 18FDG-Positron emission tomography for the early prediction of response in advanced soft tissue sarcoma treated with imatinib mesylate (Glivec). *Eur J Cancer*, 39(14), 2012-2020.
- Sung, Y. M., Lee, K. S., Kim, B. T., Choi, J. Y., Shim, Y. M., & Yi, C. A. (2006). 18F-FDG PET/CT of thymic epithelial tumors: usefulness for distinguishing and staging tumor subgroups. *J Nucl Med*, 47(10), 1628-1634.
- Wahl, R. L., Hutchins, G. D., Buchsbaum, D. J., Liebert, M., Grossman, H. B., & Fisher, S. (1991). 18F-2-deoxy-2-fluoro-D-glucose uptake into human tumor xenografts. Feasibility studies for cancer imaging with positron-emission tomography. *Cancer*, 67(6), 1544-1550.
- Wahl, R. L., Jacene, H., Kasamon, Y., & Lodge, M. A. (2009). From RECIST to PERCIST: Evolving Considerations for PET response criteria in solid tumors. *J Nucl Med*, 50(S1), 122S-50S.
- van Tinteren, H., Hoekstra, O. S., Smit, E. F., van den Bergh, J. H., Schreurs, A. J., Stallaert, R. A., Teule, G. J. (2002). Effectiveness of positron emission tomography in the preoperative assessment of patients with suspected non-small-cell lung cancer: the PLUS multicentre randomised trial. *Lancet*, 359(9315), 1388-1393.
- Yoon, H. J., Lee, J. J., Kim, Y. K., & Kim, S. E. (2011). FDG-PET/CT Is Superior to Enhanced CT in Detecting Recurrent Subcentimeter Lesions in the Abdominopelvic Cavity in Colorectal Cancer. *Nucl Med Mol Imaging*, 45(2), 132-138.
- Zito, F., Zappa, L., Canzi, C., Leonardi, L., Re, G., Tosi, G., & Gerundini, P. (2009). Radiation exposure during PET-CT transmission imaging with 6 and 64-slice-CT scanners. *Journal of Nuclear Medicine*, 50(supplement 2), 1485.

## Smoking Behavior among Adolescents in Rural Schools in Malacca, Malaysia - A Case-Control Study

Nor Afiah, M.Z.<sup>1\*</sup>, Rahmah, M. A.<sup>2</sup>, Salmiah, M.S.<sup>1</sup>, Lye, M.S.<sup>1</sup>, Shamsul Azhar, S.<sup>2</sup> and Fazilah, I.<sup>3</sup>

<sup>1</sup>Department of Community Health, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

<sup>2</sup>Department of Community Health, Hospital Universiti Kebangsaan Malaysia, Jalan Yaakob Latiff, Bandar Tun Razak, 56000 Cheras, Kuala Lumpur, Malaysia

<sup>3</sup>Centre of General Studies, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

### ABSTRACT

Smoking among rural adolescents in Malaysia is on the rise with a significant difference seen between urban and rural youths. Therefore, this study was carried out to determine a predictive model of smoking among the rural-school adolescents population in Malacca, Malaysia. An unmatched case-control study was conducted in 2010 involving 484 cases and 444 controls of Form Two students in Malacca, Malaysia, using cluster sampling. Smoking was the dependent factor of this study while the independent factors were individual, family, school and environment. Data were obtained through a self-administered questionnaire. The response rate of the study was 100% whereas the smoking prevalence was 20.9%. Binary logistic regression was used to determine the smoking predictive model. Strong predictors of smoking behavior were: influenced by artistes who smoke (Adjusted OR=8.67, 95% CI 5.53-13.58); the male gender (Adjusted OR=6.7, 95% CI 4.14-10.83); Muslim (Adjusted OR=4.46, 95% CI 2.36-8.44); and the belief that smoking is not dangerous when the teacher is seen smoking as well (Adjusted OR=3.95, 95% CI 2.19-7.10). Other predictors were: being offered cigarettes by friends (Adjusted OR=2.81, 95% CI 1.79-4.42); the belief that smoking will relax the mind (Adjusted OR=2.45, 95% CI 1.33-4.51); having friends who smoke (Adjusted OR=2.32, 95% CI 1.29-4.81); forced by friends to smoke (Adjusted OR=2.17, 95% CI 1.15-4.12); have heard of the national No-Smoking Campaign (Adjusted OR=1.89, 95% CI 1.06-3.37); have problems with the school management (Adjusted OR=1.75, 95% CI 1.07-2.88); parental consent to watch sexual activities, drug use or violence on television or at the cinema (Adjusted OR=1.73, 95% CI 1.06-2.83); and have lunch in school (Adjusted OR=1.58, 95% CI 1.04-2.41). This paper ends with the recognition of the need for intervention in dismantling the predictors that can lead to the development of smoking among Malaysian adolescents in rural schools.

#### Article history:

Received: 1 Oct 2012

Accepted: 18 Dec 2013

#### E-mail addresses:

[norafiah@upm.edu.my](mailto:norafiah@upm.edu.my) (Nor Afiah, M.Z.),

[kusote@gmail.com](mailto:kusote@gmail.com) (Rahmah, M.A.),

[salmiah@upm.edu.my](mailto:salmiah@upm.edu.my) (Salmiah, M.S.),

[lyems@upm.edu.my](mailto:lyems@upm.edu.my) (Lye, M.S.),

[shamsulazharshah@yahoo.com](mailto:shamsulazharshah@yahoo.com) (Shamsul Azhar, S.),

[fazilah@ukm.my](mailto:fazilah@ukm.my) (Fazilah, I.)

\*Corresponding Author

*Keywords:* Rural adolescents, smoking, case-control study, Malacca

---

## INTRODUCTION

In Malaysia, smoking is prevalent among the adult as well as the adolescent population; the figures were 27.0% and 14.7% respectively in 2006. The trend recorded a decline in smoking among adolescents from 16.7% in 1996 to 14.7% in 2006 (Ministry of Health Malaysia, 2008). There are more adolescents in rural schools who smoke compared to in urban schools; the figures are 73.0% and 64.4% respectively (Plotnikoff *et al.*, 2004). The prevalence of adolescents among urban smokers (12.3%) and rural smokers (18.4%) in Malaysia also showed a significant difference although many anti-smoking campaigns have been conducted (Ministry of Health Malaysia, 2008).

Early adolescents engage in abstract thinking and grow towards reflective thinking by the time they have reached mid adolescence. As they approach adulthood, they mature in their thinking and begin to develop a more distinct identity of their own (World Health Organizations, 2002).

However, in the process of developing their own identity and behavior patterns, as outlined by the Ecological System Theory, adolescents are also affected in their development by the external influences of individuals such as family members, friends, neighbors and people from school as well as extraneous forces such as the law and attitudes of society either directly or indirectly (Bronfenbrenner, 1979). The importance of these factors must be identified to nurture them to grow into good adults in their later life, helping them to manage their dismay and curiosity and eventually prevent them from engaging in negative behaviours.

As outlined by Bronfenbrenner's (1979) Ecological System Theory, smoking can be influenced by individuals, family members, elements connected to the school and environmental factors. Many studies have shown that the following factors can contribute to smoking among adolescents: male gender; being younger siblings; having good communication with parents; awareness of the dangers of smoking; having lunch at school; having a good self-image; and intake of alcohol (Sperber *et al.*, 2001; Harakeh *et al.*, 2005; Chang *et al.*, 2006, Kalesan *et al.*, 2006; Lim *et al.*, 2006; Yanez *et al.*, 2006).

Although adolescents spend more time with their peers, family members such as the father, mother, siblings and others also influence adolescent behavior in different ways (Larsons & Richards, 1991). Lim *et al.*, (2006) found that adolescents in Kota Tinggi, Johore, a southern state in Malaysia, whose fathers were smokers, had a higher significant risk for smoking compared to those who had fathers who were not smokers (OR=3.18, 95% CI 1.54-6.56). The same study also showed a similar higher risk for smoking among adolescents whose brothers were smokers (Lim *et al.*, 2006).

Besides family members, school teachers are also role models for school children. Teachers are constantly being observed by their students, and indirectly, teachers gain trust from their students especially in terms of behavior and attitudes. In a cross-sectional study reported by Wen *et al.* (2007), among 3957 school children from Grade Seven to Grade Nine in Guangzhou, China who did not smoke began smoking after they saw their teacher smoking. The school as a microcosm also plays a significant role in adolescents' decision to experiment with or



to take up smoking. If a school has a high prevalence of smoking, it is also likely to have a high number of students who smoke (Alexander *et al.*, 2001). Other influencing factors for adolescents to smoke include: the involvement of students in co-curricular activities; type of school i.e. whether public or private school; having anti-smoking activities in schools; academic performance; and the presence of no-smoking signage around the school compound (Lim *et al.*, 2006; Yanez *et al.*, 2006; Wen *et al.*, 2007; MOH, 2008).

Although environment as a factor does not seem to correlate directly with adolescents who smoke, it does contribute significantly to adolescents' behavioral development. The environment is defined not only as the environment outside the house but all that surrounds the adolescent. Anybody in the adolescent's home who smokes can influence him/her to try smoking (Castrucci & Gerlach, 2006). Peers who smoke and the pressure from peers to smoke are also important factors (Kalesan *et al.*, 2006; Damianaki *et al.*, 2008). A study conducted by Lee *et al.* (2005) on 4500 adolescent students in Negeri Sembilan, a state in central Malaysia, also showed similar findings, with the prevalence of smoking in rural areas at 15.3% while in urban areas it was 12.8% ( $p < 0.05$ ) (Lee *et al.*, 2005).

Numerous studies have been conducted on the risk factors of cigarette smoking among adolescents in general. In Malaysia, however, little is known of the actual predictive factors covering the elements of individual, family, school and environment, which are consistent with the Ecological System Theory. Therefore, this study aimed to determine the predictive factors for smoking among rural school adolescents in Malacca, Malaysia. The results of this contribute to the development of a more effective intervention programme focusing on rural adolescents.

## MATERIALS AND METHODS

This study is an unmatched case-control study conducted in the state of Malacca, Malaysia, from May to August 2010. Malaysia has 14 states, one of which is Malacca. The state has an area of 1664 km<sup>2</sup> and a population of 771,500 (Department of Statistics Malaysia, 2007).

The educational system in Malaysia consists of primary, secondary and tertiary levels. The Form-Two students of this study were in the secondary level. Only government secondary schools were chosen for this study. Malacca has 73 secondary schools and they are divided into urban, suburban and rural schools. There are 34 rural schools comprising 13,385 students (Department of Education Malacca, 2008).

The sample population was 14-year-olds who were schooling in 11 different rural secondary schools in Malacca selected through cluster random sampling. The sample size was calculated by a formula from Schlesselman and Stolley (1982) in which the alpha was taken at the level of 0.05 ( $Z_{1-\alpha/2}$ ) with 80% power ( $Z_{1-\beta}$ ). The minimum sample size was 924 after a consideration of design effect of 462 cases and 462 controls.

All students were given a screening questionnaire in order to group them as smoker (case) or non-smoker (control). The inclusion criteria for the case group were: Form-Two (14 years old) students who had taken up smoking; enrolled in regular national, multiracial and non-boarding schools (schools where not all the students stayed in a school hostel). The inclusion criteria for the control group were similar to that of the case group except for smoking status. The exclusion criterion for case and control was students who refused to participate in the study.

Based on the finding of a study investigating 1881 adolescents aged 12-14 years in the southeastern United States, which reported that prevalent estimates of smoking were similar to self-reports and cotinine, a self-administered questionnaire was used for data collection in this study (Dolcini *et al.*, 2003). The questionnaire was divided into smoking profile, socio-demographic factors (8 variables), individual factors (9 variables), family factors (13 variables), schooling factors (6 variables) and environmental factors (9 variables). Smoking is defined as having tried cigarette smoking, even if only one or two puffs (MOH, 2008). Students with school-management problems in this study referred to disciplinary issues leading to behavioral problems such as smoking, truancy, glue sniffing etc. Questions regarding commitment to religion were adapted from Krauss *et al.* (2007). There were 23 questions with a 5-scale answer option. Respondents who scored less than the mean were considered as having high religious commitment. Questions on self-image were adapted from the Rosenberg Self-Esteem Scale. Respondents were classified as suffering from low self-esteem if they scored less than 15 and exhibiting high self-esteem if they scored more than 25 (Rosenberg, 1965).

The questionnaire was newly constructed based on a literature review, observation and expert opinion in the field of smoking. It was sent for content validity to four expert individuals: a clinical psychologist, a medical anthropologist, a public health specialist with experience in the tobacco-control programme of the country and a health promotion specialist. Pre-test and pilot testing was conducted with 35 students. Test-retest using kappa statistics was also conducted since the answer options were categorical data. The duration between test and retest was 14 days (Nunnally, 1994). Kappa agreement of every statement ranged from 0.3 to 0.8.

Anonymity of each respondent was important during data collection, and, therefore, the process of collecting data did not involve any teachers or school representatives. Consent from each respondent was taken and respondents were informed that their answers were confidential. Approval for doing the study was obtained from the Ministry of Education, Malaysia while ethics approval was obtained from the National University of Malaysia, Medical Research Ethical Committee, Cheras, Kuala Lumpur, Malaysia.

Data were analyzed using the Predictive Analysis Software Statistics version 18. A bivariate analysis such as the crude odds ratio was performed. Predictors that were significant from the bivariate analysis were selected in the binary logistic regression analysis using the Enter method in order to develop the final predictive model for smoking. The odds ratio of smoking and the predictors were considered significant if 95% of the confidence interval did not include one ( $p < 0.05$ ).

## RESULTS

There were 928 respondents who participated in the study, of whom 484 were cases accounted for while 444 were controls. The mean age (year) at which smoking was first tried out was  $11.39 + 2.107$ .



TABLE 1 Association Between Case and Control by Individual Factors

Individual factors	Category		Crude Odds Ratio	95% CI
	Case N (%)	Control (N %)		
Gender				
Male	427 (88.2)	170 (38.3)	12.074	8.627-
Female	57 (11.8)	274 (61.7)	1	16.899
Ethnicity				
Malay	444 (91.7)	326 (73.4)	4.018	2.731-
Others	40 (8.3)	118 (26.6)	1	5.911
Religion				
Muslim	446 (92.1)	329 (74.1)	4.103	2.768-
Others	38 (7.9)	115 (25.9)	1	6.080
Have consumed alcohol before				
Yes	42 (9.0)..	36 (8.2)	1.109	0.696-
No	425 (91.0)	404 (91.8)	1	1.767
Aware that smoking is harmful to the health				
Yes	442 (94.4)	406 (92.7)	1.430	0.785-
No	26 (5.6)	32 (7.3)	1	2.287
Always skip breakfast				
No	275 (58.3)	25 (56.8)	1.06	0.82-
Yes	197 (41.7)	191 (43.2)	1	1.38
Have lunch in school				
Yes	319 (67.6)	250 (56.7)	1.593	1.217-
No	153 (32.4)	191 (43.3)	1	2.086
Have dinner with family				
No	101 (21.2)	86 (19.5)	1.12	0.81-
Yes	375 (78.8)	356 (80.5)	1	1.54
Belief that smoking will relax the mind				
Yes	134 (28.5)	35 (7.9)	4.649	3.119-
No	336 (71.5)	408 (92.1)	1	6.929
Have sniffed glue and used drugs				
Yes	17 (3.6)	8 (1.8)	2.013	0.860-
No	456 (96.4)	432 (98.2)	1	4.713
I am influenced by artistes who smoke				
Yes	347 (71.7)	63 (14.2)	15.318	10.991-
No	137 (28.3)	381 (85.8)	1	21.347
I have seen a doctor smoking				
I believe that smoking does not cause any harm	198 (40.9)	37 (8.3)	7.62	5.19-
I believe that smoking is dangerous	286 (63.0)	407 (94.0)	1	11.16
I have seen a teacher smoking				
I believe that smoking is dangerous	152 (33.6)	21 (4.8)	9.91	6.13-
I believe that smoking does not cause any harm	301 (66.4)	412 (95.2)	1	16.01
Level of commitment to religion				
Low	146 (30.2)	106 (23.9)	1.38	1.03-
High	338 (69.8)	338 (76.1)	1	1.84
Level of self-esteem				
Low	160 (36.0)	122 (29.4)	1.353	1.016-
Normal	284 (64.0)	293 (70.6)	1	1.802

*Individual factors*

The majority of smokers were males (88.2%), Malays (91.7%) and Muslims (92.1%). There were significant crude odds ratio for males (OR=12.07; 95% CI 8.63-16.90), Malay ethnicity (OR=4.02; 95% CI 2.73-5.91) and Muslims (OR=4.10; 95% CI 2.77-6.08) (Table 1).

Variables for the individual factors that were significant in this study using a univariate analysis were: having lunch in school (OR=1.59; 95% CI 1.22-2.09); belief that smoking is relaxing (OR=4.65; 95% CI 3.12 to 6.93); influenced by artistes who smoke (OR=15.32; 95% CI 10.99-21.35); and the belief that smoking is not dangerous when a teacher is seen smoking (OR=7.83; 95% CI 5.23-11.72). Other significant factors are given in Table 1.

*Family Factors*

Table 2 shows that the risks of smoking were higher among respondents whose mothers were smokers (OR=3.56; 95% CI 1.17-10.82); sisters or brothers were smokers (OR=2.19, 95% CI 1.62 to 2.95); and people who stayed with them in their home (except parents, siblings, grandparents) were smokers (OR=1.70, 95% CI 1.24-2.31). These were among the significant risk factors. There were many other risks factors related to the family that contributed to adolescents smoking such as the father was a smoker (OR=1.47; 95% CI 1.13-1.92); grandparents were smokers (OR=1.696; 95% CI 1.2-2.3); and never discussed the danger of smoking with their parents (OR=1.32; 95% CI 1.02-1.71). Other significant family factors are given in Table 2.

TABLE 2: Association Between Case and Control by Family Factors

Family factors	Category		Crude Odds Ratio	95% CI
	Case N (%)	Control N (%)		
Father smokes				
Yes	299 (62.8)	235 (53.4)	1.474	1.132-
No	177 (37.2)	205 (46.6)	1	1.919
Mother smokes				
Yes	15(3.2)	4 (0.9)	3.563	1.173-
No	460 (96.8)	437 (99.1)	1	10.817
Sister/Brother smokes				
Yes	168 (35.4)	88 (20.0)	2.190	1.622-
No	306 (64.6)	351 (80.0)	1	2.956
Grandparents smoke				
Yes	138 (29.1)	84 (19.4)	1.696	1.244-
No	337 (70.9)	348 (80.6)	1	2.313
Other people (except parents, siblings, grandparents) in the family smoke				
Yes	116 (24.2)	66 (15.2)	1.777	1.271-
No	363 (75.8)	367 (84.8)	1	2.485
Regulations of smoking in the family				
Present	189 (40.0)	84 (19.2)	2.81	2.08-
Absent	283 (60.0)	353 (80.8)	1	3.79
Have you ever discussed the dangers of smoking with your parents?				
No	249(52.1)	200 (45.1)	1.321	1.019-
Yes	229 (47.9)	243 (54.9)	1	1.712

TABLE 2: (continue)

Parents are always available when we need their attention				
No	155 (32.7)	327 (71.1)	1.47	
Yes	319 (67.3)	108 (24.8)	1	1.10-1.97
Parents spent their time				
No	102 (21.4)	54 (12.3)	1.94	
Yes	374 (78.6)	384 (87.7)	1	1.35-2.78
Parents are interested in discussing smoking and related issues				
Yes	102 (21.1)	80 (18.0)	1.215	0.877-
No	382 (78.9)	364 (82.0)	1	1.683
Discuss with parents how to refuse smoking if invited to by friends				
No	322 (66.5)	267 (61.4)	1.22	
Yes	162 (33.5)	168 (38.6)	1	0.93-1.59
Parents are angry if I smoke				
No	78 (16.4)	43 (9.9)	1.79	
Yes	398 (83.6)	392 (99.1)	1	1.20-2.66
Parents advise on the dangers of smoking when they see smoking activity on television or at the cinema when watching TV or movies together				
No	180 (38.0)	133 (30.4)	1.39	
Yes	294 (62.0)	304 (69.6)	1	1.06-1.84
Parental restriction against watching sexual movies, drug use and violence on television or at the cinema when watching TV or movies together				
No	129 (26.9)	83 (18.9)	1.58	
Yes	350 (73.1)	355 (81.1)	1	1.15-2.16

### *School Factors*

As shown in Table 3, seeing a teacher smoking around the school compound (OR=1.82; 95% CI 1.40-2.36); seeing persons other than the teacher smoking around the school compound (OR=1.54; 95% CI 1.17-2.04); being involved in more than one hour per week of co-curricular activities in school (OR=1.41; 95% CI 1.03-1.92) were significant risk factors.

A high prevalence of smoking in the school was among the strongest risk factors (OR=2.11; 95% CI 1.62-2.74) followed by problems with the school management (OR=2.64; 95% CI 1.925-3.638) (Table 3).

### *Environmental Factors*

Most of the environmental variables had a significant relationship with smoking. More than 80% of cases compared to the controlled cases had friends who smoked; had read the health information messages on the cigarette box; were aware that cigarettes cannot be sold to adolescents under 18 years of age; and had heard of the No-Smoking Campaign.

Peers are among the important influences in cases of adolescent smoking. In this study, being offered cigarettes by friends was the most significant risk factor: those in this category were almost 12 times more likely to smoke (OR=11.87; 95% CI 8.68-16.22). Other high

TABLE 3 : Association Between Case and Control by School Factors

School factors	Category		Crude Odds Ratio	95% CI
	Case N (%)	Control N (%)		
Have seen a teacher smoking around the school compound				
Yes	271 (56.7)	185 (41.9)	1.819	1.400-
No	207 (43.3)	257 (58.1)	1	2.363
Being given knowledge about smoking in school				
Yes	438 (92.0)	404 (91.4)	1.084	0.678-
No	38 (8.0)	38 (8.6)	1	1.734
Received advice from teacher not to smoke in school				
Yes	438 (92.0)	404 (91.4)	1.084	0.678-
No	38 (8.0)	38 (8.6)	1	1.734
Have seen signage that smoking is prohibited in the school compound				
Yes	416 (87.6)	374 (85.6)	1.188	0.811-
No	59 (12.4)	63 (14.4)	1	1.739
Have seen people other than the teacher smoking around the school compound				
Yes	348 (72.7)	279 (63.3)	1.542	1.167-
No	131 (27.3)	162 (36.7)	1	2.039
Involved in co-curriculum activities of up to more than one hour per week				
Yes	368 (79.1)	313 (73.0)	1.406	1.032-
No	97 (20.9)	116 (27.0)	1	1.915
Know that termination from school is one of the punishments for students who smoke				
Yes	73 (15.7)	62 (14.9)	1.061	
No	392 (84.3)	353 (85.9)	1	0.73-1.53
Prevalence of smoking in the school				
High	264 (54.5)	161 (36.3)		1.621-
Low	220 (45.5)	283 (63.7)	2.109	1 2.745
Problem with the school management				
Yes	159 (33.1)	70 (15.8)		1.925-
No	321 (66.9)	374 (84.2)	2.64	1 3.638

significant factors were: having friends who smoked (OR=8.55, 95% CI 5.81-12.59); having a best friend who smoked (OR=6.00; 95% CI 4.46- 8.08); having friends who forced the respondent to smoke (OR=5.30; 95% CI 3.28-8.56); and being offered items that carried a particular cigarette brand (OR=5.01; 95% CI 3.06- 8.20). The other significant risk factors are given in Table 4.

TABLE 4 Association Between Case and Control by Environmental Factors

Environmental factors	Category		Crude Odds Ratio	95% CI
	Case N (%)	Control N (%)		
Have friends who smoke				
Yes	442 (92.3)	250 (58.3)	8.553	5.812-
No	37 (7.7)	179 (41.7)	1	12.588
Have friends who offer cigarettes				
Yes	357 (74.7)	87 (19.9)	11.869	8.684-
No	121 (25.3)	350 (80.1)	1	16.223
Have friends who force me to smoke				
Yes	105 (21.9)	22 (5.0)	5.295	3.275-
No	375 (78.1)	416 (95.0)	1	8.559
Have a best friend who smokes				
Yes	284 (59.5)	87 (19.7)	6.004	4.460-
No	193 (40.5)	355 (80.3)	1	8.084
I am influenced by artistes who smoke				
Yes	115 (24.6)	75 (17.1)	1.586	1.146-
No	352 (75.4)	364 (82.9)	1	2.196
Received items with cigarette brand labels				
Yes	96 (20.1)	21 (4.8)	5.014	3.065-
No	382 (79.9)	419 (95.2)	1	8.202
Agreed with new ways to advertise such as through pens, t-shirts, belts				
Yes	139 (29.4)	103 (23.6)	1.345	1.000-
No	334 (70.6)	333 (76.4)	1	1.810
Increased cigarette price can prevent smoking				
Yes	285 (61.0)	210 (48.1)	1.693	1.300-
No	182 (39.0)	227 (51.9)	1	2.205
Aware that adolescent cigarette smoking is an offence that can be punished				
Yes	60 (12.6)	30 (6.8)	1.97	1.25-
No	416 (87.4)	410 (93.2)	1	3.12
Have read the health information messages on cigarette boxes				
Yes	407 (85.0)	312 (72.1)	2.192	1.581-
No	72 (15.0)	121 (27.9)	1	3.040
Aware that cigarettes cannot be sold to adolescents under 18 years of age				
Yes	454 (94.2)	396 (89.6)	1.883	1.155-
No	28 (5.8)	46 (10.4)	1	3.071
Have heard of the No Smoking Campaign				
Yes	419 (87.7)	361 (82.2)	1.534	1.064-
No	59 (12.3)	78 (17.8)	1	2.213

*Predictive Model of Smoking*

All significant variables in the bivariate analysis were used in the binary logistic regressions to predict the risk factors of smoking. The model was found to be a best-fit model, indicating that the assumed hypotheses were accepted. Forward stepwise logistic regression indicated that 12 variables were significant predictors of smoking with 93.1% correctly assigned by the model.

The predictors of smoking were influenced by: seeing artistes smoke (Adjusted OR=8.67, 95% CI 5.53-13.58); the male gender (Adjusted OR=6.7, 95% CI 4.14-10.83); Muslims (Adjusted OR=4.46, 95% CI 2.36-8.44); belief that smoking is not dangerous after seeing teachers smoking (Adjusted OR=3.95, 95% CI 2.19-7.10); being offered cigarettes by friends (Adjusted OR=2.81, 95% CI 1.79-4.42); belief that smoking will relax the mind (Adjusted OR=2.45, 95% CI 1.33-4.51); having friends who smoke (Adjusted OR=2.32, 95% CI 1.29-4.81); smoking as forced by friends (Adjusted OR=2.17, 95% CI 1.15-4.12); heard about the No-Smoking Campaign (Adjusted OR=1.89, 95% CI 1.06-3.37); problems with the school management (Adjusted OR=1.75, 95% CI 1.07-2.88); parents have never restricted me from watching sexual activities, drug use or violence on television or at the cinema when watching together (Adjusted OR=1.73, 95% CI 1.06-2.83); and having lunch in school (Adjusted OR=1.58, 95% CI 1.04-2.41). The Hosmer-Lemeshow goodness of fit was not significant (p=0.981) and only 68.0% of smoking factors were explained by this smoking model (Table 5).

TABLE 5: Predictors of Smoking

Variables	$\beta$	Wald	Adj OR	95% confidence interval	p-value
Gender					
Male	1.90	60.35	6.70		
Female			1	4.14-10.83	<0.001
Religion					
Muslims	1.49	21.09	4.46		
Others			1	2.36-8.44	<0.001
Have friends who smoke					
Yes	0.84	7.92	2.32		
No			1	1.29-4.18	0.004
Have friends who offered cigarettes					
Yes	1.03	20.19	2.81		
No			1	1.79-4.42	<0.001
Have friends who forced me to smoke					
Yes	0.78	5.68	2.17		
No			1	1.15-4.12	0.017
I am influenced by artistes who smoke					
Yes	2.16	88.63	8.67		
No			1	5.53-13.58	<0.001
Have seen a teacher smoking					
I believe smoking does not bring any harm	1.374	21.12	3.95		
I believe smoking is dangerous			1	2.19-7.10	<0.001

TABLE 5: (Continue)

Belief that smoking will relax the mind					
Yes	0.89	8.318	2.45		
No			1	1.33-4.51	0.004
Parents restrict me from watching sexual movies, drug use and violence on television or at the cinema when watching together					
No	0.55	4.76	1.73		
Yes			1	1.06-2.83	0.029
Problems with the school management					
Yes	0.561	4.89	1.75		
No			1	1.07-2.88	0.027
Have lunch in school					
Yes	0.458	4.493	1.58		
No				1.04-2.41	0.034
Have heard about the No- Smoking Campaign					
Yes	0.64	4.621	1.89		
No				1.06-3.37	0.032

The predictor model for smoking among adolescents in this study was:  $\text{Log}(\text{Smoking among rural adolescent}) = \text{Log}(\text{Male}) + \text{Log}(\text{Muslims}) + \text{Log}(\text{Have friends who smoke}) + \text{Log}(\text{Have friends who offered cigarettes}) + \text{Log}(\text{Have friend who forced me to smoke}) + \text{Log}(\text{I was influenced to smoke after I was artistes smoking}) + \text{Log}(\text{I believe that smoking does not bring any harm after I have seen teachers smoking}) + \text{Log}(\text{Belief that smoking will relax the mind}) + \text{Log}(\text{Parents do not restrict me from watching sexual movies, drug used and violence on television or at the cinema when watching together}) + \text{Log}(\text{Have problems with the school management}) + \text{Log}(\text{Have lunch in school}) + \text{Log}(\text{Have heard about the No-Smoking Campaign})$ .

## DISCUSSION

The Ecological System Theory by Bronfenbrenner (1979) suggests that human development is influenced by four environmental systems, namely, microsystem, mesosystem, exosystem and macrosystem. However, in this study, only the microsystem and exosystem were finally shown to be significant predictors of smoking. The microsystem components involved were individual, peers, school and family, whereas the exosystem was the mass media.

In this study, the male gender was a significant risk factor for smoking. This is consistent with the previous study which showed that males were more likely to report smoking than females (Jarvelaid, 2004, Rudatsikira *et al.*, 2008). Malaysia is a multiracial country with a predominantly Malay population followed by Chinese, Indian and other races. This current study showed that being Malay was one of the significant factors for smoking among rural adolescents in the bivariate analysis (Jarvelaid, 2004). A study conducted in Negeri Sembilan, Malaysia, also found that Malay adolescents compared to non-Malay adolescents had a

significantly higher prevalence of smoking (Lee *et al.*, 2005). However, Malays are not significant in the multivariate analysis.

At adolescence, peers are able to influence behavioral development in terms of engaging in either positive or negative activities. As in the literature, this study found a significant risk of smoking including having friends who smoke; having been offered cigarettes by friends and being forced by friends to smoke, as some of the risk factors. According to Yang *et al.* (2004), the influence of friends and classmates has the strongest effect in contributing to adolescents smoking. The findings of this study are supported by other studies in Malaysia that found that peer group influence to smoke had strong effects (Lim *et al.*, 2006). This may be due to the interaction of adolescents with their friends, particularly their peers, in their daily activities, which may provide easy access to cigarettes. Furthermore, in Malaysia, data have shown that 87% of adolescents smoked with their friends. This may explain why peer smoking and having lunch in school are among the risk factors (Sperber *et al.*, 2001). According to the Contagion Model, the most popular adolescents are the trendsetters in creating the pro-smoking or anti-smoking norm in schools (Alexander *et al.*, 2001). In addition, increased affiliation with peers who smoked mediated as indirect effect of movie-smoking exposure on smoking onset (Wills *et al.*, 2007). This study confirmed the above findings that parents who did not restrict their children from watching movies that displayed sexual content, drug use and violence on television or at the cinema when watching together was one of the predictors of smoking among rural adolescents.

In this study, the risk factor, peers who offered cigarettes was among the significant risk factors for smoking whereby it also had a strong relation to having friends who smoked. This is correlated by the results reported by Chang *et al.*, (2006) where students of the 10th Grade who had been offered cigarettes by their peers showed a significant possibility, by as high as 11 times, of taking up smoking. Another study showed that peer smoking, cigarettes being offered and a pro-smoking attitude are strong predictors of adolescent smoking (Abroms *et al.*, 2005). Whenever people want to be socially accepted in certain groups, indirectly they always tend to follow the group's activities. This social acceptance will submit adolescents to peer pressure. Furthermore, this age group is within the period of exploring and experimenting. Thus, school adolescents who received maximum negative pressure from their peers are nine times more likely to develop the risk to smoke than those who received minimum negative pressure (Kalesan *et al.*, 2006).

This study also found that smoking did not bring any harm when students saw their teachers smoking, which is one of the predictors of adolescent smoking. This is consistent with a cohort study in a southern region of Israel among respondents of the 9th Grade and their association with the smoking status in the 12th Grade, which showed that respondents are influenced to smoke as an effect of emulating their teachers who smoked even if they knew it was negative behavior or a negative influence (Sperber *et al.*, 2001). Wen *et al.*, (2007) also reported similar findings whereby observing teachers who smoked contributed twice to experimental smoking as opposed to those who had not observed teachers smoking (Hanna *et al.*, 2001). Despite the influence of the teachers, when these smoking adolescents witnessed artistes smoking, they tended to be influenced by the latter to smoke. This influence was apparent when they watched movies on television or at the cinema in which the actors smoked (Distefan *et al.*, 1999). The



findings of our study were consistent with this finding, that is, a significantly greater proportion of the respondents have smoked.

The results of this study showed that adolescent smokers feel relaxed when they smoked, and this is consistent with the findings of Distefan *et al.* (1999), Chalela *et al.* (2007) and Lee *et al.* (2005).

This study showed that students who encountered school management problems were more likely to smoke. Lee *et al.* (2005) found that there were significant associations between playing truant, being absent from school, alcohol drinking and other risk-taking behaviours and smoking. The Third National Health and Nutrition Examination Survey 1988-1994 (NHANES III) also reported that problem students who repeatedly obtained poor grades, were suspended from or who absented themselves from school were five times more likely to be smokers (Hanna *et al.*, 2001). Similarly, if a student had tried alcohol or marijuana, which was also a school offence, he/she was more likely to also indulge in smoking (Leatherdale *et al.*, 2008)

This study also found that respondents who had heard of a No-Smoking Campaign was a predictor of smoking. A study conducted by Christophi *et al.* (2008) also found that school children who read anti-smoking advertisements in a newspaper and magazine showed a higher risk to smoke. Another study by Siziya *et al.* (2007) supported these findings.

There was a possibility of misclassification of cases as the determination of smoking used screening by questionnaires only, and this could be subjected to measurement bias but the notion of confidentiality had been looked into. Behavioral disorder may involve dropouts; the recruitment of such dropouts in the study may have given better results in understanding the risk factors of adolescent smoking in rural areas. Other limitations such as the exposure factors that were studied, since the respondents were young adolescents in rural areas, showed that recall bias may also have occurred. Therefore, a cohort study is recommended in order to reduce the biases that might have occurred in this study.

## CONCLUSION

The development of any behavior is complicated and it needs the multi-system involvement as suggested by the Ecological System Theory of Bronnfennbrener (1979). This also applies in the case of an adolescent becoming a smoker. Hence, this study incorporated many factors on how adolescents developed their behavior towards smoking. Comparison of the groups in cases and controls demonstrated that the predictors of smoking among rural adolescents in this study were mainly: male; Malays; believed that smoking allowed people to relax; were influenced to smoke after seeing artistes smoke; believed that smoking is not dangerous as teachers had been seen smoking; were not prohibited by parents from watching sexual activities, drug user or violence when watching together on television or at the cinema; had problems with the school management; had friends who smoked; had friends who offered cigarettes; and were forced by friends to smoke.

The prevalence of smoking is increasing in trend particularly in rural areas; the findings of this study, therefore, are important in developing intervention that is able to address the predictors of smoking. Parents also play an important role in explaining to adolescent children the negative impacts of smoking.

## ACKNOWLEDGEMENTS

The study was funded by the Fundamental Grant of National University of Malaysia, project code FF-297-2009. The authors would like to thank the Ministry of Education, Malaysia for consenting to this study being carried out. Our gratitude also goes to all the schools and students who participated in this study.

## REFERENCES

- Abroms, L., Simons-Borton, B., Haynie, D., & Chen, R. (2005). Psychosocial predictors of smoking trajectories during middle and high school. *Addiction, 100*, 852-861.
- Alexander, C., Piazza, M., Mekos, D., & Valente, T. (2001). Peers, schools, and adolescent cigarette smoking. *Journal of Adolescent Health, 29(1)*, 22-30.
- Bronfenbrenner, U. (1979). *The ecology of human development: Experiments by nature and design*. Cambridge, MA: Harvard University Press.
- Castrucci, B. C., & Gerlach, K. K. (2006). Understanding the Association between authoritative parenting and adolescent smoking. *Maternal and Child Health, 10(2)*, 217-224.
- Chalela, P., Velez, L. F., & Ramirez, A. G. (2007). Social influences, and attitudes and beliefs associated with smoking among border Latino youth. *Journal of School Health, 77(4)*, 187-195.
- Chang, F. C., Lee, C. M., Lai, H. R., Chiang, J. T., Lee, P. H., & Chen, W. J. (2006). Social influences and self efficacy as predictors of youth smoking initiation and cessation: A 3-year longitudinal study of vocational high school students in Taiwan. *Addiction, 101*, 1645.
- Christophi, C. A, Kolokotroni, O., Alpert, H. R., Warren, C. W, Jones, N. R., Demokritou, P., & Connolly, G. N. (2008). Prevalence and social environment of cigarette smoking in Cyprus youth. *BMC Public Health, 8*:190
- Damianaki, A., Kaklamani, S., Tsirakis, S., Clarke, R., Tzanakis, N., & Makris, D. (2008). Risk factors for smoking among school adolescents in Greece. *Child Care, Health and Development, 34*, 310-315.
- Department of Statistics Malaysia. (2007). *Social Statistical Bulletin of Malaysia 2007*. Putrajaya.
- Distefan, J. M., Gilpin, E. A., & Sargent, J. D. (1999). Do movie stars encourage adolescents to start smoking? Evidence from California. *Prev Medicine, 28*, 1-11.
- Dolcini, M. M., Adler, E. N., Lee, P., & Bauman, E. K. (2003). An assessment of the validity of adolescent self-reported smoking using three biological indicators. *Nicotine & Tobacco Research, 5(4)*, 473-483
- Hammond, D., Kin, F., Prohmmo, A., Kungskulniti, N., Lian, T. Y., Sharma, K. S., Sirirassamee, B., Borland, R., & Fong, G. T. (2008). Patterns of smoking among adolescents in Malaysia and Thailand: Findings from the International Tobacco Control Southeast Asia Survey. *Asia-Pacific journal of Public Health, 20(3)*, 193-203.
- Hanna, E. Z., Yi, H., Dufour, M. C., & Whitmore, C. C. (2001). The relationship of early-onset regular smoking to alcohol use, depression, illicit drug use, and other risky behaviours during early adolescence: Results from the youth supplement to the Third National Health and nutrition Examination Survey. *Journal of Substance Abuse, 13*, 265-282.

- Harakeh, Z., Scholte, R. H. J., de Vries, H., & Engels, R. C. M. E. (2005). Parental rules and communication: Their association with adolescent smoking. *Addiction, 100*, 862-870.
- Jarvelaid, M. (2004). Adolescent tobacco smoking and associated psychosocial health risk factors. *Scand J Prim Health Care, 22*, 50-53.
- Kalesan, B., Stine, J., & Alberg, A. J. (2006). The joint influence of parental modeling and positive parental concern on cigarette smoking in middle and high school students. *Journal of School Health, 76*(8), 402-407.
- Krauss, S. E., Idris, F., & Hamzah, A. (2007). Adaptation of a Muslim religiosity scale for use with four different faith communities in Malaysia. *Review of Religious Research, 49*(2):147-164
- Larsons, R., & Richards, M. (1991). Daily companionship in late childhood and early adolescence: Changing developmental context. *Child Development, 62*, 284-300.
- Leatherdale, S. T., Hammond, D., & Ahmed, R. (2008). Alcohol, marijuana, and tobacco use patterns among youth in Canada. *Cancer Causes Control, 19*, 361-369.
- Lee, L. K., Paul, C. Y. C., Kam, C. W., & Jagmohni, K. (2005). Smoking among secondary school students in Negeri Sembilan, Malaysia. *Asia Pac. J Public Health, 17*(2), 130-136.
- Lim, K. H., Amal, N. M., Hanjeet, K., Mashod, M. Y., Wan Rozita, W. M., Sumarni, M. G., & Hadzrik, N. O. (2006). Prevalence and factors related to smoking among secondary school students in Kota Tinggi District, Johor, Malaysia. *Tropical Biomedicine, 23*(1), 75-84.
- Ministry of Health Malaysia. (2008). Smoking. The Third National Health and Morbidity Survey 2006 (NHMS III). National Institute of Health, Ministry of Health Malaysia, Kuala Lumpur.
- Morbidity and Mortality Weekly Report (MMWR). Youth risk behavior surveillance -- United States, 2005. (2006). Atlanta: Centres for Disease Control and Prevention.
- Nunnally, J. C., & Bernstein, I. H. (1994). Psychometric theory. New York: McGraw-Hill.
- Rosenberg, M. (1965). Society and the adolescent image. Princeton, New Jersey: Princeton University Press.
- Rudatsikira, E., Muula, A. S., Siziya, S., & Mataya R. H. (2008). Correlates of cigarette smoking among school-going adolescents in Thailand: Findings from the Thai global youth tobacco survey 2005. *International Archives of Medicine, 1*(8), 1-8.
- Schlesselman, J. J., & Stolley, P. D. (1982). Case control studies: Design, conduct, analysis. New York: Oxford University Press.
- Siziya, S., Rudatsikira, E., Muula, A. S., & Ntata, P. R. 2007. Predictors of cigarette smoking among adolescents in rural Zambia: Results from a cross sectional study from Chongwe district. *Rural Remote Health 7*(3):728
- Sperber, A. D., Peleg, A., Friger, M., & Shvartzman, P. (2001). Factors associated with daily smoking among Israeli adolescents: A prospective cohort study with a 3-year follow-up. *Preventive Medicine, 33*, 73-78.
- Su, T. A., & Hoe V. C. W. (2008). Reliability of a Malay-translated questionnaire for use in a hand-arm vibration syndrome study in Malaysia. *Singapore Medical Journal. 49*(12), 1038-1045.

- Wen, X., Chen, W., Muscat, J. E., Qian, Z., Lu, C., Zhang, C., Luo, Y., Liang, C., Han, K., Deng, X., Ou, Y., & Ling, W. (2007). Modifiable family and school environmental factors associated with smoking status among adolescents in Guangzhou, China. *Preventive Medicine, 45*, 189-197.
- Wills, A. T., Sargent, J. D., Stoolmiller, M., Gibbons, F. X., Worth, K. A., & Cin, S. D. 2007. Exposure to smoking cues and adolescent smoking onset: A test for mediation through peer affiliations. *Health Psychology, 26*(6), 769-776.
- World Health Organizations. (2002). Adolescent friendly health services. An agenda for change. Geneva: World Health Organizations.
- Yanez, A. M., Lopez, R., Serra-Batles, J., Roger, N., Arnau, A., & Roura, P. (2006). Smoking among adolescents: Population study on parental and school influences. *Arch Broncopneumol, 42*(1), 21-24.
- Yang, G., Ma, J., Chen, A. P., Brown, S., Taylor, C. E., & Samet, J. M. (2004). Smoking among adolescents in China: 1998 survey findings. *International Journal of Epidemiology, 33*, 1103-1110.

## Prevalence of Psychological Stress among Undergraduate Students Attending a Health Programme in a Malaysian University

Phang, C. K. \*, Sherina, M. S., Zubaidah, J. O., Noor Jan, K. O. N., Firdaus, M., Siti Irma, F. I. and Normala, I.

*Department of Psychiatry, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia*

### ABSTRACT

Psychological stress among undergraduate students is associated with poor academic results, physical ill-health and psychiatric disorders. The objectives of the study were to determine the prevalence of psychological stress and its associated factors among undergraduate students attending a health programme in a local university. This is a cross-sectional study among undergraduate students attending a health programme in a local university. The 12-item General Health Questionnaire (GHQ-12) was used to determine the presence of psychological stress at a cut-off point of 4 and above. Analysis was conducted to determine any association between gender, ethnicity, year of study in the university, recent health-seeking contact with a doctor, and psychological stress among the participants. The prevalence of psychological stress among undergraduate students attending a health program in a Malaysian University was 49.3%. There was no significant association with any of the socio-demographic factors studied ( $p>0.05$ ). The prevalence of psychological stress in this study was significantly high, and irrespective of gender, ethnicity, year of study in the university, and recent health-seeking contact with a doctor. Hence, the findings of this study show that it may be a useful strategy to integrate such health programs regularly in activities of colleges and universities, with the aim of promoting mental health and wellness among the students.

*Keywords:* Anxiety, depression, general health questionnaire (GHQ), mental health, psychological stress, undergraduates, university

### Article history:

Received: 19 November 2012

Accepted: 2 March 2014

### E-mail addresses:

pckar39011@gmail.com (Phang, C. K.)  
sherina@medic.upm.edu.my (Sherina, M. S.)  
zujamil@gmail.com (Zubaidah, J. O.)  
onkhin@medic.upm.edu.my (Noor Jan, K. O. N.)  
drfirdaus@medic.upm.edu.my (Firdaus, M.)  
sitiirma@medic.upm.edu.my (Siti Irma, F. I.)  
normala\_ib@upm.edu.my (Normala, I.)

\*Corresponding Author

### INTRODUCTION

Psychological stress among undergraduate students is associated with poor academic performance (Cookson, 2006; Kudachi *et al.*, 2008; Vaez & Laflamme, 2008), depression, anxiety, alcohol abuse, and suicide (Compton *et al.*, 2008; Mancevska *et al.*, 2008; Millan *et al.*, 1990).

The prevalence of psychological stress among undergraduate students is significantly high. In a Canadian study using the 12-item General Health Questionnaire (GHQ-12) among 7800 undergraduates from 17 universities (Adlaf *et al.*, 2001), 30% of the students reported elevated psychological stress. A similar study in 1,750 first year undergraduates in Norway using the GHQ-12 showed that the level of psychological stress was 21% (Nerdrum *et al.*, 2006). As for China, 58% of 2007 students in 17 universities experienced at least mild psychological stress (Zhang *et al.*, 2006). Local studies on psychological stress among undergraduates were mainly conducted among the medical students. The local prevalence of psychological stress among non-medical undergraduate students using GHQ-12 was 52.9% (Nor Shereen & Rozumah, 2010) and 34.4% (Noradilah *et al.*, 2009). As for local studies using GHQ-12 among medical students, the prevalence of psychological stress was 41.9% (Sherina *et al.*, 2003), 29.6% (Yusoff *et al.*, 2010), and 46.2% (Zaid, Chan, & Ho, 2007).

Psychological stress in undergraduate students is associated with several factors. A Swedish study showed that females (16.1%) had significantly higher level of psychological stress than males (8.1%) (Dahlin *et al.*, 2005). In local studies, however, gender and ethnic were not found to be associated with psychological stress (see Johari & Hassim, 2009; Nor Shereen & Rozumah, 2010; Sherina *et al.*, 2003; Yusoff *et al.*, 2010; Zaid *et al.*, 2007). Only one study indicated that psychological stress was the highest among the Chinese, followed by the Malays and Indians (Noradilah *et al.*, 2009).

With regards to year of study in the university, the highest prevalence of psychological stress was found among the 2nd (36.5%) and 4th year (35.3%) medical students (Yusoff *et al.*, 2010). In a study by Zaid *et al.* (2007), psychological stress was significantly higher among the 1st (50%) and final year (62.7%) medical students. However, three other local studies; two on medical students (Sherina *et al.*, 2003; Johari & Hassim, 2009), and another one on university students in general (Noradilah *et al.*, 2009) showed that the year of study in the university was not associated with psychological stress.

The objectives of this study were to: 1) determine the prevalence of psychological stress among undergraduate students attending a health programme in a university, and 2) determine whether there was an association between gender, ethnic, year of study in the university, recent health-seeking contact with a doctor, and psychological stress among the undergraduate students. This study is important to determine whether implementing mental health screening during university health programmes encourages students' participation, and facilitates early detection and management of mental health problems.

## **MATERIALS AND METHODS**

Participants consisted of attendees of the Youthful Health Fair programme that was held for three days in March, 2011, at a public university in Malaysia. The Youthful Health Programme, which was aimed to increase awareness and promote healthy lifestyle among university students, was the first of its kind at the university. It was held in the main hall of the university. A mental health screening booth was set up as a part of the programme to provide services that included mental health poster exhibition, video presentations, screening, and forum.

This cross sectional survey was conducted amongst all the participants who had attended the mental health screening booth that was carried out during this programme. Purposive sampling of participants was carried out in the survey. The screening was conducted by one psychiatrist, two trainee clinical psychologists, and six psychiatric nurses from the Department of Psychiatry. Data were collected using self-administered questionnaire which consisted of Part A (participants' socio-demographic data: gender, age, ethnicity, year of study in university and recent health-seeking contact with a doctor) and Part B (the 12-item General Health Questionnaire/GHQ-12).

The GHQ-12 is a well-validated instrument commonly used for screening psychiatric symptoms (Goldberg & Williams, 1988). It is also widely used by researchers for measuring mental health status especially in detection of 'caseness' of significant psychological distress. The questionnaires consist of 12 items and the participants respond to the items by choosing from four responses (from least symptoms to most symptoms). The '0-0-1-1' scoring method was used in this study; higher scores indicate more psychological distress. A cut-off score of four and above indicates significant psychological stress. The cut-off score is based on a local study by Yusoff (2010) on the Malay version of GHQ-12 among 150 medical students in Universiti Sains Malaysia (USM). The sensitivity and specificity of the GHQ-12 at the cut-off score of four were 81% and 75% respectively, while Cronbach's alpha of the scale was 0.85.

The information sheet was given to the participants and a written consent was obtained prior to the administration of the questionnaire. Each questionnaire was scored and interpreted immediately. The staff were trained by the attending psychiatrist prior to conducting the survey. All the scores were double checked by the attending psychiatrist to ensure their accuracy. The participants with high scores, (i.e., four and above) were referred immediately to the attending psychiatrist at the booth and if necessary, subsequently referred for follow-up with the mental health professionals in UPM.

IBM Statistical Package for Social Science (SPSS), Version 19.0, was used to analyse the data. The presence of psychological stress was determined based on a cut-off score of four and above in the GHQ-12 (scoring method of 0-0-1-1) (Yusoff, 2010). The Chi-square test was used to analyse the association between each factor and psychological stress. A multivariate logistic regression analysis was run to determine any variables that would predict GHQ-12 scores. A p-value of less than 0.05 was considered to be significant.

## RESULTS

Out of 324 participants who had completed GHQ-12, 306 fulfilled the selection criteria and were included in the analysis of this study. A total of 18 questionnaires were excluded; three due to missing data, eight were postgraduate students, and seven were non-students. The age of the participants ranged between 18 to 27 years with a mean of 21.67 (SD=1.72).

Table 1 shows the profile of participants in this study. Majority (85%) were female and of Malay ethnicity (65.7%). Almost half (45.8%) of the participants were freshmen (first-year students). In terms of health seeking behaviour, 5.6% of the participants consulted a doctor within the past two weeks due to medical reasons.



Table 1: Profile of the participants (N = 306)

Profile of respondents	N	%
Age (M ± SD)	21.67 ± 1.72	
Gender		
Female	260	85.0
Male	46	15.0
Ethnicity		
Malay	201	65.7
Chinese	92	30.1
Indian	7	2.3
Others	6	2.0
Year of study		
First	140	45.8
Second	78	25.5
Third	57	18.6
Fourth	28	9.2
Fifth	3	1.0
Recent health-seeking contact with a doctor		
Yes	17	5.6
No	289	94.4
Total	306	100.0

Table 2: Factors associated with Psychological Stress among participants (N = 306)

Associated factors	Psychological Stress (%)	No Psychological Stress (%)	p-value
Age (M ± SD)	21.57 ± 1.68	21.76 ± 1.76	0.33
Gender			
Female	131 (50.4)	129 (49.6)	0.39
Male	20 (43.5)	26 (56.5)	
Ethnicity			
Malays	97 (48.3)	104 (51.7)	0.79
Chinese	47 (51.1)	45 (48.9)	
Indians	3 (42.9)	4 (57.1)	
Others	4 (66.7)	2 (33.3)	
Year of study			
First	62 (44.3)	78 (55.7)	0.12
Second	48 (61.5)	30 (38.5)	
Third	25 (43.9)	32 (56.1)	
Fourth	15 (53.6)	13 (46.4)	
Fifth	1 (33.3)	2 (66.7)	
Recent health-seeking contact with a doctor			
Yes	10 (58.8)	7 (41.2)	0.42
No	141 (48.8)	148 (51.2)	

### *Prevalence of Psychological Stress*

The prevalence of psychological stress was 49.3% (N = 151/306). There was no significant association between psychological stress and any of the factors studied (Table 2). Multivariate logistic regression confirmed that none of the variables was a significant predictor of psychological stress as indicated by categorized GHQ-12 scores ( $p > 0.05$ )

## **DISCUSSION**

The prevalence of psychological stress in this study was 49.3%. This finding is more or less comparable to several local (Nor Shereen & Rozumah, 2010; Noradilah *et al.*, 2009; Sherina *et al.*, 2003; Zaid *et al.*, 2007), and international (Adlaf *et al.*, 2001; Nerdrum *et al.*, 2006; Zhang *et al.*, 2006) studies carried out among university students. However, this finding is much higher than the prevalence in the general adult Malaysian population as reported in the 2nd National Health & Morbidity Survey (GHQ-12, 10.7%) and 3rd National Health & Morbidity Survey (GHQ-28, 11.2%).

The high prevalence of psychological stress in this study was irrespective of gender and ethnicity. This finding is consistent with several local studies (Johari & Hassim, 2009; Nor Shereen & Rozumah, 2010; Sherina *et al.*, 2003; Yusoff *et al.*, 2010; Zaid *et al.*, 2007). Nevertheless, Noradilah *et al.* (2009) found that psychological stress was not associated with gender in their study, but it was associated with ethnicity instead (Noradilah *et al.*, 2009). The pattern of results in terms of gender association is different when compared to local studies on depression (instead of general psychological distress) among medical students; prevalence of depression is significantly higher among female medical students (Sherina & Kanesan, 2003; Yusoff, Rahim & Yaacob, 2011). This is not surprising as the prevalence of depression has generally been found to be higher among females in the community and general medical practice (Sherina & Kanesan, 2003).

The high prevalence of psychological stress was not significantly associated with the year of study in the university. Despite that, a descriptive statistic showed that the prevalence of psychological stress was higher among the year two (61.5%) and four (53.6%) students. This is similar to the study carried out among medical students by Yusoff *et al.* (2009), with the highest among year two, followed by year four students. However, it is dissimilar to the studies among medical students by Sherina *et al.* (2003), with higher percentage in year one and four students, as well as Zaid *et al.* (2007), who found higher percentage among year five and one students. The discrepancy is likely due to the difference in time of assessment (typically higher during examination periods) and studies curriculum between medical and non-medical students. It is interesting to note that selection criteria for university admission can have an impact on mental health. In the study by Yusoff *et al.* (2012), medical students who were in the same year of study (i.e., year one), but accepted into the medical school through different selection criteria (academic results versus academic results plus personal qualities) had different levels of psychological stress during an examination period. Those who were accepted into the medical school based on good academic results plus personal qualities had significantly less psychological stress during the examination period.

The strength of this study is that it was conducted during a university health programme, which received good response from the students. Consultation for mental health problems has always been associated with stigma in this country. It is encouraging that this study has shown that seeking help for mental health in a university health programme setting is acceptable to the students. Almost half (49.3%) of the students who had participated in the study had significant psychological stress. In other words, the programme was well attended and accepted by those with mental health needs. Therefore, this could be a good strategy for early detection, diagnosis and psychological interventions for mental health problems among university students.

As for limitation, this study was conducted involving only one university programme. In view of the high prevalence of psychological stress, it is recommended that more of such mental health screening and education be conducted together with other university programmes held throughout the year. Identifying risk factors such as childhood adversities, life-events, physical illness, substance abuse, and coping styles would help to further understand stress among the students (Maniam, Sidi, & Razali, 2013). It will be helpful if the university could offer courses or programmes related to stress reduction and wellness for the students to cope with psychological stress. This would definitely help the University to achieve its mission to produce high quality graduates who can contribute effectively to the community and nation building.

## CONCLUSION

The prevalence of psychological stress among undergraduate students attending a health programme in a Malaysian University was 49.3%. This is significantly high and irrespective of gender, ethnicity, year of study in the university, and recent health-seeking contact with a doctor. Seeking help for mental health in a university health program setting was acceptable to the students. Hence, it is a useful strategy to integrate such a health programme regularly in the university's activities for promoting mental health and wellness among the students.

## REFERENCES

- Adlaf, E. M., Gliksman, L., Demers, A., & Newton-Taylor, B. (2001). The prevalence of elevated psychological distress among Canadian undergraduates: findings from the 1998 Canadian Campus Survey. *Journal of American College Health, 50*(2), 67-72.
- Compton, M. T., Carrera, J., & Frank, E. (2008). Stress and depressive symptoms/dysphoria among us medical students: Results from a large, nationally representative survey. *Journal of Nervous and Mental Disease, 196*(12), 891-897.
- Cookson, J. (2006). Dealing with the effect of stress and adverse circumstances on examination results in medical students. *Medical Teacher, 28*(2), 101-102.
- Dahlin, M., Joneborg, N., & Runeson, B. (2005). Stress and depression among medical students: A cross-sectional study. *Medical Education, 39*(6), 594-604.
- Golberg D. (1978). *Manual of the General Health Questionnaire*. Windsor, England: NFER Publishing.
- Johari, A. & Hassim, I. (2009). Stress and Coping Strategies Among Medical Students in National University of Malaysia, Malaysia University of Sabah, and Universiti Kuala Lumpur Royal College of Medicine Perak. *Journal of Community Health, 15*, 106-115.

- Kudachi, P. S., Latti, R. G., & Goudar, S. S. (2008). Effect of examination stress on the academic performance of first year medical students. *Biomedicine*, 28(2), 142-144.
- Mancevska, S., Bozinovska, L., Tecce, J., Pluncevik-Gligoroska, J., & Sivevska-Smilevska, E. (2008). Depression, anxiety and substance use in medical students in the Republic of Macedonia. *Bratislava Medical Journal*, 109(12), 568-572.
- Maniam, T., Sidi, H., & Razali, R. (2013). Perspectives in Malaysian psychiatry. *Asia-Pacific Psychiatry*, 5 Suppl. 1, 2-3.
- Millan, L. R., Rossi, E., & De Marco, O. L. (1990). Suicide among medical students. *O suicídio entre estudantes de medicina.*, 45(3), 145-149.
- Nerdrum, P., Rustøen, T., & Rønnestad, M. H. (2006). Student psychological distress: A psychometric study of 1750 Norwegian 1st-year undergraduate students. *Scandinavian Journal of Educational Research*, 50(1), 95-109.
- Nor Shereen, J. & Rozumah, B. (2010). Using the 12-item General Health Questionnaire (GHQ-12) to Assess the Psychological Health of Malaysian College Students. *Global Journal of Health Science*, 2(1), 73-80.
- Noradilah, N., Mansor, B., & Siti, N. (2009). Personality, Loneliness and Mental Health Among Undergraduates at Malaysian Universities. *European Journal of Scientific Research*, 36(2), 285-298.
- Sherina, M. S., Rampal, L., & Kaneson, N. (2003). Prevalence of emotional disorders among medical students in a Malaysian university. *Asian Pacific Family Medicine*, 2, 213-217.
- Sherina, M. S. & Kanesan, N. (2003). The prevalence of depression among medical students. *Malaysia Journal of Psychiatry*, 11(1), 12-17.
- Vaez, M. & Laflamme, L. (2008). Experienced stress, psychological symptoms, self-rated health and academic achievement: A longitudinal study of Swedish university students. *Social Behavior and Personality*, 36(2), 183-196.
- Yusoff, M. S. B., Abdul Rahim, A. F., & Yaacob, M. J. (2010). Prevalence and sources of stress among Universiti Sains Malaysia medical students. *Malaysian Journal of Medical Sciences*, 17(1), 30-37.
- Yusoff, M. S. B. (2010). The Validity of Two Malay Versions of the General Health Questionnaire (GHQ) in Detecting Distressed Medical Students. *ASEAN Journal of Psychiatry*, 11(2), 135-142.
- Yusoff, M. S. B., Rahim, A. F. A., Babba, A. A., Ismail, S. B., & Esa, A. R. (2012). A study of psychological distress in two cohorts of first-year medical students that underwent different admission selection processes. *Malaysian Journal of Medical Sciences*, 19(3), 29-35.
- Yusoff, M. S. B., Rahim, A. F. A., & Yaacob, M. J. (2011). Depression among final year medical students in universiti sains malaysia (USM): associated, risk and determinant factors. *European Psychiatry*, 26, Supple (1), 706.
- Zaid, Z. A., Chan, S. C., & Ho, J. J. (2007). Emotional disorders among medical students in a Malaysian private medical school. *Singapore Medical Journal*, 48(10), 895-899.
- Zhang, L., Che, W. B., Li, B., & Zhang, X. D. (2006). An epidemiological survey on the psychological stress status for students in 13 Chinese colleges. *Zhonghua liu xing bing xue za zhi*, 27(5), 387-391.



## Analysing Elephant Habitat Parameters using GIS, Remote Sensing and Analytic Hierarchy Process in Peninsular Malaysia

Suhaida Aini<sup>1, 2\*</sup>, Alias Mohd Sood<sup>2</sup> and Salman Saaban<sup>3</sup>

<sup>1</sup>Malaysian Remote Sensing Agency, No. 13 Jalan Tun Ismail, 50480 Kuala Lumpur, Malaysia

<sup>2</sup>Department of Forest Production, Faculty of Forestry, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

<sup>3</sup>Division of Biodiversity Conservation, Department of Wildlife and National Parks, KM10 Jalan Cheras, 56100 Kuala Lumpur, Malaysia

### ABSTRACT

Geographic Information System (GIS) and remote sensing are geospatial technologies that have been used for many years in environmental studies, including gathering and analysing of information on the physical parameters of wildlife habitats and modelling of habitat assessments. The home range estimation provided in a GIS environment offers a viable method of quantifying habitat use and facilitating a better understanding of species and habitat relationships. This study used remote sensing, GIS and Analytic Hierarchy Process (AHP) application tools as methods to assess the habitat parameters preference of Asian elephant. Satellite images and topographical maps were used for the environmental and topographical habitat parameter generation encompassing land use-land cover (LULC), Normalized Digital Vegetation Index (NDVI), water sources, Digital Elevation Model (DEM), slope and aspect. The kernel home range was determined using elephant distribution data from satellite tracking, which were then analysed using habitat parameters to investigate any possible relationship. Subsequently, the frequency of the utilization distribution of elephants was further analysed using spatial and geostatistical analyses. This was followed by the use of AHP for identifying habitat preference, selection of significant habitat parameters and classification of criterion. The habitats occupied by the elephants showed that the conservation of these animals would require good management practices within and outside of protected areas so as to ensure the level of suitability of the habitat, particularly in translocation areas.

*Keywords:* Asian elephant, AHP, habitat preference, home range, GIS, and remote sensing

#### Article history:

Received: 7 Mar 2013

Accepted: 11 July 2013

#### E-mail addresses:

suhaidaaini@gmail.com (Suhaida Aini),  
ms\_alias@upm.edu.my (Alias Mohd Sood),  
salman@wildlife.gov.my (Salman Saaban)

\*Corresponding Author

### INTRODUCTION

As a spatial utilization measurement, home range estimation is an important tool in wildlife management. Today, the home range and habitat use of the Asian elephants are

often determined from satellite telemetry relocation points, which are the primary sources of data. Home range can be defined as an area where an individual elephant traverses in its normal activities (Burt, 1943), in relation to various uses such as feeding, drinking, resting, pathway network, defecation and marking points (Salman & Nasharuddin, 2000). There are many methods to delineate the home range pattern including minimum convex polygon (MCP), harmonic mean, kernel and Jennrich-Turner home ranges. Most studies on Asian elephants have used MCP which shows the area of animal uses and movements (e.g., Linde *et al.*, 1999; Salman & Nasharuddin, 2000; Prithiviraj *et al.*, 2008; Alfred *et al.*, 2011). However, the disadvantage of MCP is that it is very sensitive to sample size. The kernel method is a more realistic interpretation of what an animal is likely to use (Martin *et al.*, 2007) and it gives the most accurate representation of the structure of an animal's range and core area size (Ferrel, 2004).

There are many factors that influence an elephant's movement and distribution as well as its home range utilization. These include biotic and abiotic, physical and anthropogenic factors that are associated with spatial or geographical information. Hence, Geographic Information System (GIS) and remote sensing are common spatial technologies that can be used in environmental studies. These technologies provide a way to access and depict complex relationships among variables which are useful for incorporating scale and hierarchy concepts into ecosystem-based management assessments (O'Neill, 1996) and to evaluate research and management efforts (O'Neil *et al.*, 2005). According to Kushwaha *et al.* (2002), remote sensing and GIS technologies have been used for gathering information on the physical parameters of wildlife habitats. The Analytic Hierarchy Process (AHP) method, which was introduced by Saaty (1980), allows the consideration of both objective and subjective factors in selecting the best alternative. In fact, the AHP method has been applied in a wide variety of decisions and human judgment process (Lee *et al.*, 2001). This method is useful in identifying criteria and alternative in logical manner (Qureshi & Harisson, 2003).

According to the International Union for Conservation of Nature (IUCN, 2008), both the Asian and African elephants are facing a very real threat of extinction. Due to a large decrease in the number and status of elephants in Peninsular Malaysia, their status was elevated from protected species in 1972 to totally protected species in 2010. Based on the IUCN data, there are only around 40,000 Asian elephants left in the wild (Asian countries), out of which only 1,223 – 1,677 were left in Peninsular Malaysia (Salman *et al.*, 2011). Habitat loss and fragmentation remain the greatest threats to Asian elephants throughout their range in Asian countries (Santiapillai & Jackson 1990; Sukumar, 1992; Leimgruber *et al.*, 2003; Hedges *et al.*, 2005; IUCN, 2012), as well as in Peninsular Malaysia (Salman *et al.*, 2011). This is due to the conversion of forests to other forms of land use such as plantations, housing estates, highways and other development schemes (DWNP, 2006). Thus, this paper presents a study of the Asian elephant's habitat preference at two different study sites using remote sensing, GIS, and AHP approach. The home range estimated in the GIS environment through the analysis of habitat utilization based on environmental and topographical parameters would provide a better understanding of species and habitat relationships. Meanwhile, utilization distribution enables identification of significant elephant habitat parameters and prioritization of its criterion. The study is able to evaluate the parameters criteria uses and to add or modify them in order



to suit the preferences of stakeholders and Department of Wildlife and Natural Parks (DWNP) base on a multi-criteria decision making approach.

## MATERIALS AND METHODS

The study area covers two different sites of satellite transmitted data from the elephant distributions known as Mek Boh and Mek Lukut, which are located in Terengganu National Park (TNP) and Northern Johor, respectively. Mek Boh was collared with a NOAA satellite transmitter between 1999 and 2000, and Mek Lukut with a GPS Satellite Collar in 2010 by the DWNP. TNP is located in the state of Terengganu, which has been one of the major places for translocated elephants since 1992. The second study site is located in the state of Johor in Peninsular Malaysia. With an average elevation of below 50 m, this area is mostly flat as compared to TNP. The land cover of this area comprises of inland forest, peat swamp forest and agricultural land (oil palm). However, both locations are covered with primary and mixed secondary forests. They consist of four natural forest types; lowland dipterocarp forest, hill dipterocarp forest, upper hill dipterocarp forest and montane forest. Detailed information of each captured elephant is summarized in Table 1 below.

TABLE 1: Summary of individual female elephant's distribution data

Location	Existing Forest Type	Elephant Name	Estimated Age (yr)	Weight (ton)	Type of Satellite	Tracking Record Date
TNP	Natural (Inland)	Mek Boh	25	2.5	NOAA (ARGOS instruments)	22 Aug 1999 – 9 Jan 2000
Northern Johor	Natural (Inland & Peat swamp)	Mek Lukut	25	1.5	GPS Satellite Collar (Africa Wildlife Tracking)	21 Jul 2010 – 31 Dec 2011

### *Creation of Habitat Parameter Database*

Habitat parameters were obtained from digitization of features, digital processing of remote sensing data and conversion of data from other sources. These include land use-land cover (LULC) such as forest status, Normalized Digital Vegetation Index (NDVI), water sources, Digital Elevation Model (DEM), slope and aspect. Satellite imageries were used to generate the NDVI, LULC and forest status map.

The acquisition of these images was based on the satellite transmitted data of both elephant distributions. In this case, data from Landsat TM (1999) and SPOT 5 (2010-2011) were used to generate relevant habitat parameters for Mek Boh and Mek Lukut, respectively. These images were analysed using two major processes, namely, image pre-processing and detailed image processing, as shown in Fig. 1. Pre-processing involved the procedure that was carried out before the image was processed by correcting the image of various errors such as geometric, atmospheric and radiometric corrections. This process was followed by image mosaicking and enhancement. Image enhancement was performed in order to improve the

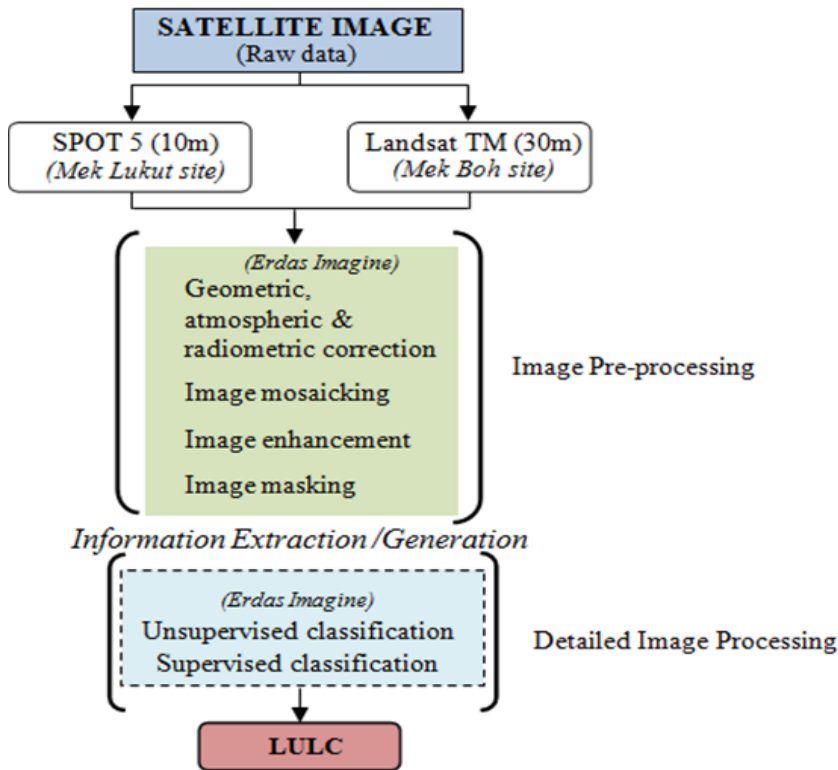


Fig.1: The main procedure of remote sensing data processing

interpretability of the image. This is an important procedure to increase the quality of the images for interpretation purposes, particularly through digitization process. Finally, image masking was applied to extract the images corresponding to the study area. Both unsupervised and supervised classifications were applied during the detailed images processing to generate an LULC map.

ArcGIS10 is the main software used in this study. Meanwhile, the Raster Calculator Tool in ArcGIS was used to generate the NDVI map layers. NDVI was proposed by Rouse *et al.* (1974), and it has been used to measure and monitor plant growth, vegetation cover, and biomass production from multispectral satellite data for many years (Jackson *et al.*, 1983; Eitel *et al.*, 2010). It is generated using the band ratio technique of the near-infrared (NIR) and red wavelength reflected by vegetation. The NDVI map is calculated from the following Map Algebra expression using the Raster Calculator Tool in ArcGIS:

$$NDVI = \text{Float} (R_1 - R_2) / \text{Float} (R_2 + R_1)$$

where  $R_1$  and  $R_2$  represent NIR and Red reflectance's, and where Float function was used in order to return a float data set with value between minus one (-1.0) and plus one (+1.0) for NDVI output. Healthy vegetation reflects much more in NIR wavelength than in visible wavelength, whilst unhealthy vegetation reflects more in visible wavelength and less in NIR wavelength.

Generally, negative values for NDVI output represent water, snow and cloud, with 0.1 to 0.2 representing soil and 0.3 to 1 representing vegetation.

LULC and forest status maps were produced by using screen digitizing of both satellite images in the GIS environment. The digitizing process was used due to the limitation of supervised classification in mapping detailed forest status types and to overcome cloud cover limitations. Unsupervised and supervised image classifications performed in the ERDAS Imagine were used as references during the digitizing process. Land use map (from the Department of Agriculture) and National Forest Inventory map (from the Department of Forestry) were also used as references and data validation for LULC and forest status maps, respectively. Meanwhile, DEM, slope, aspect and river buffer layers were generated from topographic maps using analysis tools and also simplified using spatial modeller in ArcGIS 10. A DEM map was generated from contour lines, where spatial resolution was based on the satellite resolution image used. DEM data were further processed to generate slope and aspect maps while river buffer was generated with certain distances.

#### *Satellite Transmitter Data of Asian Elephant Distribution*

The distribution data of Mek Boh and Mek Lukut were plotted on the map in Rectified Skew Orthomorphic (RSO) projection to facilitate home range and habitat preference analysis. According to DWNP, the accuracy of the transmitted location is governed by the frequency of the signals received. Based on the data, the percentage of the satellite tracking performance of Mek Boh and Mek Lukut was 24.0% and 66.7%, respectively. The poor accuracy of Mek Boh's tracking performance was possibly due to the high density of forest cover in TNP compared to Northern Johor.

Spatial utilization was analysed using Animal Movement Extension in ArcView 3.3 using kernel method and further analysed using ArcGIS 10. The home range patterns for Mek Boh and Mek Lukut were calculated using the kernel and MCP methods. However, the kernel method was used for further analysis so as to get more realistic interpretation of what an animal is likely to use (Martin *et al.*, 2007), the most accurate representation of the structure of an animal's range and the size of core area (Ferrel, 2004). The kernel home range pattern overlaid with the satellite images is shown in Fig.2, while the home range obtained from both the methods is shown in Table 2. The small size of the home range for Mek Boh could possibly have been influenced by the forest status of the area, as TNP is one of the major protected areas in Peninsular Malaysia. In contrast, the land cover in Mek Lukut's distribution area comprises of plantations (oil palm) where the home range size is influenced by the degree of habitat fragmentation (Alfred *et al.*, 2012).

#### *Analysis of Elephants' Habitat Preferences*

The home range area and the overall distribution data were analysed in ArcGIS 10 with six habitat parameters, namely, LULC, NDVI, DEM, slope, aspect, and river buffer, to study the habitat utilization by both elephants. Subsequently, the overall distribution data of the elephants were analysed to identify the significant habitat parameters and to prioritize their criterion. Using the Spatial Analyst tool, all values for each habitat parameter were extracted

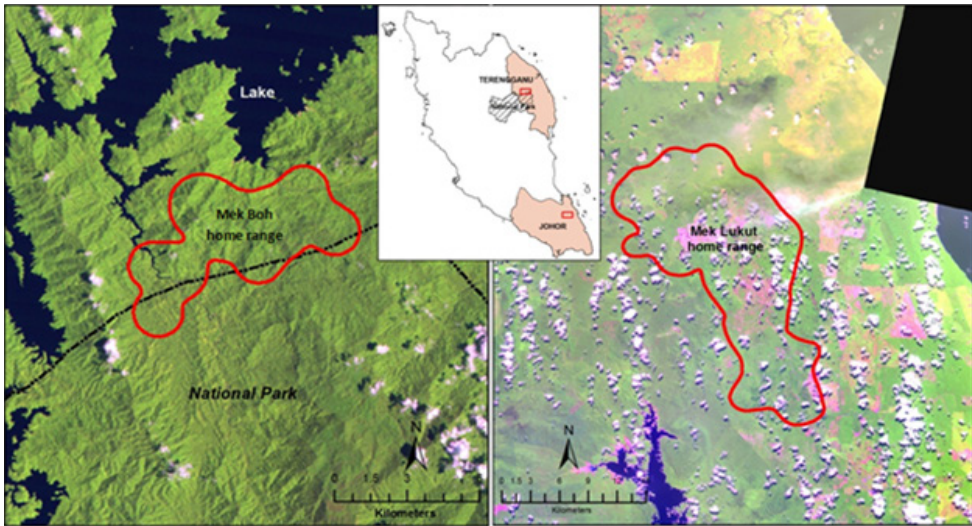


Fig.2. Mek Boh and Mek Lukut home range pattern (kernel) overlaid with Landsat TM and SPOT 5 satellite image, respectively. Inset: Map of Peninsular Malaysia showing the location of the study areas.

TABLE 2: Home range estimation using MCP and kernel

Elephant Name	Tracking Record Dates	Home range (km <sup>2</sup> )	
		≤95% MCP	Kernel
Mek Boh	22 Aug 1999 – 9 Jan 2000	21	34
Mek Lukut	21 Jul 2010 – 31 Dec 2011	411	31

and included into the elephant distribution data layers. These data layers were further analysed using the Geostatistical Analyst Tool to examine the relationship between elephant distribution and habitat parameters. Subsequently, the Histogram Tool was applied to plot the frequency of the data and to compute the statistical information where the use of utilization distribution directly enhanced the studies of animal movement, species interactions and resource (Marzluff *et al.*, 2001). In addition, significant correlation between the overall elephant distribution data and the same habitat parameters was analysed using Microsoft Excel.

### Allocation of AHP

The results of the distribution data analysis were used as references in identifying the priority score for each habitat parameter criterion. Simultaneously, priority identification was done through consultation with a representative officer from DWNP. For this purpose, each habitat parameter and its criteria were assigned weight based on the AHP procedure (see Table 3). In this regard, AHP is an appropriate method to deriving weightage to be assigned to each habitat parameters based on nine intensity of importance (Kushwaha & Roy, 2002) shown in Table 3.

TABLE 3: AHP pair-wise comparison scale

Intensity of Importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very Strong importance
8	Very to extremely strong importance
9	Extreme importance

Adapted from Saaty (1980)

Basically, the AHP procedure is employed for rating a set of alternatives or for selecting the best in a set of alternatives. The AHP procedure involves three major steps: (i) developing the AHP hierarchy, (ii) pairwise comparison of elements of the hierarchical structure, and (iii) constructing an overall priority rating (Borouhaki & Malczewski, 2008). In this study, the reciprocal matrix was calculated to generate a matrix comparison. Subsequently, this matrix was used to compute a normalized matrix in order to construct a priority rating for each habitat parameter. Finally, consistency index and consistency ratio were calculated to measure the level of consistency of the AHP results.

## RESULTS AND DISCUSSION

In general, both elephants utilized the secondary forest habitat, where ground plants were abundant, with various logging histories within their home ranges that were computed based on the kernel method. Fig.3 shows the percentage of forest habitat type utilized by Mek Boh and Mek Lukut within their home ranges. According to Olivier (1978) and Sukumar (1989), secondary forest communities often support higher biomass (i.e. higher NDVI) compared to primary forests, which are rare and have relatively small numbers of ground plants. The NDVI values for the home ranges of Mek Boh and Mek Lukut were between 0.4 to 0.5, and these are considered as having good quality and quantity of vegetation. These also indicate a moderate density of green vegetation. However, the cloud cover on the satellite image was identified as one of the constraints for NDVI data generation, particularly in Peninsular Malaysia.

In addition, ex-logging roads in the secondary forest offer good accessibility for elephant movements (Salman & Nasharuddin, 2000) and provide greater food sources (i.e. grass) which also contain higher water volume (Alfred *et al.*, 2012). In addition, Mek Lukut's home range was opened more for new selective logging and also intensively converted into other land uses, particularly for oil palm plantation as compared to Mek Boh's place (National Park) that was influenced by forest fragmentation and deforestation. Once the habitat was cleared or converted, the availability of food plants and water sources would reduced, forcing the elephants to travel to adjacent forest areas (Alfred *et al.*, 2012).

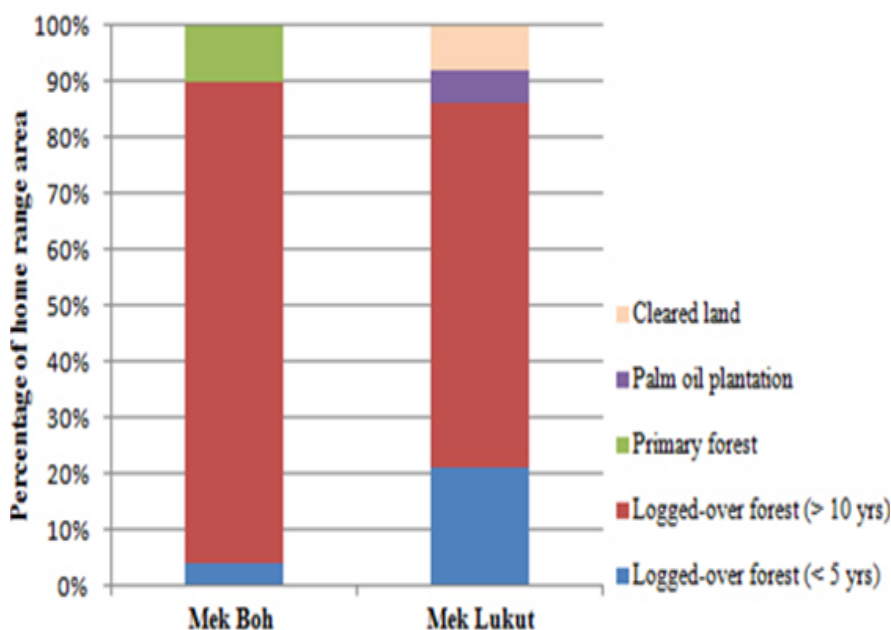


Fig.3. The percentage of the areas with different forest types utilized by tracked elephants. 90% of home range area utilized by Mek Boh is outside the protected areas (TNP) which are covered by secondary forest.

Besides, most of Mek Lukut and Mek Boh are located below 100 m and 750 m altitude with 18° and 25° slope, respectively. The results of the correlation analysis show insignificant relationships (Fig.4) between elevation, slope and elephant distribution, where elephants are capable of moving to a wide variety of range elevations, from sea level to montane (Wheelock, 1980; Sukumar, 1989; Mohd Momin Khan, 1992; Ente *et al.*, 2010). This study found that the elephants are used to areas up to 1055 meters above the sea level (Mek Boh), which is within the montane forest type. However, elephants may prefer lowland areas where there is availability of food sources as well. The differences between the criteria of DEM and slope utilized by both elephants were due to the topography of the areas, where the Southern region of Peninsular Malaysia is flatter as compared to the Northern region.

The result of the water sources analysis was also shown to be consistent with those of the previous studies which reported the ranging behaviour of elephants as being influenced by the availability of water sources (Alfred *et al.*, 2012). Thus, the availability of water sources plays an important role in the spatial and temporal distributions of elephants throughout the year (de Beer & van Aarde, 2008; Ngene *et al.*, 2009; Claudia *et al.*, 2012). The results in Fig.5 show a significant correlation between the distances from water sources and elephant distributions. Furthermore in this study, Mek Lukut and Mek Boh utilized areas that are located less than 1.5 km from permanent water sources in the elephants’ movement range areas, in which the percentages of the data gathered were 84% and 73%, respectively (Fig.6).



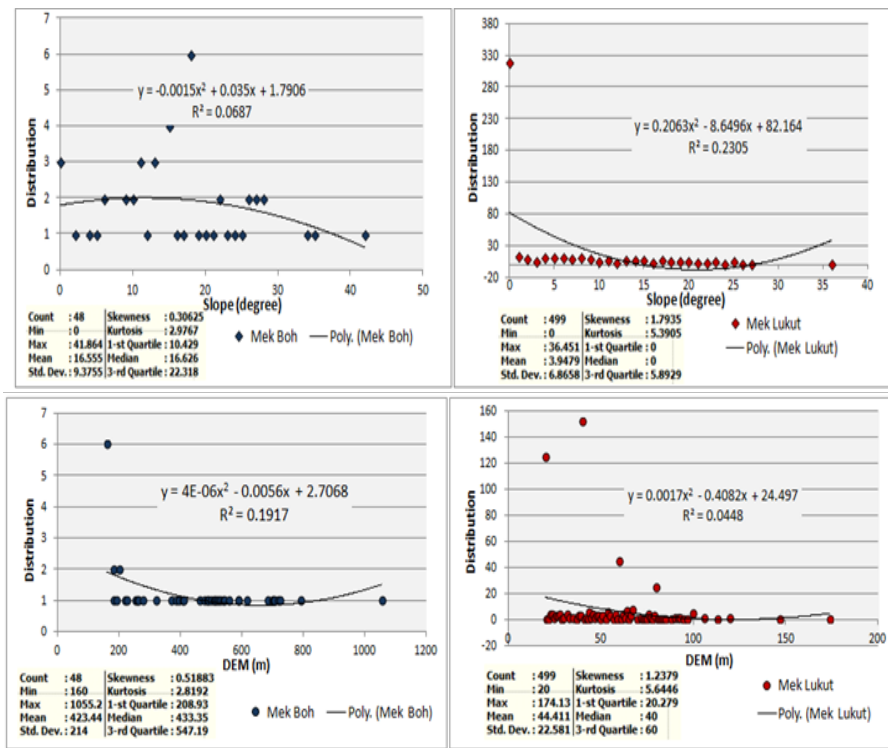


Fig.4. Polynomial regression, elephant distributions proved to be weakly constrained by slope (upper) and altitude (lower)

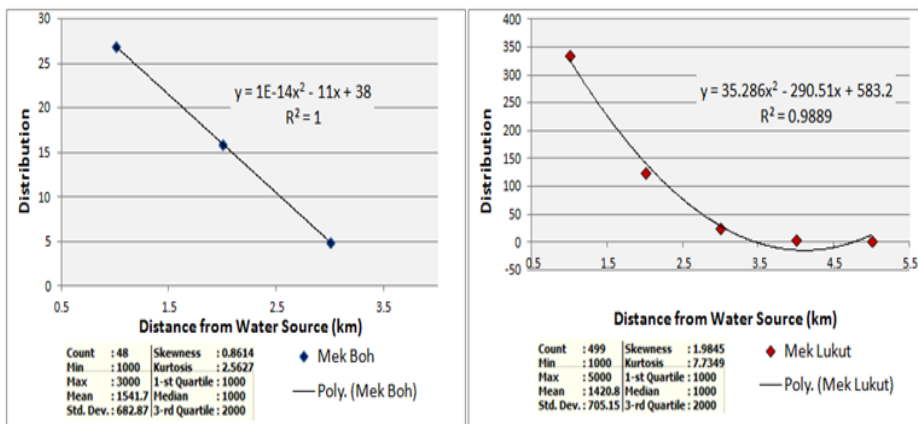


Fig.5. Negative correlation; as the distance from water source (km) increases, the number of elephant distribution decreases



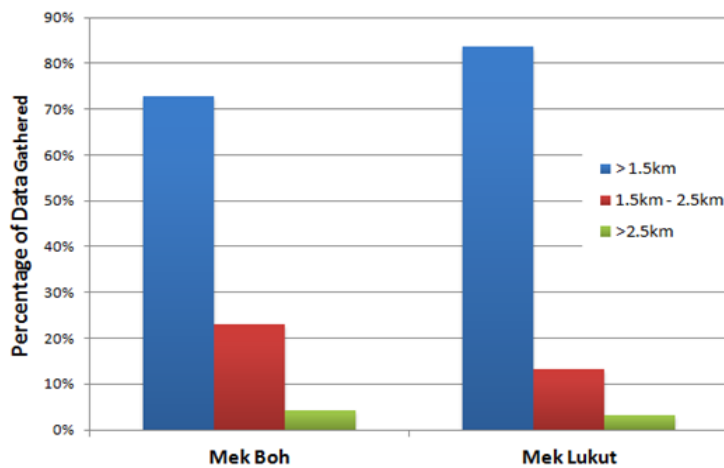


Fig.6: The percentage of different classes of distance from water sources utilized by both the elephants

#### *Selection of Significant Habitat Layers and Suggested Rules or Criteria*

Based on the GIS spatial and frequency distribution analysis, five factors were suggested as the probabilities for significant environmental and physical landscape layers for elephant habitat preferences, namely, LULC, NDVI, distance from water sources, DEM, and slope. The LULC, NDVI and distance from water sources were suggested as main significant habitat parameters, while topography was identified as a moderate predictor of the presence of elephants. However, it is the finding of this study that the aspect parameter has no influence on the elephant distribution. It is also not suggested as an elephant habitat preference parameter in order to develop a suitability habitat mapping or modelling. This does not agree with the results published by Zhixi *et al.* (2005) who showed a good relationship between elephant movement and aspect factor, particularly the east-north aspect.

Subsequently, the suggested ranking of priority computed by AHP for the significant habitat parameters were LULC (38%), NDVI (32%), distance from permanent water sources (20%), slope (6%) and DEM (4%), with a consistency ratio of 2.5% (Fig.7). Thus, it is an acceptable range for consistency. It is important to note that a consistency ratio of the order 10% or smaller is a reasonable level of consistency. However, a consistency ratio greater than 10% requires a revision of the judgment in the matrix (weights) used in the AHP analysis. The ranking of the habitat parameters computed by AHP can be used as a general guideline to identify habitat suitability mapping or modelling, particularly using weighted overlay in the GIS application. Finally, rules or criteria of significant habitat parameters computed by AHP and distribution analysis were classified into three levels of suitability, namely, highly suitable, moderately suitable, and marginally suitable (see Table 4).

Forest density (quality) is another habitat parameter that can be considered in the analysis as it influences elephant movement and it is the most significant parameter compared to NDVI (greenness). In addition, an analysis of the human activity parameters such as distance from road, agricultural buffer zone, settlements, etc. need to be taken into account for a holistic understanding of the relationship between Asian elephants and their habitat parameters.

Estimating Weights for Elephant Habitat Parameters using AHP							
Reciprocal matrix							
Habitat Parameters:	LULC	NDVI	Water Source	Slope	DEM		
LULC	1.000	1.500	2.000	6.000	8.000		
NDVI	0.667	1.000	2.000	7.000	7.000		
Water Source	0.500	0.500	1.000	4.000	6.000		
Slope	0.167	0.143	0.250	1.000	2.000		
DEM	0.125	0.143	0.167	0.500	1.000		
SUM	2.458	3.286	5.417	18.500	24.000		
Normalized matrix							
Habitat Parameters:	LULC	NDVI	Water Source	Slope	DEM	Sum	% Priority
LULC	0.407	0.457	0.369	0.324	0.333	1.890	37.80%
NDVI	0.271	0.304	0.369	0.378	0.292	1.615	32.30%
Water Source	0.203	0.152	0.185	0.216	0.250	1.006	20.13%
Slope	0.068	0.043	0.046	0.054	0.083	0.295	5.90%
DEM	0.051	0.043	0.031	0.027	0.042	0.194	3.88%
SUM	1.000	1.000	1.000	1.000	1.000	5.000	100.00%
<i>lambda max: 5.10</i> <i>consistency index (CI): 2.54%</i> <i>consistency ratio (CR): 2.27%</i>							

Fig.7: The suggested level of priority for elephant habitat parameters using AHP

TABLE 4: The suggested rules or criteria of significant habitat parameters for Asian elephants, particularly in Peninsular Malaysia

Level of Suitability	Elevation (m)	Slope (degree)	Distance from water sources (km)	NDVI	Forest status
Highly suitable	<750	0 –20	<1.5	0.4 - 0.5	Mixed secondary forest
Moderate	750 -1000	20 – 40	1.5 - 2.5	0.5 - 0.6	Mixed secondary forest; Primary forest; Protected areas;
Marginally	>1000	>40	> 2.5	<0.4 & >0.6	Primary forest; Protected areas

## CONCLUSION

The availability of spatial data from remote sensing and advances in GIS can assist in effective assessment of Asian elephants’ habitat preferences. This is because remote sensing data provide accurate and timely information on essential habitat parameters, while GIS offers an advanced tool for data analysis and modelling. In particular, the method of home range estimation provided in a GIS environment offers a viable method for quantifying habitat use and assists with a better understanding of species and habitat relationships. In addition, the use of spatial and geostatistical analyses, as well as AHP approach to select the significant habitat parameters

and classification of its criteria, provides a more reliable identification of suitable elephant habitat for preservation or translocation purpose. In addition, AHP is flexible enough to allow a revision and change expert judgment or decision marker from time to time in order to fulfil the requirement of wildlife conservation and physical development. The results also show that there is a strong relationship between distribution of elephant and forest cover, particularly the secondary forest and availability of permanent water sources. Physical landscape criteria, such as the elevation and slope, were identified as moderate habitat parameters in elephant distributions, while aspect parameter did not show any influence. The habitat utilized by elephants suggests that conservation of the species requires good management practices within and outside the protected areas to ensure that Asian elephants will still remain in tropical forests as a good umbrella species.

## ACKNOWLEDGEMENTS

We would like to take this opportunity to thank the Department of Wildlife and National Park, Malaysia, especially Biodiversity Conservation Division for providing the satellite transmitter data of elephant distributions. Special appreciation also goes to the Malaysian Remote Sensing Agency for providing the satellite imageries and related geospatial data.

## REFERENCES

- Alfred, R., Ahmad, A.H., Payne J., Williams, C., & Ambu, L.N. (2012). Home Range and Ranging Behaviour of Bornean Elephant (*Elephas maximus borneensis*) Females. *PLoS ONE* 7(2), e31400. doi:10.1371/journal.pone.0031400.
- Antunes, P., Santos, R., & Luí's Jorda~O. (2011). The application of Geographical Information Systems to determine environmental impact significance. *Environmental Impact Assessment Review*, 21, 511-535.
- Govil & Sen, P. K. (2011). Geospatial modeling to assess elephant habitat suitability and corridors in northern Chhattisgarh, India. *Tropical Ecolog*, 52(3), 275-283.
- Boroushaki, S. & Malczewski, J. (2008). Implementing an extension of the analytical hierarchy process using ordered weighted averaging operators with fuzzy quantifiers in ArcGIS. *Computers & Geosciences*, 34, 399 – 410.
- Burt, W. H. (1943). Territoriality and home range concepts as applied to mammals. *Journal of Mammalog*, 24, 346-352.
- Claudia, P., Skidmore, A.K., Hein A.M.J., van Gils, A., Herbert, H.T., & Prins (2012). Identifying transit corridors for elephant using a long time-series. *International Journal of Applied Earth Observation and Geoinformation*, 14, 61-72.
- de Beer, Y., & van Aarde, R.J. ( 2008). Do landscape heterogeneity and water distribution explain aspects of elephant home range in southern Africa's arid savannas? *Journal of Arid Environments*, 72, 2017-2025.
- Dixon, K.R. & Chapman, J. A. (1980). Harmonic mean measure of animal activity areas. *Ecology*, 61, 1040-1044.

- DWNP (2006). *Elephant Capturing Manual in Peninsular Malaysia*. Department of Wildlife and National Parks.
- Ewer, R. F. (1968). *Ethology of Mammals*, New York: Plenum Press, p. 418.
- Ferrel, V. O. (2004). The concept of home range in relation to elephants in Africa (2004). *Journal of the African Elephant, African Rhino and Asian Rhino Specialist Groups, Pachyderm*, 37, July–December.
- Hasmadi. M.I. (2009). Developing policy for suitable harvest zone using multi-criteria evaluation and GIS-based decision support system. *International Journal of Economics and Finance*, 1(2), 105-117.
- Hedges, S., Tyson, M.J., Sitompul, A.F., Kinnaird, M.F., Gunaryadi, D., & Aslan (2005). Distribution, status, and conservation needs of Asian elephants (*Elephas Maximus*) In Lampung Province, Sumatra, Indonesia. *Biological Conservation*, 124, 35-48.
- IUCN SSC Asian Elephant Specialist Group, H., Rübel, A., & Wikramanayake, E. (2008). *Elephas maximus*. In IUCN 2012. *IUCN Red List of Threatened Species*. Version 2012.1.
- Jackson, R.D., Slater, P.N., & Pinter Jr, P.J. (1983). Discrimination of growth and water stress in wheat by various vegetation indices through clear and turbid atmospheres. *Remote Sensing of Environment*, 13(3), 187-208.
- Jan, U., Eitel, H., Keefe, R.F., Dan, S., Long, A., Davis, S. & Vierling, L.A. Active ground optical remote sensing for improved monitoring of seedling stress in nurseries. *Sensors*, 10, 2843-2850.
- Katajisto, J. (2006). Kernel-based home range method for data with irregular sampling intervals. *Ecological Modelling*, 194, 405-413.
- Kernohan, B. J., Millsaugh, J. J., Jenks, J.A., & Naugle, D. E. (1998). Use of an adaptive kernel home-range estimator in a GIS environment to calculate habitat use. *Journal of Environmental Management*, 53, 83-89.
- Kushwaha, S.P.S. & Roy, P.S. (2002). Geospatial technology for wildlife habitat evaluation. *Tropical Ecology*, 43(1), 137-150.
- Lee, W.B., Lau, H., Liu, Z., & Tam, S. (2001). A fuzzy analytical hierarchy process approach in modular product design. *Expert System*, 18, 32 – 42.
- Leimgruber, P., Gagnon, J.B., Wemmer, C., Kelly, D.S., Songer, M.A., & Selig, E.R. (2003). Fragmentation of Asia's remaining wild lands: implications for Asian elephant conservation. *Animal Conservation*, 6, 347-359.
- Linde E. T. O., Young, T.P., Silver, S.C., & Koontz, F.W. (1999). A Geographic Information System Method for estimating home range size. *The Journal of Wildlife Management*, 63, 748-755.
- Martin, N.T., Foguekem, D., Macallister, M., Ngassam, P., & Loomis, M. (2007). Application of ArcView Animal Movement Analysis Extension as a tool for monitoring elephant movement: preliminary results from northern Cameroon. *Pachyderm*, 43, July–December.
- Marzluff, J.M., Knick, S.T., & Millsaugh, J.J. (2001). High-tech behavioral ecology: modelling the distribution of animal activities to better understand wildlife space use and resource selection. In J.M. Marzluff (Ed.), *Radio Tracking and Animal Populations*. San Diego, CA: Academic Press.
- Ngene, S.M., Skidmore, A.K., van Gils, H., Douglas-Hamilton, I., & Omondi, P. (2009). Elephant distribution around a volcanic shield dominated by a mosaic of forest and savanna (Marsabit Kenya). *African Journal of Ecology*, 47, 234–245.

- Olivier, R. (1978). Distribution and Status of the Asian Elephant. *Oryx*, 14, 379 -424.
- O'Neill, R.V. (1996). Recent development in ecological theory: hierarchy and scale. Gap analysis – a landscape approach to biodiversity planning, *American Society for Photogrammetry and Remote Sensing*. Bethesda, Maryland, USA.
- O'Neil, T.A., Bettinger, P., Marcot, B.G., Luscomb, B.W., Koeln, G.T., Bruner H.J., Barrett, C., Pollock, J.A., & Bernatas, S. (2005). Application of Spatial Technologies in Wildlife Biology. *The Wildlife Society*, 418 – 447.
- Prithiviraj, F., Eric, D., Wikramanayake, H.K., Janakaa, L.K.A., Jayasinghe, M. G., Sarath, W. K., Weerakoon, D., & Pastorini, J. (2008). Ranging behavior of the Asian elephant in Sri Lanka. *Mamalian Biology*, 73, 2-13.
- Qureshi, M.E. & Harrison, S.R. (2003). Application of the analytical hierarchy process to riparian revegetation policy options. *Small-scale Forest Economics, Management and Policy*, 2(3), 441 – 458.
- Rouse, J.W., Haas, R.H., Schelle, J.A., Deering, D.W., & Harlan, J.C. (1974). Monitoring the vernal advancement or retrogradation of natural vegetation. *NASA/GSFC, Type III, Final Report, Greenbelt*, MD, 371.
- Saaty, T. L. (1980). *The Analytic Hierarchy Process*. McGraw-Hill International Book Co. (New York and London). Book (ISBN 0070543712).
- Salman, S. & Nasharuddin, O. (2000). A study on the home range and habitat utilization of a translocated elephant (*Elephas maximus*) using satellite transmitter in Terengganu National Park. *Journal of Wildlife and Park*, 20, 21-26.
- Salman Saaban, Nasharuddin Bin Othman, Mohd Nawayai Bin Yasak, Burhanuddin Mohd Nor, Ahmad Zafir, & Ahimsa Campos-Arceiz, (2011). Current Status of Asian Elephants in Peninsular Malaysia. *Journal of the Asian Elephant Specialist Group Gajah*, 35, 67-75.
- Santiapillai, C. & Jackson, P. (1990). The Asian elephant: an action plan for its conservation. *IUCN/SSC Asian Elephant Specialist Group, Gland*.
- Sukumar, R. (1989). *The Asian elephant: ecology and management. Cambridge studies in applied ecology and resource management*. Cambridge: Cambridge University Press.
- Sukumar, R. (1990). Conservation of Asian elephants: problems and prospects. *Species*, 22, 13-14.
- Zhixi, L., Hongga, L., & Feng, L. (1995). Evaluation of Asian Elephant Habitat. *GIS Development ASPRS/ACSM*.

## Removal of Dissolved Organic Carbon from Peat Swamp Runoff Using Assorted Tropical Agriculture Biomass

Sim, F. S. \*, Mohd Irwan Lu, N. A. L., Lee, Z. E. T. and Mohamed, M.

*Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia*

### ABSTRACT

In this study, agriculture biomass was used to remove dissolved organic matter from peat swamp runoff. The functional groups and morphological properties of 6 tropical agriculture biomasses (coconut husk, rice husk, empty fruit bunch, sago *hampas*, saw dust and banana trunk) in their raw and citric acid-treated states were examined. The Fourier transform infrared (FTIR) spectra showed that various biomasses were typically characterised with lignocellulosic compounds. The spectra analysis further demonstrated that citric acid treatment resulted in the dissolution of lignin and hemicelluloses to various extents where carboxyl groups were also introduced. These changes hypothetically suggest improved adsorption ability. Treatment of peat swamp runoff with various untreated biomasses showed no adsorption. With the modified biomass, adsorption was evidenced, with rice husk illustrating the highest removal efficiency of 60% to 65%. The biosorbent can be used in the water treatment process especially for treating water with a high dissolved organic matter content. The spent sorbent can be subsequently applied as a soil conditioner as the dissolved organic fraction, commonly known as humic matter, possesses important agricultural value.

*Keywords:* Agriculture biomass, adsorption, citric acid treatment, dissolved organic matter, peat swamp runoff

### INTRODUCTION

In Malaysia, peat soil encompasses 7.45% of the total land area of the country, of which 70% is found in Sarawak, the northern part of Borneo Island (Wetlands International, 2010). The water

catchment in this area serves as an important source of freshwater supply to settlements and townships residing in the peatland. According to statistics, an estimated 3,000 million litres of water are extracted annually from the streams tainted by peat swamp leachate throughout Sarawak (McCartney & Acreman, 2009). Typically, the water is yellowish to

#### *Article history:*

Received: 2 April 2013

Accepted: 25 August 2013

#### *E-mail addresses:*

sfsim@frst.unimas.my (Sim, F. S.),  
nurulstrikerz@yahoo.com (Mohd Irwan Lu, N. A. L.),  
terrilze@gmail.com (Lee, Z. E. T.),  
murtedza@gmail.com (Mohamed, M.)

\*Corresponding Author

brownish in colour due to the presence of dissolved organic matter and thus, is often called tropical black water. The dissolved organic matter is technically termed as humic substances; it is well known for its agricultural importance as a soil supplement, but its presence could have a significant impact on the treatability of the water. It is often difficult for the conventional water treatment process to remove the organic fraction effectively, which results in the formation of disinfection by-products. In a study by Sim and Mohamed (2005), treated water sourced from peat swamp runoff was found to contain a higher amount of trihalomethanes compared with non-peat water sources. In addition, the tropical humic molecules were found to be more susceptible to electrophilic cleavage, increasing the risk of trihalomethanes (Sim & Mohamed, 2007). Over the years, some treatment plants treating organic-rich water in Sarawak have switched from the conventional sedimentation processes to the dissolved air flotation system. This latter technology is commonly known for its better efficiency, especially in treating humic-rich water; however, it incurs a relatively higher operational cost (van Puffelen *et al.*, 1995; Heinänen *et al.*, 1995; Edzwald, 2010).

## **MATERIALS AND METHODS**

### *Sample preparation*

The biomasses selected were coconut husk (CH), banana trunk (BT), sago *hampas* (SW), rice husk (RH), oil palm empty fruit bunch (EFB) and saw dust (SD). The biomasses were washed extensively with running tap water and cut into smaller pieces (1-2 cm). They were then oven-dried at 105°C for 24 hrs, and then were ground (< 2 mm) and stored in desiccators. In addition, the biomasses were chemically treated with citric acid in an attempt to improve the adsorption ability. Five grams of biomass were added to 30 mL of 0.8 M citric acid and agitated for 3 hrs under room temperature (25-28°C), then washed and dried. The advantage of citric acid over other alternatives is that it is a weak organic acid that is commonly used in various applications such as food, cosmetics, pharmaceuticals etc. thus, the risk of acute toxicity is low.

### *Characterisation of agricultural biomass*

The functional groups of biomass were analysed using Fourier transform infrared (FTIR). All spectra were obtained on a ThermoScientific FTIR spectrometer (Thermo Nicolet Analytical Instruments, Madison, WI) using the KBr disc method with 2 mg of sample in 100 mg of KBr. The samples were scanned in triplicate with the scanning range of 4000-400  $\text{cm}^{-1}$  at a resolution of 4  $\text{cm}^{-1}$ . The morphological characteristics were observed using a scanning electron microscope (Model JEOL JSM-6390LA, Japan) with an accelerating voltage of 5kV at  $\times 500$  magnification. The samples were coated with a thin film of conducting materials prior to examination.

### *Adsorption of dissolved organic carbon*

The adsorption of dissolved organic carbon was examined based on the absorbance at 465 nm using a UV-Visible spectrophotometer (Jasco V-360 Spectrophotometer) (Gan *et al.*, 2007; Ghabbour & Davies, 2009). Numerous wavelengths have been used for the quantification



of natural organic matter, for example, 250, 254, 272, 280, 285, 330, 365, 400, 465, and 665 nm (Hautala *et al.*, 2000; Chen *et al.*, 2002; Świetlik & Sirkorska, 2005; Zbytniewski & Buszewski, 2005). According to Hautala *et al.* (2000), the absorbance at 465 nm is the most recommended for measurement of the colour in water caused by a given fraction of humic matter. Fundamentally, absorbance corresponds proportionally to the humic content; if adsorption takes place, a reduction in absorbance is anticipated. For the adsorption study, 1g of biomass (treated or untreated) was agitated with 20 mL of humic-rich water collected from the Asa Jaya River with pH 3.5-4 for 15 min. The Asa Jaya River is surrounded by peat swampland where the water is highly coloured. The water was passed through a glass column at a flow rate of approximately 1 mL/min. After treatment, the pH of the water ranged between 2.8 and 3.5 with banana trunk and sago hampas respectively, demonstrating the lowest pH. Note that the operating conditions, including the contact time, flow rate and dosage were optimised for maximal adsorption. The eluate was then collected and the absorbance at 465 nm was recorded in triplicate.

### Data analysis

The FTIR spectra were analysed using the peak detection algorithm reported elsewhere, yielding a peak table with rows representing samples and columns indicating the peaks identified (in wave number,  $\text{cm}^{-1}$ ) (Sim & Ting, 2012; Sim *et al.*, 2012). Each cell relates to the corresponding peak areas. The resulting peak table of 36 rows and 53 columns was square-rooted and standardised prior to the Principal Component Analysis (PCA) to demonstrate whether the functional group properties of different biomasses are distinguishable (Esbensen, 1998; Brereton, 2009). The t-statistic was employed to identify variables discriminating two groups of samples (Brereton, 2009); typically, variables with higher absolute t-values are concluded to have greater discriminatory abilities. The paired t-test at a confidence level of 95% was used to examine the statistical significance.

## RESULTS AND DISCUSSION

### Characteristics of treated and untreated biomass

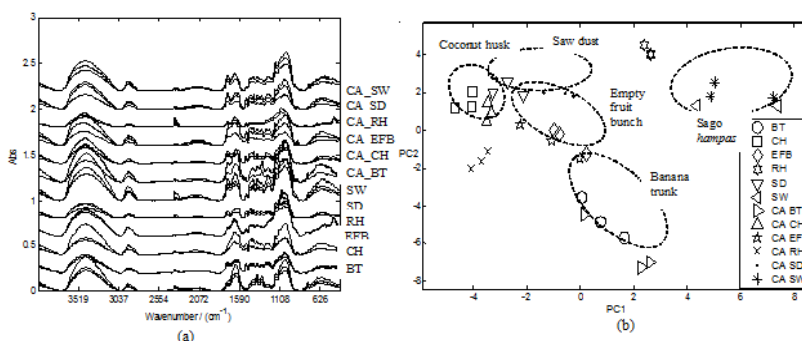


Fig. 1: (a) The FTIR spectra of various treated and untreated biomasses; (b) the scores plot of PC2 vs. PC1 prepared with the peak table of FTIR spectra [sago hampas (SW); saw dust (SD); rice husk (RH); empty fruit bunch (EFB); coconut husk (CH); banana trunk (BT); citric acid (CA)]

Several absorption bands at 1097  $\text{cm}^{-1}$ , 1159  $\text{cm}^{-1}$ , 1376  $\text{cm}^{-1}$  and 1425  $\text{cm}^{-1}$  were observed in various agriculture biomasses. The absorption band at 1159  $\text{cm}^{-1}$  was consistently identified; it was assigned to glycosidic linkages that are typical in lignocellulosic compounds (Sim *et al.*, 2012). Fig.1(a) shows the FTIR profile of the treated and untreated biomass. The scores plot of the peak table (PC2 versus PC1) in Fig.1(b) demonstrates that different biomasses are distinguishable with citric acid treatment, resulting in some considerable changes, particularly in rice husk. Other biomasses (treated and untreated) remain closely clustered, implying less alteration.

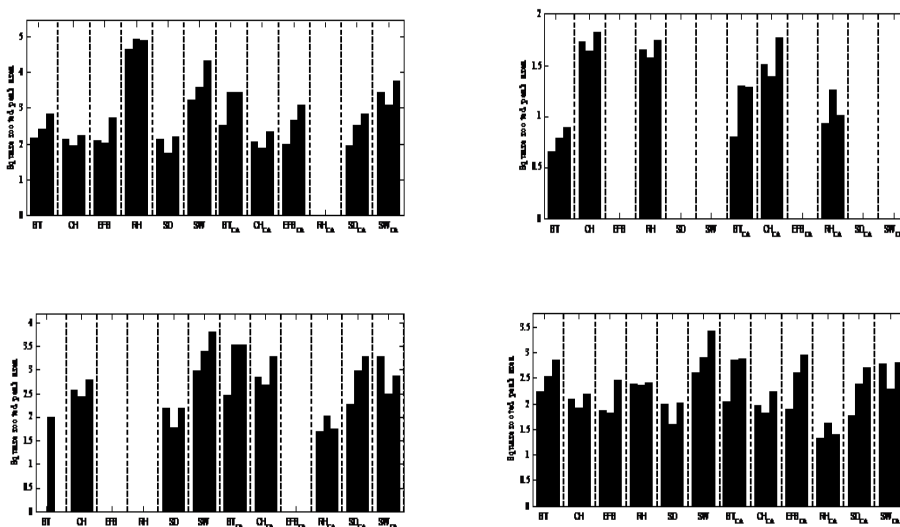


Fig.2: The abundance of important variables distinguishing the untreated and treated biomass

Fig.2 shows the abundance of several important bands discriminating the raw and modified rice husk. The band at 1159  $\text{cm}^{-1}$  is completely absent after treatment, indicating extensive hydrolysis. A weak absorption band at 1513  $\text{cm}^{-1}$  due to C=C stretching of lignin, on the other hand, is noticeably reduced, implying lignin degradation; this often takes place collectively with hemicelluloses dissolution, which is confirmed by the diminished bands at 1056  $\text{cm}^{-1}$ , 1375  $\text{cm}^{-1}$  and 1330  $\text{cm}^{-1}$  (Peng *et al.*, 2009). Ester linkages are anticipated to form upon treatment as a result of the reaction between hydroxyl groups of cellulose and citric acid (Thanh&Nhung, 2009; Farid *et al.*, 2010). The reaction is usually corroborated with the presence or increased absorption band at 1750-1730  $\text{cm}^{-1}$  ascribed to C=O stretching. This is observable in most treated biomass except empty fruit bunch, suggesting that the material may be less susceptible to treatment. One of the modifications encountered by empty fruit bunch is the shifting of hydroxyl band at 3419  $\text{cm}^{-1}$  to 3438  $\text{cm}^{-1}$  as a consequence of the breakage of hydrogen bonds in crystalline cellulose, according to Mohkami and Talaeipour (2010). Essentially, the hydrogen bonds can also be found between the polymers forming lignocelluloses i.e. cellulose-hemicelluloses, hemicelluloses-lignin and cellulose-lignin.

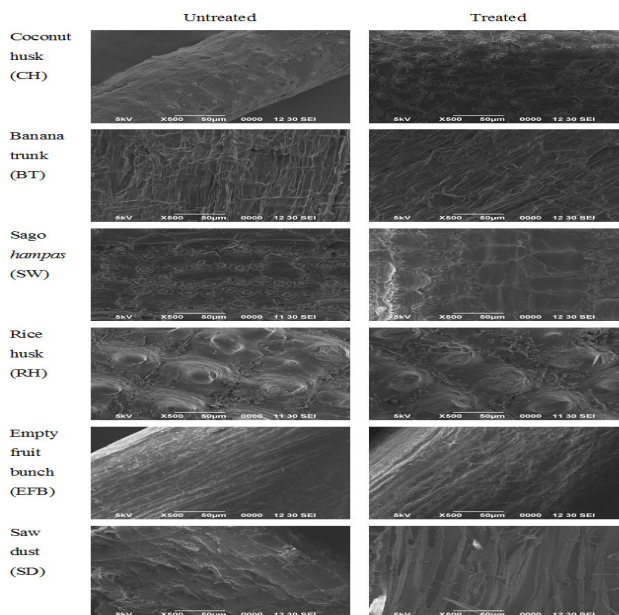


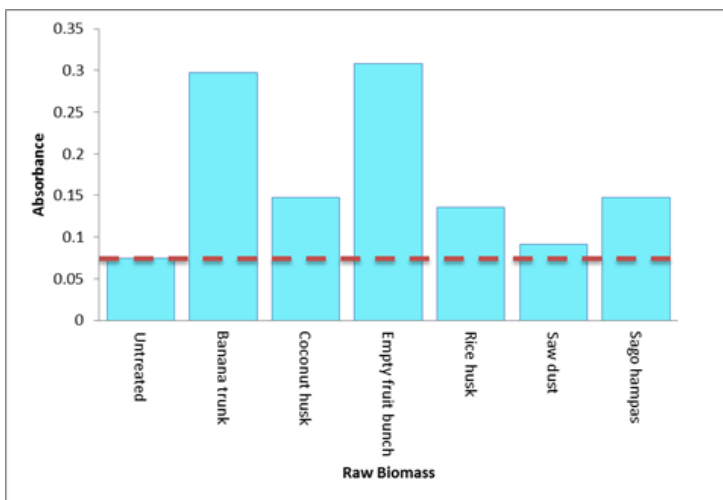
Fig.3: Scanning electron micrographs of various treated and untreated biomasses ( $\times 500$ )

Fig.3 shows the scanning electron micrographs of biomasses before and after treatment. The raw biomass exhibits fibril surfaces; after treatment, some indicate the presence of globular protrusions due to the removal of extractives, waxes and oils (Rout *et al.*, 2001; Troedec *et al.*, 2008). However, some demonstrate peeled-off surfaces whilst others illustrate minimal disruption. The observations generally suggest that the treatment is rather mild where no extensive damage is seen. Overall, the alterations experienced primarily involve the removal of lignin and hemicelluloses to various extents where carbonyl groups are also introduced; these changes hypothetically suggest improved adsorption abilities.

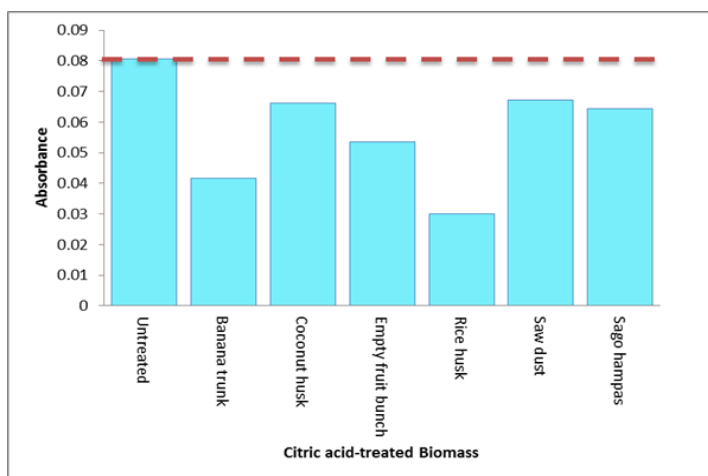
#### *Adsorption of humic content from the peat swamp runoff*

The peat swamp runoff obtained from the Asa Jaya River was subjected to treatment with various untreated and treated biomasses. Fig.4(a) illustrates the absorbance at 465 nm before and after treatment with raw biomass. Apparently, no reduction in absorbance is observed. On the contrary, the treated water demonstrates increased absorbance, suggesting the leaching of lignin, tannins and pigment that have added to the humic content of the water. The results imply that the removal of dissolved organic carbon was unsuccessful, possibly because the active functional sites were concealed within the lignin-hemicellulose matrix. The organic-rich water was alternatively subjected to biomass treated with citric acid; the absorbance of the river water is clearly reduced after treatment (except with the treated banana trunk), suggesting the removal of dissolved organic matter (Fig.4(b)). Among the biomasses, rice husk demonstrates the lowest absorbance, indicating better adsorption performance. The inset of Fig.4(b) shows the appearance of water before and after treatment with rice husk treated with citric acid; the yellowish colour has noticeably decreased. Statistically, it is concluded that the absorbance of

rice husk is significantly lower than that of biomasses ( $p < 0.05$ ). Theoretically, the absorbance is proportional to the concentration of dissolved organic carbon; based on this assumption, the removal efficiency of treated rice husk is suggested at approximately 60% to 65%. The superior adsorption ability of modified rice husk is possibly associated with the somewhat extensive changes experienced during treatment.



(a)



(b)

Fig.4: The absorbance of water at 465 nm after treatment with (a) raw biomass and (b) citric acid (CA)-treated biomass (Inset of figure illustrates the water before and after treatment with modified rice husk).

## CONCLUSION

Agriculture biomasses in their untreated state are unlikely to be useful as biosorbents for the removal of dissolved organic matter. Additional treatment with citric acid was found to remove the lignin-hemicellulose matrix resulting in the esterification of hydroxyl groups yielding carbonyl functionalised biomass. These changes are experienced by biomasses to various extents. In this study, rice husk appears to be more susceptible to treatment, which in turn results in better adsorption ability with a removal percentage of 60% to 65% based on the absorbance measurements. As a conclusion, the application of agriculture biomass to remove dissolved organic matter could help to improve the existing water treatment process, alleviating the problem due to the naturally occurring trihalomethanes precursors and also reducing the amount of coagulant needed. On the other hand, the spent biosorbent is enriched with humic substances that have been well-established for its beneficial effects in plants, thus, it can be potentially employed as a soil conditioner in agriculture applications.

## ACKNOWLEDGEMENTS

The authors thank the Ministry of Science & Technology for funding this project (06-01-09-SF0086).

## REFERENCES

- Achak, M., Hafidi, A., Ouazzani, N., Sayadi, S., & Mandi, L. (2009). Low-cost bioadsorbent “banana peel” for the removal of phenolic compounds from olive mill wastewater: Kinetic and equilibrium studies. *Journal of Hazardous Material*, *166*, 117-125.
- Brereton, R. G. (2009). *Chemometrics for pattern recognition*. Chichester: Wiley.
- Calvete, T., Lima, E. C., Cardoso, N. F., Vagheti Silvio, J. C. P., Dias, L. P., & Pavan, F. A. (2010). Application of carbon adsorbents prepared from Brazilian-pine fruit shell for the removal of reactive orange 16 from aqueous solution: kinetic equilibrium, and thermodynamic studies. *Journal of Environmental Management*, *91*, 1095-1706.
- Chen, J., Gu, B. H., LeBoeuf, E. J., Pan, H. J., & Dai, S. (2002). Spectroscopic characterisation of the structural and functional properties of natural organic matter fractions. *Chemosphere*, *48*, 59-68.
- Edzwald, J. K. (2010). Dissolved air flotation and me. *Water Research*, *44*, 2077-2106.
- Esbensen, K. (1998). *Multivariate analysis in practice*. Oslo: Camo.
- Farid, T., Dimitar, B. K., & Irni, A. (2010). Production of bioethanol from wheat straw: An overview on pretreatment, hydrolysis and fermentation. *Bioresource Technology*, *101*, 4744-4753.
- Gan, E., Kotob, S. I., & Walia, D. S. (2007). Evaluation of a spectrophotometric method for practical and cost effective quantification of fulvic acid. *Annals of Environmental Sciences*, *1*, 11-15.
- Garg, V. K., Gupta, R., Yadav, A. B., & Kumar, R. (2003). Dye removal from aqueous solution by adsorption on treated sawdust. *Bioresource Technology*, *89*, 121-124.
- Ghabbour, E. A., & Davies, G. (2009). Spectrophotometric analysis of fulvic acid – a second look. *Annals of Environmental Sciences*, *3*, 131- 138.

- Hautala, K., Peuravuori, J., & Pihlaja, K. (2000). Measurement of aquatic humus content by spectroscopic analyses. *Water Research*, 34, 246-258.
- Heinänen, J., Jokela, J., & Ala-Peijari, T. (1995). Use of dissolved air flotation in water treatment plant in Finland. *Water Science and Technology*, 31, 225-238.
- Ibrahim, A. O., & Amuda, O. S. (2006). Industrial wastewater treatment using natural material as adsorbent. *African Journal of Biotechnology*, 5, 1483-1487.
- Imyim, A., & Prapalimrungsi, E. (2010). Humic acids removal from water by aminopropyl functionalised rice husk ash. *Journal of Hazardous Material*, 184, 775-781.
- Laskhmi, U. R., Chandra, V., Mall, I. D., & Lataye, D. H. (2009). Rice husk ash as an effective adsorbent: Evaluation of adsorptive characteristics for Indigo Carmine dye. *Journal of Environmental Management*, 90, 710-720.
- Lohani, M. B., Singh, A., Rupainwar, D. C., & Dhar, D. N. (2008). Studies on efficiency of guava (Psidiumguajava) bark as bioadsorbent for removal of Hg(II) from aqueous solution. *Journal of Hazardous Material*, 159, 626-629.
- Mahvi, A. H. (2008). Application of agricultural fibers in pollution removal from aqueous solution. *International Journal of Environmental Science and Technology*, 5, 275-285.
- McCartney, M. P., & Acreman, M. C. (2009) *Wetlands and water resources*. Singapore: Wiley-Blackwell.
- Mohkami, M., & Talaeipour, M. (2010). Investigation of the chemical structure of carboxylated and carboxy methylated fibers from waste paper via XRD and FTIR analysis. *Bioresources*, 6, 1988-2003.
- Peng, F., Ren, J. L., Bian, J., Peng, P., & Sun, R. C. (2009). Comparative study of hemicelluloses obtained by graded ethanol precipitation from sugarcane bagasse. *Journal of Agricultural and Food Chemistry*, 57, 6305-6317.
- Raymundo, A. S., Zanarotto, R., Belisário, M., Pereira, M. D. G., Ribeiro, J. N., Verónica, A., & Ribeiro, F. N. (2010). Evaluation of sugar-cane bagasse as bioadsorbent in the textile wastewater treatment contaminated with carcinogenic congo red dye. *Brazilian Archives of Biology and Technology*, 53, 931-938.
- Rout, J., Misra, M., Tripathy, S. S., Nayak, S. K., & Mohanty, A. K. (2001). The influence of fibre treatment on the performance of coir polyester composites. *Composites Science and Technology*, 61, 1303-1310
- Sathasivam, K., & Mas Haris, A. R. M. (2010). Banana trunk fibers as an efficient bioadsorbent for the removal of Cd(II), Cu(II), Fe(II) and Zn (II) from aqueous solutions. *Journal of Chilean Chemical Society*, 55, 278-282.
- Sim, S. F., & Mohamed, M. (2005). Occurrence of trihalomethanes in drinking water tainted by peat swamp runoff in Sarawak. *Journal of Science & Technology in Tropics*, 1, 132-135.
- Sim, S. F., & Mohamed, M. (2007). Chemical characterisation of humic substances occurring in the peats of Sarawak, Malaysia. *Organic Geochemistry*, 38, 967-976.
- Sim, S. F., & Ting, W. (2012). An automated approach for analysis of Fourier Transform Infrared (FTIR) spectra of edible oils. *Talanta*, 88, 537-543.
- Sim, S. F., Mohamed, M., MohdIrwan Lu, N. A. L., Sarman, N. S. P., & Samsudin, S. N. S. (2012). Computer-assisted analysis of Fourier Transform Infrared (FTIR) spectra for characterisation of various treated and untreated agriculture biomass. *Bioresources* 7, 5346-5380.

- Świetlik, J., & Sirkorska, E. (2005). Characterisation of natural organic matter fractions by high pressure size exclusion chromatography, specific UV absorbance and total luminescence spectroscopy. *Polish Journal of Environmental Studies*, 15, 145-153.
- Thanh, N. D., & Nhung, H. L. (2009) Cellulose modified with citric acid and its absorption of Pb<sup>2+</sup> and Cd<sup>2+</sup> ion. In *Proceedings of the 13th International Electronic Conference on Synthetic Organic Chemistry*, Sciforum Electronic Conferences Series. Basel, Switzerland.
- Troedec, M. L., Sedan, D., Peyratout, C., Bonne, J. P., Smith, A., Guinebretiere, R., Gloaguen, V., & Krausz, P. (2008). Influence of various chemical treatments on the composition and structure of hemp fibres. *Composites Part A*, 39, 514-522.
- vanPuffelen, J., Buijs, P. J., Nuhn, P. N. A. M., & Hijnen, W. A. M. (1995). Dissolved air flotation in potable water treatment: The Dutch experience. *Water Science and Technology*, 13, 149-157.
- Wan Ngah, W. S., & Hanafiah, M. A. K. M. (2008). Removal of heavy metal ions from wastewater by chemically modified plant wastes as adsorbents: A review. *Bioresource Technology*, 99, 3935-3948.
- Wetlands International. (2010). *A quick scan of peatlands in Malaysia*. Petaling Jaya: Wetlands International-Malaysia.
- Zbytniewski, R., & Buszewski, B. (2005). Characterisation of natural organic matter (NOM) derived from sewage sludge compost. Part 1: chemical and spectroscopic properties. *Bioresource Technology*, 96, 471-478.





## **Optimization of Drilling Parameters for Delamination Associated with Pre-drill in Chopped Strand Mat Glass Fibre Reinforced Polymeric Material**

**T. Panneerselvam\* and S. Raghuraman**

*School of Mechanical Engineering, Shanmugha Arts, Science, Technology and Research Academy (SASTRA University), Thanjavur - 613 401, Tamil Nadu, India.*

### **ABSTRACT**

Glass fibre reinforced polymeric (GFRP) composites are used in various applications such as aircraft, marine and automobile industries because of their high specific strength, high specific stiffness, light weight, corrosion resistance and non-magnetic properties. They also replace traditional materials in many critical applications. Nonetheless, the machining behaviour of GFRP material is still a challenge to the researchers due to its complicated interaction between fibre and matrix material. On machining, this kind of material suffers by surface delamination, fibre peel up, fibre push up, fibre pull out, fibre fracture, and matrix breaking. With an objective to minimize delamination, an investigation was carried out on Chopped Strand Mat GFRP (CSMat GFRP) material by studying the effects of drill diameter and drill diameter ratio besides spindle speed and feed rate. The experiments were designed by  $L_{18}$  Orthogonal Array and conducted by using standard High Speed Steel tools. The obtained results were analyzed by Signal-to-Noise ratio and Analysis of variance. Based on the Signal-to-Noise ratio analysis, drill diameter of  $\text{\O}8\text{mm}$ , drill diameter ratio of 0.8, spindle speed of 3000rpm and feed rate of 50mm/min were identified as optimal parameters for drilling CSMat GFRP material with minimum delamination. The ANOVA table results reveal that drill diameter, drill diameter ratio, spindle speed and feed rate have shown statistical significance on delamination.

*Keywords:* CSMat GFRP, Delamination, Orthogonal Array, Signal-to-Noise ratio, ANOVA.

---

#### *Article history:*

Received: 19 April 2013

Accepted: 5 February 2014

---

#### *E-mail addresses:*

[tpansel@mech.sastra.edu](mailto:tpansel@mech.sastra.edu) (T. Panneerselvam),

[raghu@mech.sastra.edu](mailto:raghu@mech.sastra.edu) (S. Raghuraman)

\*Corresponding Author

### **INTRODUCTION**

The light weight materials are becoming emerging materials for many applications to save energy consumption. GFRP is used in structural components for automobile, aircraft, marine industries, etc. In drilling Glass Fibre Reinforced Polymer, delamination

is the major and critical damage. The rejection of parts in the aircraft industry was mostly reported due to drilling-induced delamination during final assembly (Stone & Krishnamurthy, 1996). It could also be seen from the earlier studies that the main objective was to minimize the drilling-induced delamination of composite laminates through delamination-free drilling experiments (Hocheng & Tsao, 2005; Enemuoh *et al.*, 2001; Tsao, 2006). The effects of input variables such as feed rate, cutting speed and point angle of twist drill on drilling-induced delamination have been studied by many researchers. It was reported that the observed drilling-induced delamination increases with feed rate at any different cutting speeds for various drill bits due to the increase of thrust force during drilling of composite laminates. Khashaba *et al.* (2010) reported in their work that delamination decreased with cutting speed during conventional drilling of woven-ply GFRP composite laminates. Gaitonde *et al.* (2008) also noticed a similar inference that drilling-induced delamination decreased with cutting speed during high speed drilling of CFRP composite laminates. Karnik *et al.* (2008) have studied and inferred that the tendency of delamination increases with the increase of point angle of twist drill during both conventional drilling and high speed drilling of woven-ply CFRP composite laminates.

Won and Dharan (2002) conducted drilling experiments on carbon fiber-reinforced composite laminates to study the effects of the chisel edge on the thrust force and the effects of pre-drilling the laminate with a pilot hole. Their results showed a large reduction in the thrust force by the use of pilot hole, which in effect, removes the chisel edge contribution on delamination. Jain and Yang (1993) concentrated to establish an analytical model to predict thrust force and feed rate which avoid delamination in drilling polymeric composite and the chisel edge width has been identified as an important factor that contributes the thrust force and delamination. Tsao and Hocheng (2003) studied the effects of chisel edge length and pilot hole diameter on delamination in drilling woven carbon/epoxy composite. Their experimental results showed that the critical thrust force could be reduced with pre-drilled hole by cancelling the chisel edge effect on delamination. Tsao (2007) proposed an analytical approach to identify the role of the pilot hole on drilling woven carbon fibre reinforced plastics in order to reduce the thrust force-induced delamination during saw drilling. The experimental results with saw drill showed that the increase in pilot hole ratio could potentially attribute to reduce thrust force and delamination. Tsao and Hocheng (2004) studied the delamination factor of carbon fibre reinforced plastics with the objective to establish a correlation by multi-variable linear regression and the model values were compared with experimental results. Tsao (2008a, 2008b) selected orthogonal array of  $L_{18}$  to study the effects of diameter ratio, feed rate and spindle speed on induced delamination for various step core drills and he found the best combination of parameters for all step core drills within the tested range. He also studied the effects of thrust force of step core drill with drilling parameters.  $L_9$  Orthogonal array and Signal-to-noise ratio were applied to optimize the levels of parameters for minimum delamination in drilling CSMat GFRP material (Panneerselvam & Raghuraman, 2012). Aji *et al.* (2013) investigated the hybridized kenaf (bast)/ pineapple leaf fibre (PALF) bio-composites with an objective of improving tensile property and the results obtained were analyzed statistically at 95% confidence level.

This paper investigates the way to use conventional tool for minimum delamination in drilling CSMat GFRP material. The influences of drill diameter, drill diameter ratio, spindle speed, and feed rate on delamination were studied with the objective to select the optimal conditions for minimum delamination.

## EXPERIMENTAL DETAILS

### *Material and Method*

The material specimen used in this work is a laminated slab of 300mm x 300mm x 23mm, and it was fabricated from the hand lay-up process. The material has chopped strand mat glass fibre in isophthalic polyester resin. It contains 40% glass fibre with a density of 1.5Mg/m<sup>3</sup>. It has the heat resistance up to 175°C and its tensile strength and compressive strength are 140MPa and 170MPa, respectively.

This work is planned with Taguchi method of approach. The Taguchi method provides a special design to set the process parameters with minimum number of experiments by saving time and resources. The method also combines the experimental design theory and the quality loss function concept in order to solve the problem of industrial product quality and reliability. Thus, Taguchi's experimental design, a L<sub>18</sub> (2×3<sup>7</sup>) orthogonal array, was selected in this work to study the effect of drill diameter and drill diameter ratio separately, along with spindle speed and feed rate on delamination. The factors and their levels considered in conducting the experiments are listed in Table 1 and Table 2.

TABLE 1: Factors and levels (to study the effects of drill diameter on delamination)

Symbol	Factor	Level 1	Level 2	Level 3
A	Drill diameter (mm)	8	15	-
B	Spindle speed (rpm)	1000	2000	3000
C	Feed rate (mm/min)	50	150	250

TABLE 2: Factors and levels (to study the effects of drill diameter ratio on delamination)

Symbol	Factor	Level 1	Level 2	Level 3
A	Drill diameter ratio	0.8	0.53	-
B	Spindle speed (rpm)	1000	2000	3000
C	Feed rate (mm/min)	50	150	250

### *Machining and Measuring Equipment*

MCV- 400 machining centre, with a workspace of 600 x 415 x 460 mm and a speed range of 60 – 6000 rpm, was used to perform drilling operations on CSMat GFRP material. The effect of drill diameter on delamination was initially studied by using standard High Speed Steel (HSS) twist drill of Ø8 mm and Ø15mm. Later, the drilled Ø8mm holes were subsequently drilled by Ø10mm and Ø15mm according to L18 Orthogonal Array design to study the effect of drill diameter ratio on delamination. The drilled holes used for the delamination studies are shown in Fig.1.

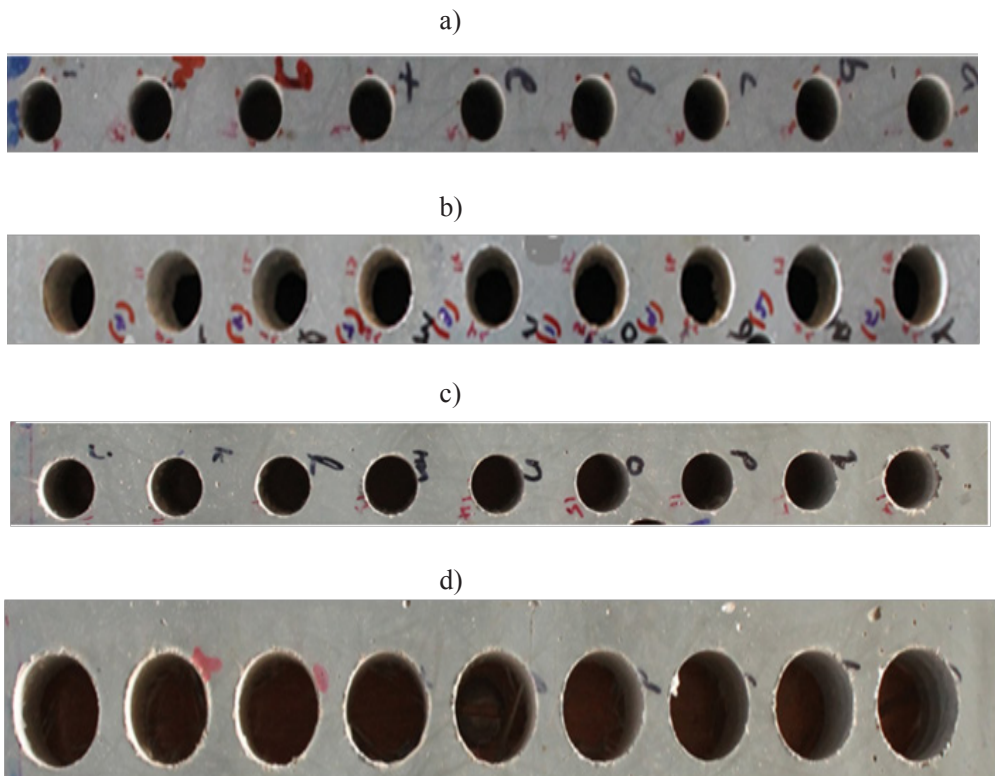


Fig.1: Drilled holes for delamination studies; a)  $\text{Ø}8\text{mm}$  drilled holes, b)  $\text{Ø}15\text{mm}$  drilled holes, c)  $\text{Ø}10\text{mm}$  holes obtained by drill diameter ratio of 0.8 and d)  $\text{Ø}15\text{mm}$  hole obtained by drill diameter ratio of 0.53

Delamination is a physical separation of constituent materials which gives a serious problem in the fibre reinforced composite materials at the entry and exit of holes. This can be evaluated by tool maker's microscope, profile projector or image processing analyzer. In this work, DYNASCAN Profile Projector, model PT 400 EM, was used with a magnification of 20X for an accuracy of 0.001mm. It is capable of measuring  $200\text{mm} \times 150\text{mm}$  in X/Y axis. The maximum diameter in the delaminated area was measured as the scheme shown in Fig.2.

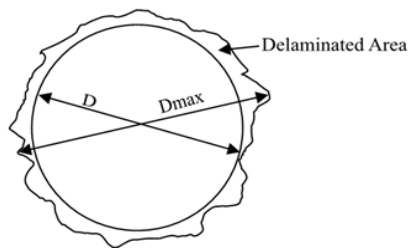


Fig.2: A scheme of measurement for maximum diameter in the delaminated area

The delamination factor was determined by the ratio between the maximum diameter in the damaged zone and the drill diameter, i.e.

$$F_d = \frac{D_{\max}}{D} \quad \text{Equation 1}$$

where  $D_{\max}$  – Maximum diameter measured in the delaminated area and  $D$  – Drill diameter

## RESULTS AND DISCUSSION

### *Signal-to-noise Ratio*

A Taguchi approach, Signal-to-Noise (S/N) ratio, was used to measure the quality characteristics which deviate from the desirable value. In the Signal-to-Noise ratio, the term ‘Signal’ represents the desirability of response parameters and the term ‘Noise’ represents the undesirability for the response parameters. The objective of the work was to identify the factors and their combination that influence the drilling process and to minimize the delamination. For minimum delamination, the smaller-the-better quality characteristic was used to calculate S/N ratio and S/N ratio is determined by:

$$\text{S/N ratio} = -10 \times \log \left( \frac{1}{n} \sum_{i=1}^n y_i^2 \right) \quad \text{Equation 2}$$

where  $n$  is the number of measurements in a trial/row, in this case,  $n = 2$  and  $y_i$  is the  $i^{\text{th}}$  measured value in a run.

The results of the delamination factor and the corresponding calculated S/N ratio values are given in Table 3 to study the effects of drill diameter and the effects of drill diameter ratio on delamination during drilling CSMat GFRP material. In order to study the drill diameter effect and drill diameter ratio on delamination, the main effects plots were drawn with the help of Minitab16, and these are shown in Fig.3 and Fig.4.

From Fig.3, it can be seen that the increasing drill diameter, decreasing spindle speed and increasing feed rate have demonstrated the increasing delamination. The reduction in the delamination observed for small drill diameter is due to the fact that decreasing drill diameter actually has the effect to reduce the delamination by reducing the cutting torque and thrust force. The authors of many research papers have investigated that cutting torque and thrust force are the contributing parameters in increasing the delamination values (see Stone & Krishnamurthy, 1996; Tsao, 2007; Tsao, 2008b). The mechanism which is capable of reducing cutting torque and thrust force can reduce delamination and hence small drill diameter has the effect to reduce the delamination value.

A reduction in delamination was also observed for the use of pre-drill and the higher drill diameter ratio was shown to have reduced delamination (Fig. 4). This is due to the fact that the use of pre-drill has an effect to reduce the chisel effect, cutting torque, thrust force and

TABLE 3:  $L_{18}(2 \times 3^7)$  Orthogonal Array design, Delamination factor (Fd) and Signal-to-noise (S/N) ratio

Trial No.	A	B	C	To study the effect drill diameter		To study the effect of drill diameter ratio	
				Fd	S/N ratio (dB)	Fd	S/N ratio (dB)
1	1	1	1	1.034	-0.292	1.025	-0.211
2	1	1	2	1.079	-0.663	1.061	-0.514
3	1	1	3	1.094	-0.783	1.088	-0.733
4	1	2	1	1.026	-0.227	1.024	-0.207
5	1	2	2	1.066	-0.559	1.053	-0.449
6	1	2	3	1.091	-0.755	1.066	-0.558
7	1	3	1	1.025	-0.218	1.021	-0.183
8	1	3	2	1.058	-0.491	1.042	-0.355
9	1	3	3	1.061	-0.515	1.058	-0.492
10	2	1	1	1.079	-0.657	1.038	-0.324
11	2	1	2	1.084	-0.704	1.071	-0.597
12	2	1	3	1.100	-0.825	1.099	-0.819
13	2	2	1	1.073	-0.614	1.036	-0.307
14	2	2	2	1.088	-0.734	1.070	-0.588
15	2	2	3	1.092	-0.766	1.079	-0.663
16	2	3	1	1.070	-0.590	1.034	-0.290
17	2	3	2	1.072	-0.600	1.053	-0.446
18	2	3	3	1.087	-0.725	1.074	-0.616

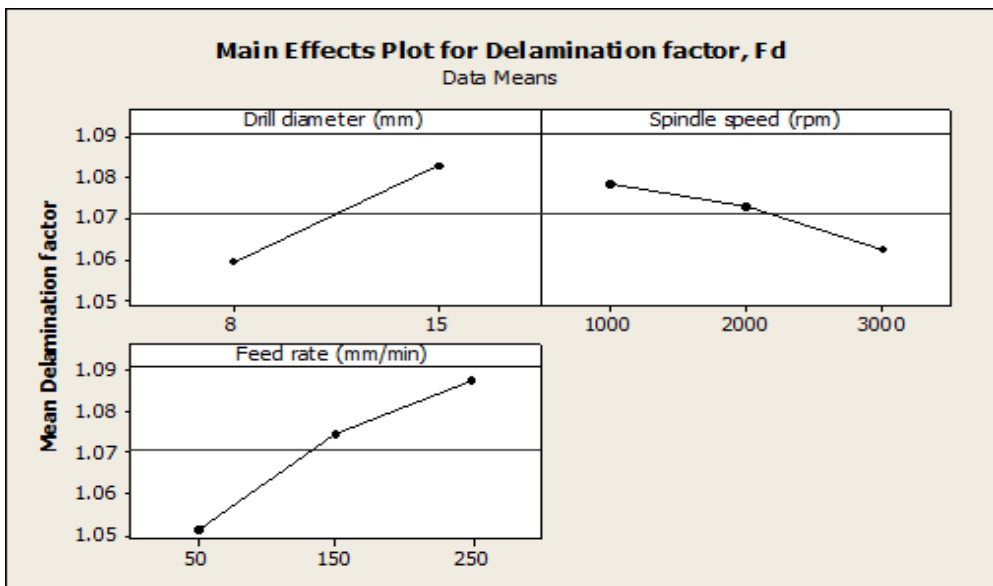


Fig. 3: The main effects plot for Delamination factor (effect of drill diameter)



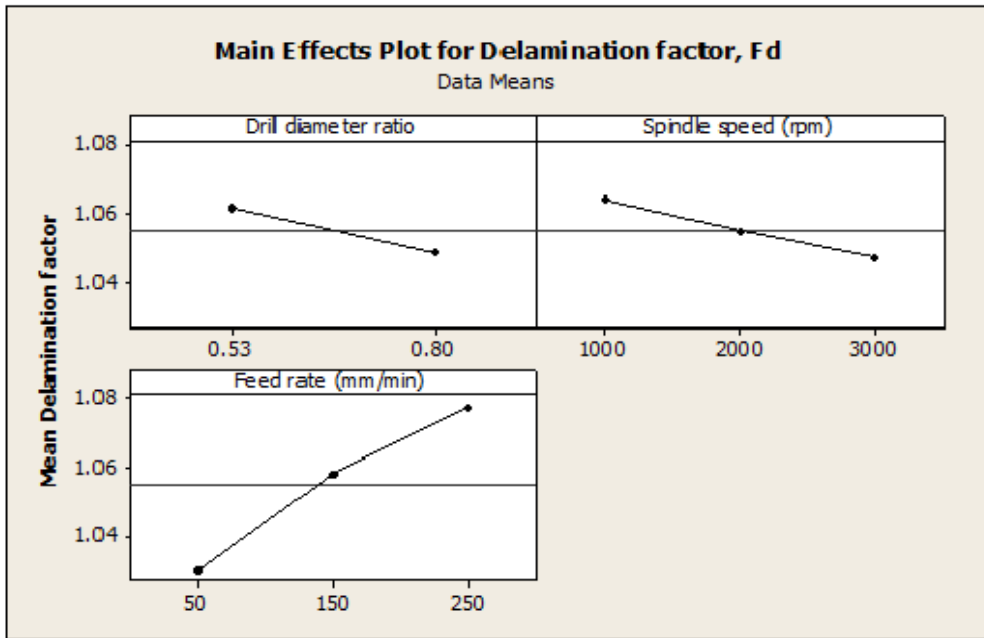


Fig.4: The main effects plot for Delamination factor (effect of drill diameter ratio)

the amount of material removed (Won & Dharan, 2002; Tsao & Hocheng, 2003; Tsao, 2006; Tsao, 2007) and hence, reduced delamination was observed for higher drill diameter ratio. Meanwhile, it is also noted that the use of pre-drill with higher drill diameter ratio permits to go for higher diameter drilling of CSMat GFRP material with minimum delamination. The main effect plots of both also reveal that the increasing spindle speed and decreasing feed rate have the effects in reducing delamination. This is due to the fact that the cutting torque and thrust force contributions are reduced by the increasing spindle speed and decreasing feed rate (Khashaba *et al.*, 2010). Hence, delamination is reduced for higher spindle speed and lower feed rate (Panneerselvam & Raghuraman, 2012).

TABLE 4: S/N Response table for delamination factor (effect of drill diameter)

Levels	Factor		
	A	B	C
1	-0.5	-0.654	-0.433
2	-0.691	-0.609	-0.625
3	---	-0.523	-0.728
Max-min	0.191	0.131	0.295
Rank	2	3	1

The study of the S/N response (Table 4) and S/N response graph (Fig.5) for the effects of drill diameter indicates that drill diameter and feed rate are the significant factors for minimum delamination and the slope gradient is larger for drill diameter and feed rate. The optimal

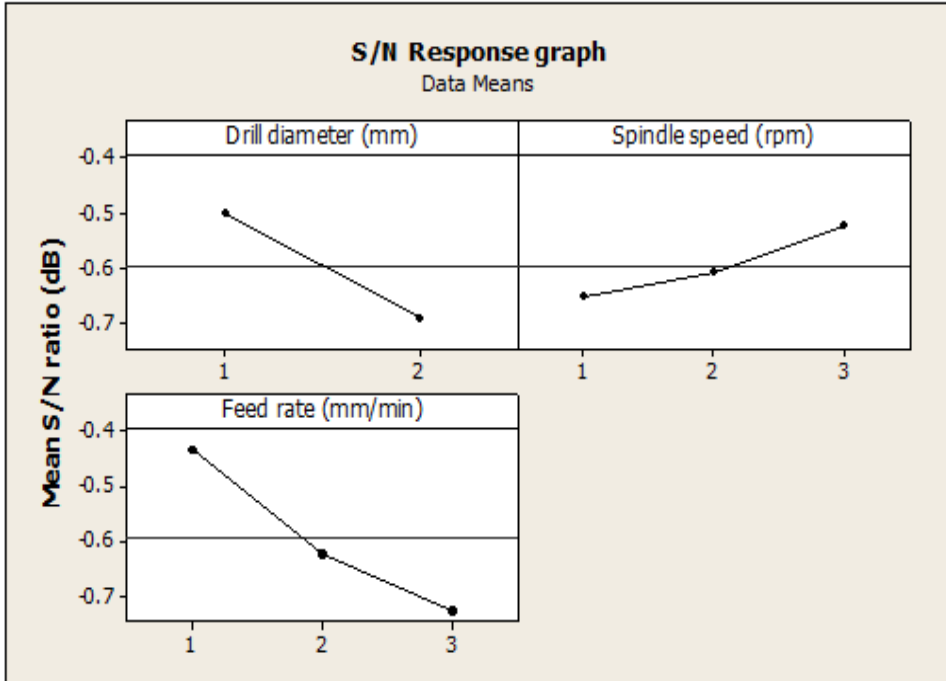


Fig.5: S/N Response graph for Delamination factor (effects of drill diameter)

cutting conditions leading to the minimum delamination were identified based on the parameter settings which have the highest S/N ratio as the highest S/N ratio always gives optimum quality with minimum variance. Accordingly, it is evident from Table 4 and Fig.5 that level 1 of drill diameter (Ø8mm), level 3 of spindle speed (3000rpm) and level 1 of feed rate (50mm/min) have the highest S/N ratio. These levels of combination are determined as the optimal levels for minimum delamination for drilling CSMat GFRP material.

Similarly, the study of the S/N response (Table 5) and the S/N response graph (Fig.6) for the effects of drill diameter ratio indicates that drill diameter ratio, spindle speed and feed rate are the significant factors for minimum delamination. From Table 5 and Fig.6, the optimal parameter combination corresponding to level 1 of drill diameter ratio (0.8), level 3 of spindle speed (3000rpm) and level 1 of feed rate (50mm/min) are determined to get the minimum delamination for drilling CSMat GFRP material.

TABLE 5: S/N Response table for delamination factor (Effects of drill diameter ratio)

Levels	Factor		
	A	B	C
1	-0.411	-0.533	-0.254
2	-0.517	-0.462	-0.492
3	---	-0.397	-0.647
Max-min	0.106	0.136	0.393
Rank	3	2	1

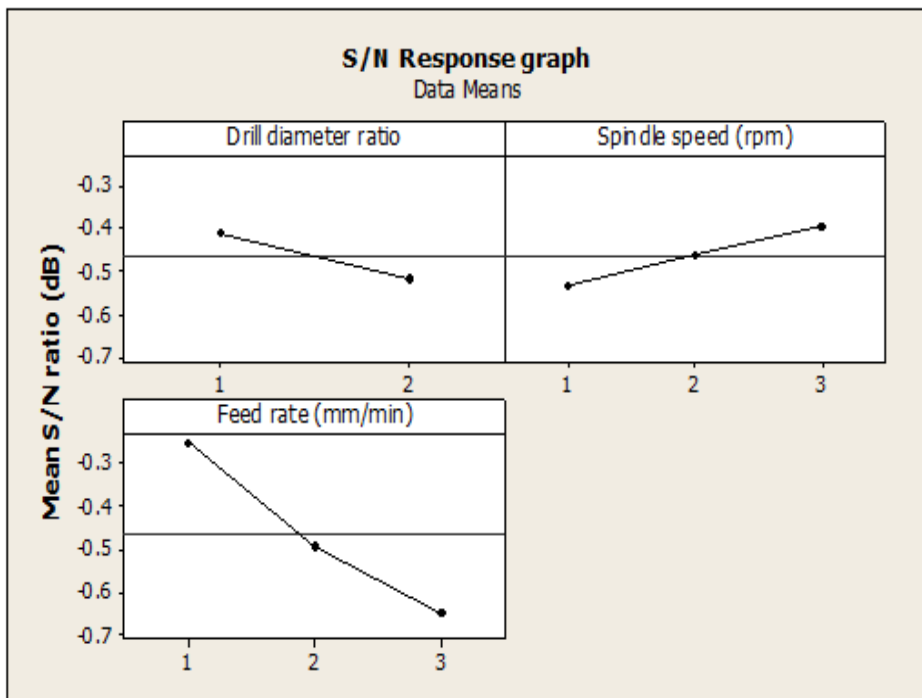


Fig.6: The S/N Response graph for Delamination factor (effect of drill diameter ratio)

*Analysis of Variance*

The purpose of the analysis of variance is to find the parameter’s significance on the quality characteristics. The ANOVA results developed for this experimental work are summarized in Table 6 and Table 7. It can be seen from Table 6 that drill diameter and feed rate have shown statistical significance on the delamination factor. In addition, both have 27.72% and 45.85% of contributions on total variation, respectively.

TABLE 6: ANOVA for Delamination factor (Effect of drill diameter)

Source	SS	DOF	MS	F <sub>cal</sub>	F <sub>table</sub>	C %
A*	0.163	1	0.163	19.136	4.75	27.72
B	0.053	2	0.027	3.127	3.89	9.06
C*	0.270	2	0.135	15.826	3.89	45.85
Error	0.102	12	0.009	---	---	17.38
Total	0.588	17	---	---	---	100.00

\*Significant

SS- Sum of Squares, DOF- Degrees of Freedom, MS – Means of Square, F<sub>cal</sub> – F-distribution value calculated, F<sub>table</sub> – F-distribution value from table at 5% significant level, C – contribution in total variations

TABLE 7: ANOVA for Delamination factor (Effect of drill diameter ratio)

Source	SS	DOF	MS	F <sub>cal</sub>	F <sub>table</sub>	C %
A*	0.050	1	0.050	22.836	4.75	8.29
B*	0.056	2	0.028	12.689	3.89	9.22
C*	0.471	2	0.235	107.591	3.89	78.14
Error	0.026	12	0.002	---	---	4.36
Total	0.602	17	---	---	---	100.00

**\*Significant**

SS- Sum of Squares, DOF- Degrees of Freedom, MS – Means of Square, F<sub>cal</sub> – F-distribution value calculated, F<sub>table</sub> – F-distribution value from table at 5% significant level, C – contribution in total variations

The results of ANOVA (Table 7) indicate that drill diameter ratio (8.29%), spindle speed (9.22%) and feed rate (78.14%) have the statistical significance on the delamination factor. In both the ANOVA tables, it is observed that feed rate plays a major contribution in controlling the delamination factor, apart from the other drilling parameters.

**CONCLUSION**

The experimental studies on delamination associated with drill diameter, drill diameter ratio, spindle speed and feed rate in drilling CSMat GFRP material are presented in this work. The following conclusions are drawn from this investigation: in the first set of the experiment, the effect of drill diameter was considered and it is seen that Ø8mm HSS twist drill offers minimum delamination compared to Ø15mm HSS twist drill. The delamination increases with increase in drill diameter; in the second set of the experiment, the effect of diameter ratio was considered, and it is observed that drill diameter ratio of 0.8 offers the minimum delamination compared to drill diameter ratio of 0.53. Delamination decreases with the increase in drill diameter ratio; the results also show that the increase in spindle speed and decrease in the feed rate reduced the delamination value; based on the S/N response table and S/N response graph for the study on the effect of drill diameter, drill diameter of Ø8mm, spindle speed of 3000rpm and feed rate of 50mm/min were found as the optimal parameter combination for drilling CSMat GFRP material with minimum delamination. Similarly for the study on the effect of drill diameter ratio, the drill diameter ratio of 0.8, spindle speed of 3000rpm and feed rate of 50mm/min were identified as the optimal parameter combination for minimum delamination; the ANOVA results for the study on the effects of drill diameter reveal that the drill diameter and feed rate have statistical significance on delamination factor, while the ANOVA results for the study on the effect of drill diameter ratio reveal that drill diameter ratio, spindle speed and feed rate have the statistical significance on delamination factor; and in the ANOVA analysis, it is also noted that feed rate has more percentage of contribution on total variation for both the studies on the effects of drill diameter and the effects of drill diameter ratio on delamination.

## REFERENCES

- Aji, I. S., Zinudin, E. S., Khairul, M. Z., Abdan, K., & S. M. Sapuan, S. M. (2013). Induced Tensile Properties With EB- Cross Linking of Hybridized Kenaf/Palf Reinforced HDPE Composite. *Pertanika Journal of Science and Technology*, 21(1), 135 – 140.
- Enemuoh, E. U., El-Gizawy, A. S., & Okafor, A. . (2001). An approach for development of damage-free drilling of carbon fiber reinforced thermosets. *International Journal of Machine Tools & Manufacture*, 41, 1795–1814.
- Gaitonde, V. N., Karnik, S. R., Campos Rubio, J., Esteves Correia, A., Abrao, A. M., & Paulo Davim, J. (2008). Analysis of parametric influence on delamination in high-speed drilling of carbon fiber reinforced plastic composites. *Journal of Material Processing Technology*, 203,431–438.
- Hocheng, H. & Tsao, C. C. (2005). The path towards delamination-free drilling of composite materials. *Journal of Material Processing Technology*, 167, 251–264.
- Jain, S. & Yang, D. C. H. (1993). Effects of Feed rate and Chisel Edge on Delamination in Composites Drilling. *ASME Journal of Engineering for Industry*, 115, 398- 405.
- Karnik, S. R., Gaitonde, V. N., Campos Rubio, J., Esteves Correia, A., Abrao, A. M., & Davim, J. P. (2008). Delamination analysis in high speed drilling of carbon fiber reinforced plastics (CFRP) using artificial neural network model. *Material and Design*, 29, 1768–1776.
- Khashaba, U. A., EI-Sobaty, I. A., Selmy, A. I., & Megahed, A. A. (2010). Machinability analysis in drilling woven GFR/epoxy composites: part I – effect of machining parameters. *Composites: Part A*, 41, 391–400.
- Panneerselvam, T. & Raghuraman, S. (2012). Experimental Investigations on Delamination to improve the hole quality in Chopped Strand Mat GFRP Material during Drilling Operation. *Journal of applied sciences*, 12(10), 1063-1066.
- Stone, R. & Krishnamurthy, K. (1996). A neural network thrust force controller to minimize delamination during drilling of graphite-epoxy laminates. *International Journal of Machine Tools & Manufacture*, 36, 985–1003.
- Tsao, C. C. (2006). The effect of pilot hole on delamination when core drill drilling composite materials. *International Journal of Machine Tools & Manufacture*, 46, 1653–61.
- Tsao, C. C. (2008a). Investigation into the effects of drilling parameters on Delamination by various step-core drills. *Journal of Material Processing Technology*, 206, 405-411.
- Tsao, C. C. (2007). Effect of pilot hole on thrust force by saw drill. *International Journal of Machine Tools & Manufacture*, 47, 2172–2176
- Tsao, C. C. (2008b). Experimental study of drilling composite materials with step-core drill. *Materials and Design*, 29, 1740-1744.
- Tsao, C. C. & Hocheng, H. (2003). The effect of chisel length and associated pilot hole on delamination when drilling composite materials, *International Journal of Machine Tools & Manufacture*, 43, 1087–1092.
- Tsao, C. C. & Hocheng, H. (2004). Taguchi analysis of delamination associated with various drill bits in drilling of composite material, *International Journal of Machine Tools & Manufacture*, 44, 1085-1090.

T. Panneerselvam and S. Raghuraman.

Won, M. S. & Dharan, C. K. H. (2002). Chisel Edge and Pilot Hole Effects in Drilling Composite Laminates. *ASME Journal of Manufacturing Science and Engineering*, 124, 242-247.

## **RFID-Enabled Web-Based Interface for a Chemical Storage Management System**

**Rosiah Osman<sup>1\*</sup>, Abd. Rahman Ramli<sup>2</sup>, Wan Azizun Wan Adnan<sup>2</sup> and Intan Helina Hasan<sup>1</sup>**

<sup>1</sup>*Functional Devices Laboratory, Institute of Advanced Technology, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia*

<sup>2</sup>*Dept. of Computer and Communication Systems Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia*

---

### **ABSTRACT**

The management of a chemical inventory is necessary for safety purposes as well as for fulfilling regulatory compliance. In most academic laboratories, the management of chemicals is still being done manually, which is time-consuming. As a result, data are not updated and expired chemicals are unintentionally used. This research proposes that UHF Class 1 Gen 2 Radio Frequency Identification (RFID) technology be used in the development of a chemical inventory information system to ease chemical tracking as well as to shorten the inventory process time. An information system integrating RFID data and a web-based rule identification interface was developed. WAMP 2.2.17, PHP 5.3.5 and MySQL 5.5.8 were downloaded and a programming language was written to check the expiration date of the chemicals as well as to produce alert notification status. Wireless technology through GSM modem helped in producing alert messages using the Short Message System (SMS) of the nearly expired chemicals to the handphone of the person in charge in real time.

*Keywords:* Chemical inventory, chemical management system, Radio Frequency Identification (RFID) Technology, information system, web-based interface

---

---

#### *Article history:*

Received: 2 April 2013

Accepted: 27 July 2013

---

#### *E-mail addresses:*

rosiah@upm.edu.my (Rosiah Osman)

arr@eng.upm.edu.my (Abd. Rahman Ramli)

wawa@eng.upm.edu.my (Abd. Rahman Ramli)

i\_helina@upm.edu.my (Intan Helina Hasan)

\*Corresponding Author

### **INTRODUCTION**

The chemical inventory process is essential in the chemical storage management system. The storage must be managed systematically for safety purposes as well as for regulatory compliance and standardisation. A good inventory system contains complete information about storing, tracking and



reporting and must be easy to manage so that the person in charge can take the necessary action for remedial tasks as and when needed. It is important for an academic institution to have or develop its own chemical inventory management system so that its chemicals inventory annual report can be easily produced. By developing and building an accurate chemical inventory system, better decisions can be made to maximise worker safety, safeguard the community, reduce waste and cost and also ensure more timely and effective environmental compliance (Kraus, 2005).

Chemicals are one type of hazardous material which are regularly used and stored in the laboratories of academic institutions. Some chemicals are corrosive and must be properly handled. Normally, Personal Protective Equipment (PPE) such as hand gloves, lab coats and goggles have to be put on for safety and self protection when chemicals are used.

On the other hand, Good Laboratory Practice (GLP) requires the chemical inventory to be updated at least once annually. In addition, it is essential for a proper chemical inventory process to be deployed in laboratories that complies with the International Organisation of Standardization (ISO) regulations and Occupational Safety and Health Act (OSHA) Hazardous Communication Standard (Vijayan, 2005). The proper management of the system will prevent accidents while handling chemicals as well as ensure accurate research results. Foster (2005) suggests that storage of these chemicals must be managed systematically and the quantity and expiration date should be monitored carefully to ensure chemicals are stored in safe amounts, to prevent expired chemicals from being used, to prevent a stockpile of unneeded chemicals and also to provide more efficient use of laboratory storage space.

However, performing the inventory process manually is very time-consuming as the printed data on the labels of containers have to be read and inspected one by one. As mentioned by Gibbs (2005), the task is becoming more challenging for diverse and decentralised laboratories in an organisation. Indeed, the inventory process in some laboratories in academic institutions is not being done regularly due to the tedious work involved and lack of time, resulting on non-conformity reports being issued during compliance and surveillance audits. In some instances, chemicals with expired shelf life have been found or were accidentally used.

In the era of globalisation, new technologies have been invented and developed to ease task performance. It is a good practice to develop an inventory system that can enhance the performance of research labs and shorten the time needed for inventory taking. A knowledge-based information system, the Internet and wireless connection, a web server, Global System for Mobile Communication (GSM) modems, Short Message Service (SMS), Radio Frequency Identification (RFID) and barcodes are some of the considerable choices available that allow global interoperability and ubiquitous interaction between devices (Steinberg, 2009) that can aid in efficient inventory-taking. A web server consists of a computer connected to the Internet (typically with an allocated static IP address) and the necessary software (Grout *et al.*, 2012). In recent years, SMS has become the first choice method for reaching audiences (Ismail, 2013).

RFID is wireless sensor technology that is based on the detection of electromagnetic signals (Domdouzis *et al.*, 2007), thus RFID reading can be done remotely. It does not require a direct line of sight to transfer information because it is sent via radio waves. No contact between chemicals and human skin is necessary, thus tracking of chemicals is easier. Therefore RFID technology is believed to be an added advantage in performing the chemical inventory process.

*Existing Chemical Inventory Systems*

Nowadays, several individual institutions have started using or have deployed their own chemical inventory system. Some acquire a commercial system and implement it while others develop their own system based on their requirements. With such initiatives, the chemical inventory process is becoming top priority in most organisations to ensure safety and compliance.

Williams (2013) mentions that an accurate chemical inventory is the foundation for overall chemical management initiatives. He suggests eight tips to be considered before starting an inventory. Inventory accuracy can be used as the leading indicator, which will help one identify root causes and develop corrective actions for maintaining a safe, reliable and accurate system (Quigley *et al.*, 2012).

Rooney (2001) summarised a few examples and features of chemical inventory software available in the market such as Chemoventory, CISPro by ChemSW, Chemtracker by Stanford University, Hazmin by Logical Technology Inc., EMAX by EMAX Solution, SMART by MDL Information Systems, ChIM by Ventere and some others as shown in Table 1. Some of these products are open-source-web-based but with limited capabilities while others come as full versions with licence but cost some amount of money. Gibbs (2005) reports that in 2005 Stanford University had developed a web-based application for chemical inventory information management for non-profit organisations through consortium members.

TABLE 1: Summary of Existing Chemical Inventory Software

Inventory Name	Company	Features
Chemoventory	ChemoventoryInc, CA, USA	Two versions: Standard and Lite. Requires open source PHP web server and MySQL database
CISPro	ChemSWInc, CA, USA	Can be implemented with wireless palm top scanner. Can scan chemicals anywhere in a facility and uplink the info to the database using wireless network
Chemtracker	Chemtracker Consortium/ Stanford University	Web-based application, accessible to other non-profit organisations through consortium membership
Chem Alert	Local Gov. Corporate Services Australia	Annual Licence
Hazmin	Logical Technology Inc., IL, USA	Browser-based access, one database for multisite reports
ESSIHS	HIS Inc, Colorado, AZ, USA	Tracks locations and amounts of hazardous materials on site
EMAX	EMAX Solution/SciQuest	Specialised in chemical e-business, relates to the pharmaceutical marketplace
OARDC	Ohio State University	Web-based, managed by location of room

### *Integrating Chemical Inventory Software with RFID*

Eventhough an institution might have already built or purchased chemical inventory software, it is essential for the institution to conduct regular inspections on the chemicals. Besides the tedious work, the inventory process must be performed regularly to ensure that the chemicals are in a proper state and condition.

Currently, RFID technology is being used for chemical identification and location monitoring (Wang *et al.*, 2008). RFID is a wireless sensor technology that is based on the detection of electromagnetic signals to automatically identify people, animal or objects. A typical RFID system consists of three components: a transceiver/reader, an antenna and a transponder (RF tag), which is electronically programmed with unique information (Stanczak, 2007). If an RFID passive tag is found in the electromagnetic zone that is produced by the antenna, the tag detects the activation signal of the reader. There are two main categories of RFID systems: passive and active tags. Chien and Chen (2007) mention that RFID devices with power supply that actively transmit to a reader are known as active tags and un-powered tags that are triggered by a reader are called passive tags. RFID works in different frequencies depending on its use. RFID technology is being used worldwide in diversified applications such as supply chains, asset tracking, transportation, libraries, animal tagging, e-passport and others (Angeles, 2005). Asset tracking enables the user to track asset locations and monitor asset usage status in real time by using a mobile wireless sensor attached to each asset (Dickman *et al.*, 2007).

There are two RF technologies currently available in the market for item level tagging. The high-frequency (HF) system, which operates on 13.56 MHz frequency, has long been believed to be the best system (Potyrailo *et al.*, 2007). Previously, Ultra High Frequency (UHF), which operates on 858-960 MHz, did not work that well for item level tagging. However, with current technologies, the manufacturer of UHF has been able to create 'Near Field UHF', which has similar performance capabilities as HF tags (Fletcher, 2010). Roberti (2006) mentions that the maximum reading range for HF is approximately 3 feet whilst for UHF it is approximately 30 feet or 10 metres. Kelly (2005) reports that in comparison to barcode or magnetic strip technology, RFID device does not need to be positioned precisely relative to the scanner to read the data. Furthermore, RFID tags are able to hold more information. With a response time of less than 100 ms, RFID readers can read many tags virtually instantaneously (Roberts, 2006). Since RFID readers can retrieve all data stored in pre-programmed tags in a split second, using them helps to reduce the time and effort required by the storekeeper to conduct the regular inspection process and update the inventory data.

Many suppliers use RFID together with Geographic Information System (GIS) and Global Positioning System (GPS) to track the movement of chemical barrels or drums between the warehouse and the manufacturing facilities. Only in recent years some efforts are being done to integrate RFID and the chemical inventory management system on a smaller scale such as in one particular institution or academic laboratory.

Gillespie (2006) reports that ChemSW. Inc. in California has launched CISProMobile, the integration of high frequency (HF) RFID solution with its chemical inventory system, CisPro Inventory Management System. A handheld software client allows CISProMobile users to

enter inventory data into a Windows-compatible handheld device. However, it is known that the HF system has limited read range capabilities.

The technical group of Kali Laboratories (2010) report that they use the ICEGEIN RFID solution to enhance and control their work process and provide instant access to chemical information. They use fixed readers mounted on a wall near the laboratory doors. The reader picks up the signal if a chemical container is moved through the door. With this kind of system quite a number of readers are required to be installed. A lot of investment has to be made, and this method is only suitable for big organisations.

To deploy a system, one institution has to decide which technology best suits its need. All decisions depend on the institution's need, arrangement of its chemical lab facilities and its financial potential.

## MATERIALS AND METHOD

This research proposes the use of a type of RFID Ultra High Frequency system (UHF) to perform the task of chemical tracking in one of the laboratories in Universiti Putra Malaysia. Figure 1 illustrates the proposed Chemical Storage Management System that uses RFID application and wireless technology.

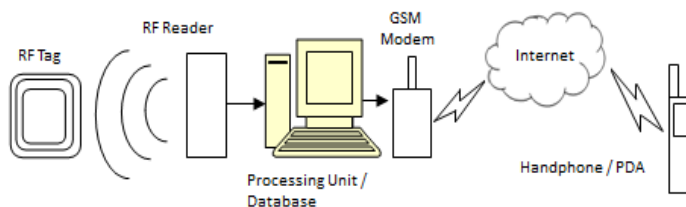


Fig.1: The Proposed Chemical Management System

In the first phase of this project, an information system for chemical tracking is developed using Radio Frequency Identification (RFID) technology. First, unique identification data is programmed into the chip in each RF tag. The pre-programmed tags are then tagged to each bottle of chemicals. The reader then decodes the data, which are encoded in the integrated circuit of the tag.

The next phase is to develop the chemical information system from the data imported from the RFID readings. All related data from the RFID reader can be transferred to any computer system for processing. The additional data is entered in the database such as Chemical Name, Manufacture, Amount, Location, Room Number, Expiry Date, Person in Charge and Contact Number. The information system is also used for monitoring and analysing the utilisation of chemicals in an identified laboratory.

In the final phase, a knowledge-based rule identification interface supporting the RFID and wireless sensor network is developed for the notification of nearly-expired chemicals through Short Message System (SMS) to the storekeeper in charge. The identification interface is developed using PHP and MySQL in a Server. The Server is connected to a GSM Modem so that data of the triggering system can be sent to personal mobile devices such as a handphone or PDA monitored by the store keeper in real time.

### *Hardware*

The proposed RFID system structure consists of UHF RFID transponder (UHF passive tags), interrogator with antenna (UHF reader) and a middleware (embedded in a computer). The wireless system integration is between a computer and a GSM Modem. The specifications for each device used in this project are as follows:

#### *RFID Tags*

In this project, UPM RaflatacDogBone passive tags were used because of the efficiency, reliability and low cost. They operated on Global 860-960 MHz frequency and EPC Class 1 Gen 2 Protocol. They consisted of up to 240-bit EPC memory including 32-bit unique serial number. They were of adhesive type with an antenna size of 93 x 23 mm (3.7 x 0.9 inch).

#### *RFID Mobile Reader/Scanner*

The UHF Gen2 Mobile Reader (MUHF H300) used in this project was a UHF scanner device with Bluetooth connectivity to a Personal Digital Assistance (PDA). It operated on the frequency range of 902 -928 MHz band. It used EPC Class 1 Gen 2 Tag Air Interfaces.

#### *GSM Modem*

This project used SMS Gateway Development kit (Q24 Modem) for the modem as the interfacing device. Connecting a GSM modem to a computer allows the computer to communicate over the mobile network by sending and receiving Short Message System (SMS) and Multimedia Message System (MMS) messages. The SMS Engine is a Windows application that sends and receives SMS messages. This SMS Engine uses the MS Access Database, namely "SMSEngine5.mdb", to store incoming SMS messages and to check if there are any pending SMS messages to be sent out. The operator only needs to insert the record into the database to send out SMS messages and then retrieve the record from the database to read received SMS messages.

#### *The Software*

The operation software, namely "RFID Asset Tagging", is installed in the Personal Digital Assistance (PDA) database. In this project, the information captured was kept in a local database and could be exported to other computers through a .csv file through USB connection. The software was built on .Net Compact Framework 3.5 in Windows CE operating system.

#### *Asset Registering*

In the proposed system, firstly, all the passive tags have to be registered. Each chemical tag must be registered according to the pre-programmed unique serial number (tag id number) as the fixed identifier. Chemical information such as the chemical name and location or any other information is then added in the specified fields accordingly and saved in the integrated chip inside the tag. Then, the tags are affixed to chemical containers or bottles in a specified

location or laboratory accordingly. In this project, this process was repeated until all the chemical containers were tagged.

### Assets Scanning

One of the essential steps in the inventory process is asset tracking, which in this case, is chemical tracking. It is important to update current lists of chemicals that are in stock. Results from the process will provide information of chemicals that are out of place or missing. Fig. 2 shows the scanning process of RFID tags in this project with the data then being transferred to a computer for further processing.

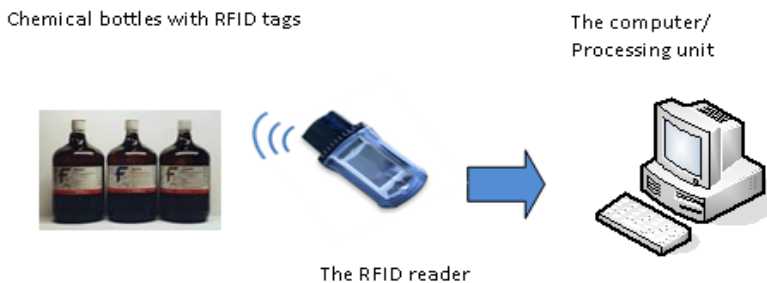


Fig.2: Process of Scanning/Transferring RFID Data into Processing Unit

To start the scanning process, the reader is placed near the containers with affixed pre-programmed tags. In this project, during the scanning process, the reader scanned and decoded the data which was encoded in the integrated circuit chip of the nearby tags randomly. The programme was written such that the tag numbers would be sorted in ascending order after the “stop” button was pressed. The unique serial number of the tags and pre-programmed information were displayed on the PDA screen in ascending order for easy checking. Missing tag numbers in the list indicated that those particular chemicals were out of place as shown in Figure 3. This information could be exported to a computer or any processing unit for further processing.

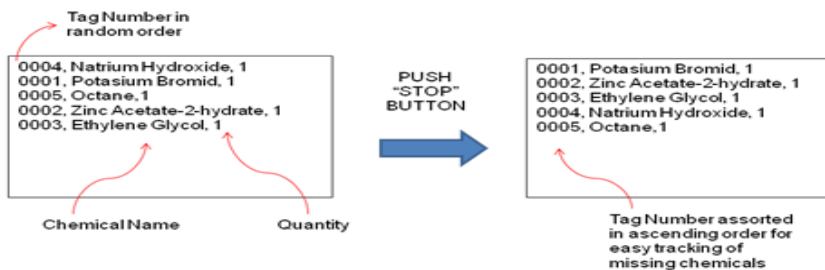


Fig.3: Mechanism of Chemical Tracking



*Development of Information System for Chemical Expiration Alert Status*

In this project, the results of the scanning were transferred to a computer in a spreadsheet file (.csv) and then saved as an Excel file (.xls or .xlsx). From this data, an information system or complete database was created for further data manipulation. More information regarding particular chemicals such as Manufacturer, Quantity, Location, Expiry Date, Person in Charge, Contact Number, MSDS and so on could be added and tabulated according to person in charge preferences. Figure 4 illustrates the development of a wireless system.

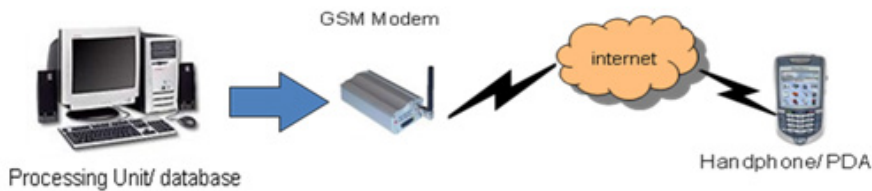


Fig.4: Wireless System Development

In this project, this information system or database was then uploaded to a server and could be accessed by everyone through Internet connection with a specified address. However, only identified moderators with a specified password acted as administrator. Thus, any changes made in the database could be seen by the other users from their locations as the devices supported the wireless Internet application. In general, it is advisable to convert the spreadsheet from Excel (.xls or .xlsx) to Access (.mdb). The database is more flexible and easily upgraded in .mdb rather than .xls form. As long as the tag number is retained as identifier, all the data can be added and transferred easily and linked to the host through Open Data Base Connectivity (ODBC).

In general, once the database has been developed, the status of each chemical has to be determined by checking the expiration date. In this research, the alert status was printed out if a chemical was going to expire within a specific number of days (for example, 10 days) to notify the user to take necessary action. In order to send the alert message about nearly-expired chemicals to the user, a calculation of the difference between today's date and expiration date of the chemicals has to be made.

In this research, the chemical inventory system was produced using web-based scripting languages such as JavaScript or PHP Hypertext Preprocessor (PHP) and MySQL database. It is easier to refresh the page automatically using PHP since it works in a web-based environment. The time in the programme is compared to the time and date on the server. The programme for a display running clock in this project was written in PHP.

The following is the process in general. Firstly, a web server such as WAMP (for Windows-based) has to be downloaded. The PC is then upgraded to become a local-host server. In this project, WAMP 2.2.17 was downloaded since it is Windows-based. After that, a programme is written to read or extract data from the access database and to display the information in a table using PHP scripting language; the file name is then saved to index.php and kept in a



folder in the “www.directory”. The “local host” is then clicked and the programme is prompted to go to the Wampserver homepage and open the folder with the saved file name. The result is then displayed.

The third phase of the project is to send the alert message to the storekeeper’s handphone if any chemical is going to expire at a certain time. The system will read the “status” from the database, compare the date and send an alert through the Internet or a wireless connection. Therefore, a GSM Modem has to be linked to the server using ODBC again. A GSM modem provides an interface that allows applications such as send/receive messages over the modem interface. It is a connection that is created to define a connection between a computer and a database stored on another system.

## RESULTS AND DISCUSSION

In this research data of chemicals were taken from one of the laboratories in the Institute of Advanced Technology, namely Advanced Materials and Nanotechnology Laboratory (AMNL1). The chemicals were kept in seven separate shelves or compartments namely A1, A2, B1, B2, C1, C2 and D2 respectively. The chemical containers were made of various types such as plastic, glass and metal and were of different sizes and shapes. The list of all the chemicals involved in this research is shown in Table 2.

TABLE 2: List of Chemicals Tracked in this Research

Tag Id	Name of Chemicals	Location	Tag Id	Name of Chemicals	Location
21	Zinc Oxide 99.7%	A1 AMNL1	53	Nickel Powder 99.8%	B1 AMNL1
22	Zinc Oxide 99.7%(2)	A1 AMNL1	55	Strontium Nitrate	B1 AMNL1
23	Zinc Acetate Dihydrate	A1 AMNL1	56	Silica Gel (Lab Reagent)	B1 AMNL1
27	Zinc Oxide 99.9%	A1 AMNL1	57	Silica Gel (Bendisen)	B1 AMNL1
30	Sodium Hydroxide-Merck	A2 AMNL1	59	Nickel Powder 99.8% (2)	B1 AMNL1
31	Sodium Hydroxide	A2 AMNL1	60	Nickel (II) Oxide 99+%	B1 AMNL1
32	Sodium Hydroxide(2)	A2 AMNL1	61	Zinn(IV)-oxidreinst	C1 AMNL1
34	Nickel Powder 99.5%	B1 AMNL1	62	Nickel(II) Oxide 99.8%	C1 AMNL1
35	Titanium (IV) Oxide	B2 AMNL1	63	Cobalt (II) Chloride	C1 AMNL1
36	Aluminium Nitrate Nanohydrate	B2 AMNL1	64	Polyvinyl Alcohol 98-99%	C1 AMNL1
37	Bismuth (III) Nitrate	B2 AMNL1	65	Poly(vinylidene fluoride)	C1 AMNL1
38	Bismuth (III) Nitrate (2)	B2 AMNL1	66	Citric Acid	C1 AMNL1
39	Potassium Permanganate	B2 AMNL1	67	Glycine	C1 AMNL1
40	Iron (III) Nitrate Nanohydrate 98+	B2 AMNL1	68	Copper (II) Sulfate-5-hydrate	C1 AMNL1

TABLE 2: (Continue)

41	Nickel (II) Nitrate	B2 AMNL1	69	Iron (II,III) Oxide 99.9%	C1 AMNL1
42	Nickel (II) Nitrate (2)	B2 AMNL1	70	Barium Chloride Dihydrate	C1 AMNL1
43	Barium Peroxide 95%	B2 AMNL1	201	Graphite	C2 AMNL1
44	Iron (III) Chloride 6-hydrate	B2 AMNL1	202	Graphite(2)	C2 AMNL1
46	Maleic Acid	B2 AMNL1	203	Graphite(3)	C2 AMNL1
47	Yttrium (III) Oxide	B2 AMNL1	204	Carbon(powder)	C2 AMNL1
48	Zinc Nitrate 6-hydrate (Hmbg)	B2 AMNL1	83	Iron (III) Oxide 99.5% (metal)	D2 AMNL1
49	Zinc Nitrate 6-hydrate (BODI)	B2 AMNL1	84	Strontium Carbonate, 99%	D2 AMNL1
50	Cyclopentanone	B1 AMNL1	85	Bismuth(III) Oxide, 99.90%	D2 AMNL1
51	Copper (II) Nitrate Trihydrate	B1 AMNL1	86	Strontium Acetate	D2 AMNL1
52	Cobalt Powder	B1 AMNL1	87	Calcium Acetate Monohydrate, 98%	D2 AMNL1

### *Chemical Registering and Tracking*

As mentioned before, this system used UHF RFID passive tags. A total number of 50 samples (passive tags) were used and pre-programmed with each chemical's name and location according to the tag number. Each tag was then affixed to the back of each bottle. The bottles were placed on the shelves. Using MUHF H300 UHF Gen2 Mobile Reader, the tags were scanned to check the location of the bottles. The output displayed the missing chemicals, if any.

### *Information System Development*

In this project two methods of developing the information system were considered. The first method was Microsoft Excel Spreadsheet. However, Excel cannot refresh a page on its own; this has to be done by an operator. Therefore, the date and time cannot be compared automatically in real time. To overcome this problem, a scripting language had to be used. JavaScript was chosen at first. In JavaScript, refreshing the page required the use of "meta equiv", and this was not compatible with the display running clock. So a second alternative, HTML, was tested. In this programme, a meta refresh tag or meta redirect tool is used for reloading and redirecting web pages. The meta tag in this programme is found within the <head> of the HTML document. When a page is refreshed, the syntax looks like this:

```
<meta http-equiv="refresh" content="600">
```

where, 'http-equiv="refresh"' is the attribute that informs the browser that this meta tag is sending a HTTP command rather than a standard meta tag. Refresh is an actual HTTP

header used by the web server. It tells the server that the page is going to be reloaded or sent somewhere else whilst ‘content=’600’ is the amount of time in seconds for the browser to reload the current page.

However, Meta refresh tags have some drawbacks. Meta refresh redirects have been used by spammers to fool search engines. So, search engines remove those sites from their database. If a lot of Meta refresh tags are being used to redirect pages, the search engines may decide the site is spam and delete it from their index.

PHP scripting language was chosen for consideration next. In PHP, to refresh a page, the function “header” is chosen. This worked fine with the display running clock.

An example of the programme is shown below:

```
<?php
// this refreshes current page after 5 seconds.
header( "refresh:5;" );
?>
<?php
```

Another problem arose when calculating and comparing two dates. If a direct date feature was used, the output sometimes gave the wrong answer. To overcome this problem, the “strtotime” function had to be used. It is a function that changes “date format” to “string format” for easy subtraction between the two dates. The function “strtotime” will parse about any English textual date time description into a Unix timestamp (the number of seconds since January 1, 1970 00:00:00 GMT). All dates are calculated in milliseconds since that date, with a day containing 86,400,000 milliseconds. An example of the programme using “strtotime” is shown below:

```
$today = strtotime($today_date);
$expiration_date = strtotime($exp_date);
if ($expiration_date > $today) {
    $valid = "yes";
} else {
    $valid = "no";
}
```

During this phase, a complete information system or database should be fully developed. The output will result in easy inventory checking as well as producing an inventory report.

### *Development of Alert Notification Message via SMS*

The final phase of the project was to send the alert notification notice via SMS to the person in charge for necessary action to be taken. A programme was written in Javascript, PHP and MySQL to print the header, current date and time at the top of the output display. This enabled

it to read the data from the Access file and to print out the output in a new table form. Date comparison between the current date and the expiration date was done to print out the “status” of each chemical. If the status was “alert”, it would read the phone number of the person in charge and send the SMS accordingly. The flowchart of the programme and the system interface are shown in Fig.5 and Fig.6 respectively.

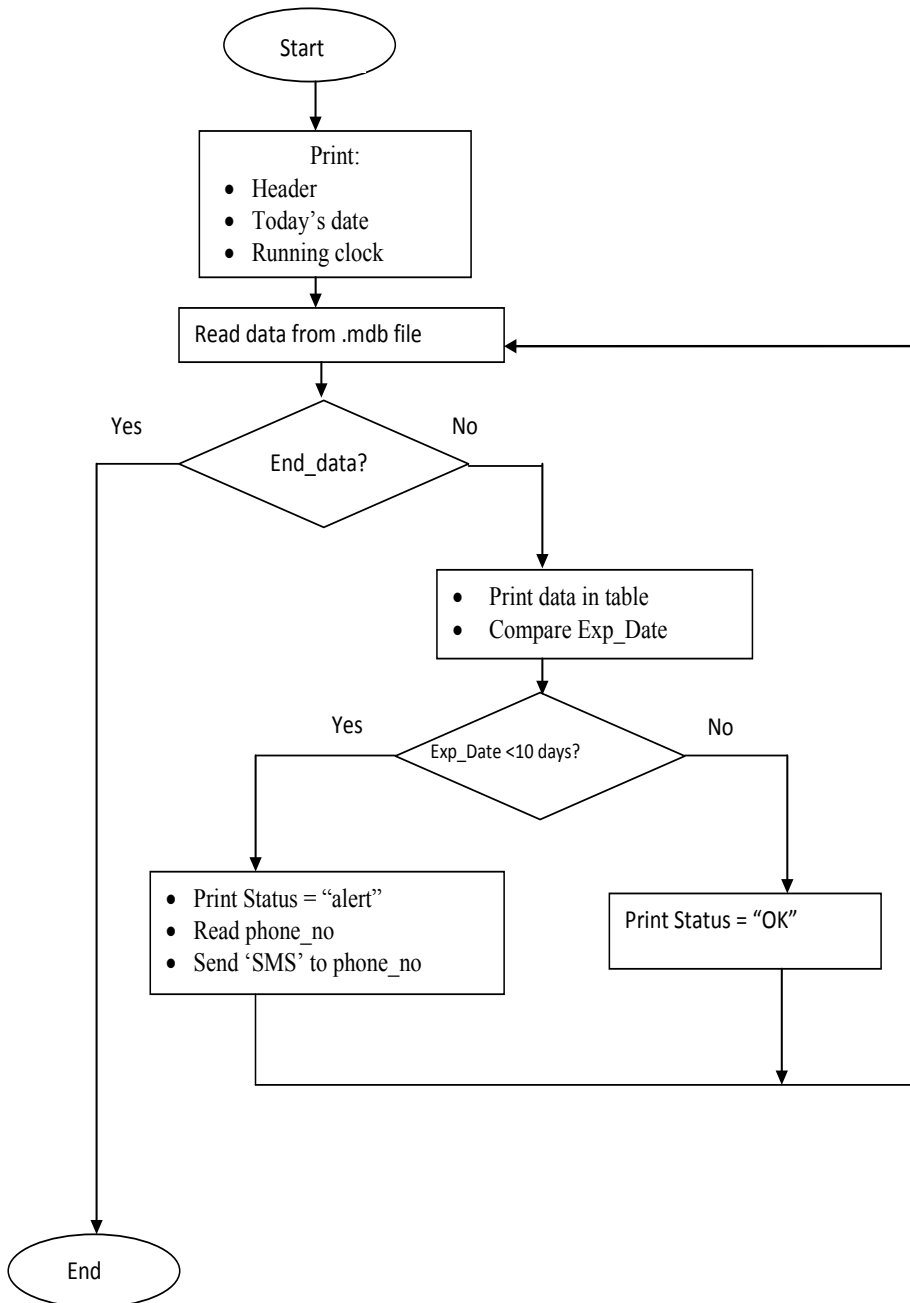


Fig.5: Flowchart of the Programme

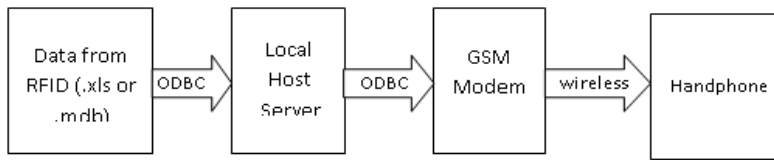


Fig.6: System Interface

The basic programme for sending SMS messages as shown below was suggested by MOBITEK System Sdn. Bhd. (2007):

```

<?php

//establish connection to Access database via ODBC
$conn = odbc_connect('SMSEngine3','','');
if (!$conn)
    {exit("Connection Failed: " . $conn);}

//queue outgoing SMS into Outbox table
$sql="INSERT INTO Outbox (Message, Mobile,
DateTimeQueue, SentStatus) VALUES
('$ _POST[Message]','$ _POST[Mobile]',date(),'P')";
$rs=odbc_exec($conn, $sql);

echo "Your message - " . " " . $ _REQUEST["Message"] . " " .
" " to this phone number - " . " " . $ _REQUEST["Mobile"] . " " .
"is being queued. It will be send out in a moment.";
//close connection to database
odbc_close($conn);
?>
  
```

With the many drawbacks taken care of, the example output of the information system is shown in Fig. 7, whilst Fig. 8 shows an example of outgoing SMS messages sent to the respective person in charge.

## CONCLUSION

In this project, an information system for chemical tracking was developed using UHF Radio Frequency Identification (RFID) technology application. UHF was chosen because it provides a longer read range (up to one hundred metre) compared to HF technology, which is normally used by several companies. The information system that was developed interfaced with the exported RFID data for chemical tracking as well as for providing expiration date alert notifications. In the last phase, the remote-based alert system was developed through a wireless connection to send alert notifications to the respective persons-in-charge.

INSTITUT TEKNOLOGI MAJU

Chemical Storage Management System

17:38:01

Wed Jan 11 2012 17:37:35 GMT+0800 (Malay Peninsula Standard Time)

Today's date is 2012-01-11

ChemId	ChemicalName	Chemical Expiry Date	Telephone Number	Chemical Location	Chemical Status
71	Manganous Sulfate Monohydrate powder (4)	2012-02-01 00:00:00	0192335363	B1 AMNL1	OKI
72	Manganous Sulfate Monohydrate powder (3)	2012-01-20 00:00:00	0192335363	B1 AMNL1	Alert!
73	Manganous Sulfate Monohydrate powder (2)	2012-10-16 00:00:00	0192335363	B1 AMNL1	OKI
74	Calcium Sulfate Hemihydrate(4)	2012-01-15 00:00:00	0192335363	B1 AMNL1	Alert!
75	Calcium Sulfate Hemihydrate(3)	2012-06-25 00:00:00	0192335363	B1 AMNL1	OKI
76	Calcium Sulfate Hemihydrate (2)	2012-04-15 00:00:00	0192335363	B1 AMNL1	OKI
77	Manganous Sulfate Monohydrate powder	2012-02-15 00:00:00	0192335363	B1 AMNL1	OKI
78	Calcium Sulfate Hemihydrate	2012-05-30 00:00:00	0192335363	B1 AMNL1	OKI
79	Molecular Sieve UOP type 13x	2012-02-15 00:00:00	0192335363	B1 AMNL1	OKI
80	Magnesium Hydroxide xtra pure	2012-10-31 00:00:00	0192335363	B1 AMNL1	OKI
93	Sodium Sulfate Anhydrous	2012-12-01 00:00:00	0192335363	B2 AMNL1	OKI
94	Sodium Nitrate	2012-01-31 00:00:00	0192335363	B2 AMNL1	OKI
95	Sodium Nitrate	2012-02-15 00:00:00	0192335363	B2 AMNL1	OKI
96	Aluminium Nitrate Nanohydrate	2011-12-31 00:00:00	0192335363	B2 AMNL1	Alert!
97	Aluminium Nitrate 9-Hydrate	2012-02-20 00:00:00	0192335363	B2 AMNL1	OKI
98	Magnesium Nitrate 6-Hydrate	2012-03-31 00:00:00	0192335363	B2 AMNL1	OKI

Fig.7: Database Developed Using PHP Scripting Language

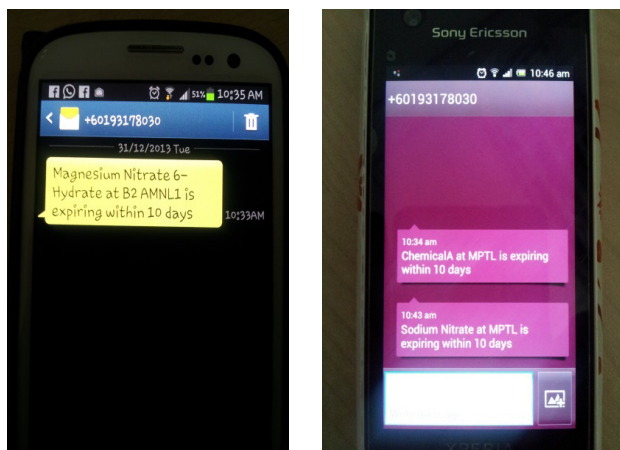


Fig.8: Alert Message Sent to the Person in Charge via SMS

As discussed previously, when using RFID technology, the tracking of chemicals in a lab becomes easy and the time taken to perform the inventory process is shortened as an RFID reader can retrieve all data stored in a programme simultaneously at the same time. No PPE and direct contact are required between the operator and the chemicals. The results of this project may help lab storekeepers to manage their chemical inventory in a proper and simplified way.

The system that was developed in this study is user-friendly. It can be used for tracking and monitoring chemicals as well. For instance, the data for expiration date from the database will be used for automated checking of nearly-expired chemicals. A wireless system was developed to trigger alert notifications to the storekeeper that certain chemicals were approaching their expiration dates. Thus, necessary remedial actions could be taken by the storekeeper to avoid unforeseen accidents. As has been explained above, using a web-server scripting language gives better results than using a spreadsheet method for date comparison as the expiration date can be easily calculated and compared to the server time, which is always running. The designed remote-based triggering system alerts and notifies the storekeeper if a chemical is approaching its expiration date. The message can be sent at any time (even after office hours or on public holidays) through Short Message System (SMS) to the handphone or any mobile device of the storekeeper.

For future work, the proposed system in this research can be applied in any other asset tracking besides chemicals.

## ACKNOWLEDGEMENTS

This paper presents a part of the research performed in the project “Development of a Chemical Storage Management System” supported by Universiti Putra Malaysia under the Research University Grant Scheme (RUGS) funding (05-01-09-0640RU). The authors are grateful for the support.

## REFERENCES

- Angeles, R. (2005). RFID Technologies: Supply-Chain Applications and Implementation Issues, *Information Systems Management*, (winter), 51-64.
- Chien, H. Y. & Chen, C. H. (2007). Mutual Authentication protocol for RFID Conforming to EPC Class 1 Generation 2 Standards, *Computer Standards and Interfaces*, 29, 254-259.
- Dickman, P., McSorley, G., Liddell, J., Glen, J., & Green, J. (2007). The Design and Development of an RFID-enabled Asset Tracking System for Challenging Environments, *International Journal of Internet Protocol Technology*, 2(3/4), 232-239.
- Domdouzis, K., Kumar, B. & Anumba, C. (2007). Radio Frequency Identifications Applications: A Brief Introduction, *Advanced Engineering Informatics*, 21, 350-355.
- Fletcher R. (2010). Near field UHF versus HF, *Energy Harvesting & Storage*. Boston: USA. pp.16-17.
- Foster, B. L. (2005). The Chemical Inventory Management System in academia, *Chemical Health and Safety*, 12, 21-25.
- Gibbs, L. M. (2005). ChemTracker Consortium – The Higher Education Collaboration for Chemical Inventory Management and Regulatory Reporting, *Chemical Health and Safety*, 12, 9-14.



- Gillespie H. (2006). *ChemSW launches RFID with CISProMobile for faster, more flexible inventory management, Fairfield, California*. Tech. Rep. news release, Jan 6, 2006.
- Grout, I., Murphy, C., & Da Silva, A. C. R. (2012). Remote laboratory experiment access via an RFID interface”, *2012 9th International Conference on Remote Engineering and Virtual Instrumentation, REV 2012*, Article number 6293103, Bilbao. Spain; 4-6 June 2012.
- Ismail, S. (2013). Improving information dissemination and collective data directory for focus group via web based system and SMS. *Proceedings Of The 7th International Conference On Ubiquitous Information Management And Communication, ICUIMC 2013* (2013-01-01) ISBN: 9781-450319584.
- Kelly, D. A. (2005). Turning in to RFID, *Oracle Magazine*, May/June 2005.
- Kraus, J. (2005). World-class compliance that doesn't cost a fortune, *Chem. Eng.*, 112, 50-54.
- MOBITEK System Sdn. Bhd. (2007). SMS Engine Basic Edition version 5.2.3, *Manual for System Integrator and Software Developer*.
- Potyrailo R. A., Mouquin H., & Morris W. G. (2008). Position-Independent Chemical Quantitation With Passive 13.56-MHz Radio Frequency Identification (RFID) Sensors, *Talanta*, 5/15, 75, 624-628.
- Quigley, D., Freshwater, D., Alnajjar, M., Siegel, D., Kuntamukkula, M. and Simmons, F.(2012), Use of chemical information database accuracy measurements as leading indicators, *Journal of Chemical Health and Safety*, 19(3), 18-22.
- Roberti M., (2006). The Great RFID Debate: HF or UHF? *RFID Journal*, released 06/30/2012.
- Roberts, C. M. (2006). Radio Frequency Identification (RFID), *Computers & Security*, 25, 18-26.
- Rooney, T. A. (2001). Chemical Inventory Tracking, *Computers in Chemistry*, 10, 15-19.
- Stanczak, M., (2007). The ABCs of RFID, *Discovery Guides*, ProQuest.
- Steinberg, I. M. & Steinberg, M. D. (2009). Radio-frequency Tag with Optoelectronic Interface for Distributed Wireless Chemical and Biological Sensor Applications, *Sensor and Actuators B: Chemical*, 138, 120-125.
- Technical Group (2010). RFID Based Chemical Bottle Tracking at PAR Pharma's KALI Laboratories Campus, NJ, USA, *ICEGEIN*, 2010, 1-5.
- Vijayan, J. (2005). Hosted Services Tapped to Manage Data on Chemicals, *Computer World – Business Intelligence*.
- Wang, X., Liu, J., Liu, S. & Gao, L. (2008). Design and Realization of Intelligent Monitoring System Based Object Identification, *Proceeding of the World Congress on Intelligent Control and Automation 2008*.
- Williams, K., (2013). Eight tips to get a grip on your chemical inventory, *Occupational Health and Safety*, Issue MAY, May 2013.

## Modelling of Carbon Dioxide Absorption into Aqueous Ammonia Solution in a Wetted Wall Column

Ujjal Kumar Ghosh<sup>1\*</sup>, Chiu Choon Hong<sup>1</sup>, Jobrun Nandong<sup>1</sup> and Shufeng Shen<sup>2</sup>

<sup>1</sup>Department of Chemical Engineering, School of Engineering & Science, Curtin University CDT 250, 98009 Miri, Sarawak, Malaysia

<sup>2</sup>School of Chemical and Pharmaceutical Engineering, Hebei University of Science and Technology, No.70, Yuhua East Road, Shijiazhuang, China 050018

### ABSTRACT

In this paper, a mathematical model is developed based on mass and momentum balance for carbon dioxide absorption into aqueous ammonia solution. The model is simplified based on the assumption that the CO<sub>2</sub> absorption into aqueous ammonia is a pseudo-first-order reaction. Laplace transform method is applied in order to solve the partial differential model equation. Finally, the CO<sub>2</sub> molar flux is expressed as a function of partial pressure of CO<sub>2</sub>, concentration of aqueous ammonia, temperature and gas-liquid contact area. Variation of CO<sub>2</sub> molar flux with partial pressure of CO<sub>2</sub> and temperature is discussed and a comparison is performed with experimental data from literature. Variation of CO<sub>2</sub> molar flux is also shown with gas-liquid contact area. The calculated flux from the model follows the same trend as that of the experimental data reported in literature and the accuracy is within the accepted limit. The mathematical model is very helpful to predict the CO<sub>2</sub> molar flux as a function of partial pressure of CO<sub>2</sub>, concentration of aqueous ammonia, temperature and gas-liquid contact area.

*Keywords:* Carbon dioxide capture, absorption, aqueous ammonia, modelling, wetted wall column.

### INTRODUCTION

Global warming is one of the most serious environmental problems in this century (IPCC, 2005). It is generally accepted that the issue is closely related to the anthropogenic carbon dioxide (CO<sub>2</sub>)

emission activities, mainly the combustion of the fossil fuels and chemical transformation. Due to their low cost, availability, existing reliable technology for energy production and energy density, fossil fuels currently supply over 85% of the energy needs of the United States and a similar percentage of the energy

#### Article history:

Received: 14 October 2013

Accepted: 16 October 2013

#### E-mail addresses:

ujjalche@gmail.com, ughosh@qu.edu.qa (Ujjal Kumar Ghosh)

choonhong\_88@live.com (Chiu Choon Hong)

jobrun.n@curtin.edu.my (Jobrun Nandong)

shufengshen@gmail.com (Shufeng Shen)

\*Corresponding Author

used worldwide (EIA, 2006a, b). Six billion tonnes of CO<sub>2</sub> emission are produced by fossil fuel combustion, while 1.8 billion tonnes of the total are from power plant generation (Diao *et al.*, 2004). At present, power plants are one of the biggest discharge points of CO<sub>2</sub> into the atmosphere, whereby the amounts of boiler flue gases are as large as 10 million m<sup>3</sup> hourly (Suda *et al.*, 1997). The reduction of CO<sub>2</sub> emission from large industrial point sources such as the power stations and iron- and steel-making plants is considered to be one of the highest priorities by both industry and the lay public. In general, various technologies have been applied to separate CO<sub>2</sub> from the flue gas of conventional fossil fuel fired power plants. These technologies are membrane separation, physical adsorption, chemical absorption, cryogenic methods and biological fixation (Kohl, & Nielsen, 1997; Smith *et al.*, 2009; Suda *et al.*, 1997). Chemical absorption is the widely applied technology to capture CO<sub>2</sub> from the power plant flue gases (Suda *et al.*, 1997; Shen *et al.*, 2013). Aqueous alkanolamine solutions are frequently used for the removal of CO<sub>2</sub> from power plants. The current state-of-the-art technology for CO<sub>2</sub> removal from flue gases is considered to be 30 wt% aqueous solution of monoethanolamine (MEA) (Ghosh *et al.*, 2009). While amine solution is widely used for CO<sub>2</sub> capture process, it has some drawbacks such as (a) low CO<sub>2</sub> absorption capacity; (b) easier degradation in the presence of acid gases and oxygen; (c) high energy requirement for regeneration, and (d) corrosive nature (Diao *et al.*, 2004; Yeh *et al.*, 2005). Therefore, it is necessary to develop alternative solvents with higher absorptive capacity and lower reaction energy demands for regeneration.

One of the alternatives is the ammonia solution that provides the advantages of higher CO<sub>2</sub> absorption capacity, no absorbent degradation, as well as low regeneration energy requirement and lower temperature operation (0-10°C, 273-283K) (Yeh & Bai, 1999; Darde *et al.*, 2009; Diao *et al.*, 2004; Kim *et al.*, 2008, 2009; Yeh *et al.*, 2005). It allows for precipitation of ammonium carbonate compounds and thereby high carbon dioxide loadings in the slurry. Ammonium salt will be formed due to the presence of sulphur and nitrogen oxide. This salt carries a commercial value as fertilizer (Puxty *et al.*, 2010). The vaporization of ammonia during the absorption is limited by low absorption temperature. Thermodynamic and equilibrium based studies have shown the potential of ammonia technology, especially the potential for a low heat requirement in the carbon dioxide desorber and for desorption at elevated pressure that allows for power savings in the subsequent compression of CO<sub>2</sub> (Darde *et al.*, 2010). Dave and co-workers (2009) performed an economic assessment on CO<sub>2</sub> capture using aqueous ammonia. The study showed that under operating condition of ammonia concentration less than 5 wt%, temperature less than 10°C and no precipitation of ammonium bicarbonate, aqueous ammonia based CO<sub>2</sub> capture solvent has overall energy requirement comparable to the conventional 30 wt% aqueous MEA based process. Concentration of aqueous ammonia is significant to the system. Liu and co-workers (2009) concluded that the optimum concentration should be in between of 5% to 10% during the experiment at 20°C and 40°C. This range is yielded after the consideration of 90% removal and occurrence of volatilization. Darde and co-workers (2009) had earlier conducted the chilled ammonia process for CO<sub>2</sub> capturing where the operating temperature was between of 2°C to 10°C, whereas Zeng and co-workers (2011) suggested 35°C to 40°C as suitable for column and reactor. A similar experiment of CO<sub>2</sub> absorption was also conducted by Feng and co-workers (2010), whereby the operating temperature ranged from 15°C to 48°C.

Detailed kinetic data are required for the optimal design in terms of gas-liquid contact area and operation of an absorber. The kinetic data are therefore strongly related to the size of the absorber and thereby to the capital costs for capturing carbon dioxide using ammonia. The rate of reaction in a spray tower was given by Diao and co-workers (2004) for temperatures from 28 to 43°C. Puxty and co-workers (2010) presented their latest kinetics results for a reaction in a wetted wall column reactor at temperatures from 5 to 20°C. The zwitterions mechanism was applied to CO<sub>2</sub> absorption in ammonia solution in a stirred cell reactor from 5 to 25°C by Derks and Versteeg (2009). Feng and co-workers (2010) applied the termolecular and zwitterions mechanisms to characterize the kinetics and mechanisms of the absorption of CO<sub>2</sub> in aqueous ammonia solutions having different concentrations and different temperatures, which were determined using a string of discs contactor. In the previous communication, the authors had developed a mathematical model based on mass balance for the carbon dioxide absorption into aqueous ammonia (Ghosh & Yee, 2013). In this paper, a mathematical model was developed based on mass and momentum balance for CO<sub>2</sub> absorption into aqueous ammonia in a wetted wall column. The model was simplified based on the assumption that the CO<sub>2</sub> absorption into aqueous ammonia is a pseudo-first-order reaction. Laplace transform method was applied to solve the partial differential model equation. Finally, the CO<sub>2</sub> molar flux was expressed as a function of partial pressure of CO<sub>2</sub>, concentration of aqueous ammonia, temperature and gas-liquid contact area. Variation of CO<sub>2</sub> molar flux with partial pressure of CO<sub>2</sub> and temperature is discussed and a comparison is performed with experimental data from literature. Variation of CO<sub>2</sub> molar flux is also shown with gas-liquid contact area.

## WETTED WALL COLUMN

Generally, absorption of carbon dioxide occurs through mass transfer is accompanied by chemical reaction mechanism when a gas mixture consisting of CO<sub>2</sub> is brought into direct contact with the chemical solvent. This paper focuses on the removal of carbon dioxide from inlet gas by aqueous solution of ammonia in a falling film in a wetted wall column as shown in Fig.1. This column has been widely used in theoretical studies of mass transfer rates of components and in analytical distillation.

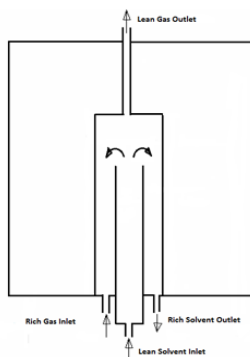
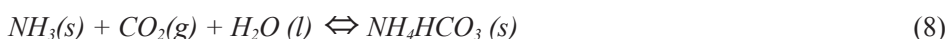
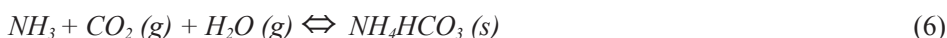
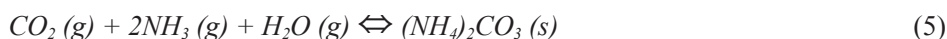
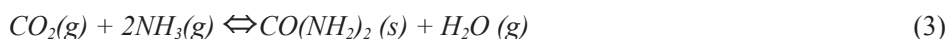
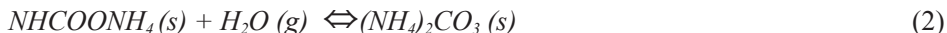


Fig.1: A schematic view of a wetted wall column

In experimental studies which carried out by other researchers, gas mixture was constantly and proportionally injected into the absorber from the bottom and flown upwards. The gas mixture refers to flue gas from typical coal fired power plant. A typical flue gas composition is (in mole %): N<sub>2</sub>, 74; H<sub>2</sub>O, 7; CO<sub>2</sub>, 13.8; O<sub>2</sub>, 3.5; CO, 0.2; NO, 0.4; SO<sub>2</sub>, 0.07 at 300°C and 1 atm (Strube *et al.*, 2011). The rich gas is contacted with the lean solvent that is falling down from the middle tube. This is the core of the process where the mass transfer and chemical reaction takes place. A fluid layer can be determined whilst the lean solvent is overflowed. This fluid layer plays important role as to enlarge contact surface area and extent of gas penetrate into liquid. In addition, there are numerous factors contributing to the efficiency of the absorption which will be later defined. Generally, the column is rigidly supported to be free from external vibration and is made truly vertical. The liquid flow is merely subjected to gravity force. The surface of the wetted wall column is often cleaned chemically to avoid the possibility of the occurrence of liquid channelling on the tube wall that will later result in the wetting properties. This system is always wrapped up by a temperature protection layer in order to make sure there is neither heat lost nor heat gain by surrounding factors.

## CHEMICAL REACTIONS

According to Liu and co-workers (2009), numerous chemical reactions happen in a wetted wall column. The possible reactions are summarized below:



These reactions in CO<sub>2</sub>-NH<sub>3</sub>-H<sub>2</sub>O system are also in agreement with the findings of other researchers (e.g., Strube *et al.*, 2011; Puxty *et al.*, 2010; Diao *et al.*, 2004).

To simplify the set of reactions, the total reaction of CO<sub>2</sub> absorption into aqueous ammonia can be represented by Eq. (1) (Liu *et al.*, 2011). Puxty and co-workers (2010) also suggested that the direct reaction between CO<sub>2</sub> and ammonia is immediate and significant. Based on Eq. (1), both the forward and reverse reactions may be considered as first order with respect to each species.

As the concentration of ammonia doesn't change considerably during the course of reaction with CO<sub>2</sub> the reaction can be considered pseudo-first-order irreversible reaction Qin *et al.* (2010). Puxty and co-workers (2010) have agreed that the reaction is pseudo-first-order irreversible reaction based on the surface renewal principles that the concentration of ammonia is not depleted across the liquid film.

## MATHEMATICAL MODEL DEVELOPMENT

### Model Assumptions

A mathematical model is developed based on mass, energy, and momentum balances. The following are model assumptions:

- One-dimensional diffusion;
- Tube surface is smooth and cleaned chemically. Wetted wall column stands vertically. Therefore, no liquid channelling occurs on tube surface;
- Replenished liquid surface with enough diluted aqueous ammonia solution that allow complete reaction with CO<sub>2</sub>;
- Pseudo-first-order reaction of the system;
- Only CO<sub>2</sub> from the flue gas is diffused into liquid layer and reacted with aqueous ammonia solution;
- Constant properties of CO<sub>2</sub>.

### Mathematical Model Derivation

A mathematical model begins from the component molar balance with subscript A representing CO<sub>2</sub>.

$$-\frac{\Delta m_A}{M_A} - R_A \Delta x \Delta y \Delta z = \frac{\delta C_A}{\delta t} \Delta x \Delta y \Delta z \quad (9)$$

Where,  $\Delta x \Delta y \Delta z$  represents the axis volume (m<sup>3</sup>),  $m_A$  is mass rate of carbon dioxide (kg s<sup>-1</sup>),  $M_A$  is the molecular weight of carbon dioxide (g mol<sup>-1</sup>), reaction rate of carbon dioxide,  $-R_A$  has unit mol m<sup>-3</sup>s<sup>-1</sup>,  $C_A$  is the concentration of carbon dioxide (mol m<sup>-3</sup>), and the difference

between molar inlet rate and molar outlet rate of system,  $-\frac{\Delta m_A}{M_A}$  is shown as:

$$\begin{aligned} -\frac{\Delta m_A}{M_A} = & \left[ v_x C_A - D_A \frac{\delta C_A}{\delta x} \right]_x - \left( v_x C_A - D_A \frac{\delta C_A}{\delta x} \right)_{x+\Delta x} \Delta y \Delta z \\ & + \left[ v_y C_A - D_A \frac{\delta C_A}{\delta y} \right]_y - \left( v_y C_A - D_A \frac{\delta C_A}{\delta y} \right)_{y+\Delta y} \Delta x \Delta z \\ & + \left[ v_z C_A - D_A \frac{\delta C_A}{\delta z} \right]_z - \left( v_z C_A - D_A \frac{\delta C_A}{\delta z} \right)_{z+\Delta z} \Delta y \Delta x \end{aligned} \quad (10)$$

Substituting Eq. (10) into Eq. (9) and dividing by  $\Delta x \Delta y \Delta z$ :

$$\frac{\delta C_A}{\delta t} = -\left( \frac{\delta v_x C_A}{\delta x} + \frac{\delta v_y C_A}{\delta y} + \frac{\delta v_z C_A}{\delta z} \right) + D_A \left( \frac{\delta^2 C_A}{\delta x^2} + \frac{\delta^2 C_A}{\delta y^2} + \frac{\delta^2 C_A}{\delta z^2} \right) + R_A \quad (11)$$

Assume constant density due to the insignificant pressure changes.

$$\frac{\delta C_A}{\delta t} = -(v_x \frac{\delta C_A}{\delta x} + v_y \frac{\delta C_A}{\delta y} + v_z \frac{\delta C_A}{\delta z}) + D_A (\frac{\delta^2 C_A}{\delta x^2} + \frac{\delta^2 C_A}{\delta y^2} + \frac{\delta^2 C_A}{\delta z^2}) + R_A \quad (12)$$

CO<sub>2</sub> absorption into aqueous ammonia in a falling film can be considered as mass transfer in stagnant element. Besides, this model is only interested in 1 dimension, i.e., no dispersion is assumed.

$$\frac{\delta C_A}{\delta t} = D_A \frac{\delta^2 C_A}{\delta x^2} + R_A \quad (13)$$

The boundary conditions are shown below:

When  $x = 0, t > 0; C_A = C_{Ai}$ ;

When  $x > 0, t = 0; C_A = 0$ ;

When  $x = \alpha, t > 0; C_A = 0$ . (14)

The first condition in Eq. (14) shows that CO<sub>2</sub> is contacted with liquid after certain time. This occurs at the vapour-liquid interface. Therefore, the concentration of CO<sub>2</sub> is expressed as C<sub>Ai</sub>. While CO<sub>2</sub> diffuses into liquid layer, which is beyond the liquid-vapour interface, it will react immediately with the solvent. Consequently, it approaches to zero CO<sub>2</sub> after an extent of thickness. Third condition discusses no solute is found in infinite liquid layer on account to significant reduce of CO<sub>2</sub> concentration in liquid film. This shows that solvents must be sufficient and able to react continuously. A concentration profile of CO<sub>2</sub> is drawn and shown in Fig.2 below.

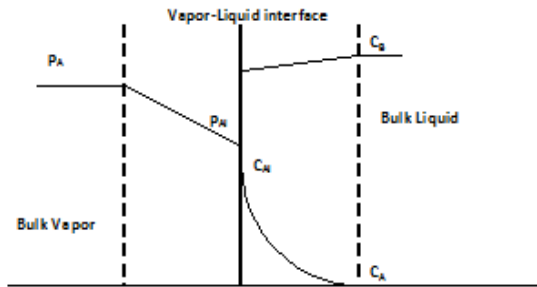


Fig.2: A concentration profile of carbon dioxide

As the enough solvent is assumed based on replenish principle, a pseudo-first-order reaction can be achieved. This has also been explained by Levenspiel (1999). If another reactant remains approximately constant at all times, the second order reaction will approach pseudo first-order reaction. Therefore, Eq. (13) can be re-written as:

$$\frac{\delta C_A}{\delta t} = D_A \frac{\delta^2 C_A}{\delta x^2} - k_1 C_A \quad (15)$$



This equation is difficult to be solved. Therefore, Laplace Transform is performed and after the re-arrangement,

$$\frac{d^2 C_A(s)}{dx^2} - \frac{(k_1 + s)}{D_A} C_A(s) = 0 \quad (16)$$

Integral of Eq. (16) gives

$$C_A(s) = A_1 e^{\sqrt{\frac{(s+k_1)}{D_A}} x} + A_2 e^{-\sqrt{\frac{(s+k_1)}{D_A}} x} \quad (17)$$

With the defined boundary conditions in Eq. (14), it can be simplified into:

$$C_A(s) = \frac{C_{\#}}{s} e^{-\sqrt{\frac{(s+k_1)}{D_A}} x} \quad (18)$$

Inverse Laplace Transform is performed to Eq. (18) in order to return to t-domain:

$$C_A = \frac{C_{\#}}{2} e^{-\sqrt{\frac{k_1}{D_A}} x} \operatorname{erfc}\left(\frac{x}{2\sqrt{D_A t}} - \sqrt{k_1 t}\right) + \frac{C_{\#}}{2} e^{\sqrt{\frac{k_1}{D_A}} x} \operatorname{erfc}\left(\frac{x}{2\sqrt{D_A t}} + \sqrt{k_1 t}\right) \quad (19)$$

The flux of A at the interface at any time is obtained by differentiating Eq. (19), which is also indicated as Fick's law (Froment & Bischoff, 1979).

$$N_A(t) = C_{\#} \sqrt{k_1 D_A} \left( \operatorname{erf}(\sqrt{k_1 t}) + \frac{e^{-k_1 t}}{\sqrt{\pi k_1 t}} \right) \quad (20)$$

On the account of vertical wetted wall column position, smooth liquid flow is assumed. Hence, Higbie's uniform age is applied for the average rate of absorption at contact surface (Froment & Bischoff, 1979).

$$N_A = \sqrt{D_A (k_1 + s)} C_{\#} \quad (21)$$

The parameter,  $s$ , can be either related to the transfer coefficient or diffusivity (Froment & Bischoff, 1979). Since  $\text{CO}_2$  is in gas phase, it is more proper to express in term of partial pressure. Therefore, Henry law is suggested.

$$C_{\#} = \frac{p_A}{H_A} \quad (22)$$

$H_A$  refers to Henry constant of  $\text{CO}_2$  at specific temperature ( $\text{mol Pa m}^{-3}$ ) and  $p_A$  is the partial pressure of  $\text{CO}_2$  (Pa). Substituting Eq. (22) back into Eq. (21) will give:

$$N_A = \sqrt{D_A k_1} \frac{p_A}{H_A} \quad (23)$$

This expression shows the relationship between the partial pressure and the CO<sub>2</sub> molar flux. The account of the equation shown above is based on the scenario of single pseudo-first-order reaction, thus, a modification of the equation regards on the real situation is necessary. Consequently, the concentration of aqueous ammonia (mol m<sup>-3</sup>) is included in Eq. (24):

$$N_A = \sqrt{D_A k_1} [\text{NH}_3] \frac{P_A}{H_A} \quad (24)$$

Also, the objective of this paper is to investigate the effect of temperature to CO<sub>2</sub> removal where diffusivity, Henry constant and kinetics are the function of temperature. These functions are also highlighted in other research (see Puxty *et al.*, 2010; Qin *et al.*, 2010; Cullinane & Rochelle, 2004).

$$D_{\text{CO}_2\text{-H}_2\text{O}} = 2.35 \times 10^{-6} e^{-\frac{2199}{T}} \quad (25)$$

$$H_{\text{CO}_2\text{-H}_2\text{O}} = 2.82 \times 10^{-6} e^{-\frac{2044}{T}} \quad (26)$$

$$k = k_{\text{ref}} e^{-\frac{E}{R} \left( \frac{1}{T} - \frac{1}{T_o} \right)} \quad (27)$$

Eq. (25) and Eq. (26) are established based on the relation between water and CO<sub>2</sub> by experimental constant. Although there are theoretical methods for estimating the diffusivity of the interested system, these equations are still acceptable since the diluted aqueous ammonia solution mainly consists of water. The reference kinetic,  $k_{\text{ref}}$  is 0.915 m<sup>3</sup> mol<sup>-1</sup>s<sup>-1</sup>, reference temperature,  $T_o$ , at 283K, activation energy,  $E$  is 61 kJ mol<sup>-1</sup> and  $R$ , gas constant, 8.314 J mol<sup>-1</sup> K<sup>-1</sup> (Puxty *et al.*, 2010; Qin *et al.*, 2010). Lastly, by summarizing all the equations, it can be shortened as follow:

$$N_A = 0.22 \times 10^{-3} \sqrt{[\text{NH}_3]} P_A e^{-\frac{6822}{T}} \quad (28)$$

The molar flux of carbon dioxide can be also expressed as in molar rate,  $J_A$  (mol s<sup>-1</sup>) over a contact area,  $A_c$  (m<sup>2</sup>).

$$N_A = \frac{J_A}{A_C} \quad (29)$$

The contact area of vapour liquid can be defined as in Fig.1. It consists of semi-sphere at the pipe end side and the surrounding of the tubes. The equation is expressed in term of tube radius,  $r$  (m) and the tube height,  $h$  (m).

$$A_C = 2\pi r(r + h) \quad (30)$$

Height of the column is crucial after considering a real unit apply in a CO<sub>2</sub> captured power plant. This is because of the cost and investment into this project depends on column height and chemical solvents. Based on the rules of thumb, the ratio of height to diameter of a column should not exceed a certain designed figure due to safety purposes (Kister, 1992). Combining Eq. (30) into the previous equation, CO<sub>2</sub> molar rate can be expressed as below.

$$J_A = 0.22 \times 10^{-3} \sqrt{[NH_3]} P_A e^{\frac{6822}{T}} 2\pi r(r+h) \quad (31)$$

On the other hand, pipe diameter is relatively small compared to the height of the column, while the term for the semi-sphere can be ignored.

$$J_A = 0.22 \times 10^{-3} \sqrt{[NH_3]} P_A e^{\frac{6822}{T}} 2\pi rh \quad (32)$$

In general, it is crucial and essential to perform model checking on the account of validating the reliability of developed model. Moreover, a reliable model can assist on future work, especially on the predicting the influences and outcomes of alternating parameter via the investigation of the trend. The objectives of this paper are to study the effects of partial pressure and temperature to the CO<sub>2</sub> molar flux. Thus, model verification is based on the two parameters that are further discussed in the following subsection.

## RESULTS AND DISCUSSION

### *Effects of Partial Pressure*

Some previous investigators had worked on the kinetic of CO<sub>2</sub> absorption into aqueous ammonia experimentally under various conditions. These results are referred in this paper to determine the reliability of the developed mathematical model. Liu and co-workers (2009) conducted experiments which were conducted twice at different temperatures, 293K and 313K, respectively. According to Eq. (25) – Eq. (27), diffusivity, Henry constant and kinetic rate constant have been calculated at different temperatures. The findings are listed in Table 1.

TABLE 1: Parameters at different temperature

Parameter	Temperature (K)	
	293	313
D <sub>co2</sub> (m <sup>2</sup> s <sup>-1</sup> )	1.3 x 10 <sup>-9</sup>	2.1 x 10 <sup>-9</sup>
H <sub>co2</sub> (Pa m <sup>3</sup> mol <sup>-1</sup> )	2633.68	4112.95
k (m <sup>3</sup> mol <sup>-1</sup> s <sup>-1</sup> )	2.217	10.980

Two sets of CO<sub>2</sub> molar flux,  $N_{CO_2,model,inlet}$  and  $N_{CO_2,model,lm}$  based on the inlet partial pressure and log mean partial pressure, respectively, were calculated from the model using aqueous ammonia concentration of 10 vol% and reported in Table 2. The molar carbon dioxide flux from the model is plotted as a function of CO<sub>2</sub> partial pressure at the temperatures 293K and 313K and reported in Fig.3 and Fig.4, respectively. The literature data (Liu *et al.*, 2009) are also included in Fig.3 and Fig.4. It can be seen from both Fig.3 and Fig.4 that the molar flux of CO<sub>2</sub> increases as the partial pressure of CO<sub>2</sub> increases. The calculated flux from the model follows the same trend as that of the experimental data.

TABLE 2: CO<sub>2</sub> molar flux at different partial pressures

Temp (K)	P <sub>CO<sub>2</sub>,in</sub> (Pa)	P <sub>CO<sub>2</sub>,out</sub> (Pa)	P <sub>CO<sub>2</sub>,lm</sub> (Pa)	N <sub>CO<sub>2</sub></sub> , literature (mol m <sup>-2</sup> s <sup>-1</sup> )	N <sub>CO<sub>2</sub></sub> , model, inlet (mol m <sup>-2</sup> s <sup>-1</sup> )	N <sub>CO<sub>2</sub></sub> , model, lm (mol m <sup>-2</sup> s <sup>-1</sup> )	Ratio of literature data over model
293	7840	6580	7191.6	0.008	0.015	0.014	0.56
	16640	14120	15345.5	0.015	0.031	0.029	0.52
	23390	20170	21740.3	0.021	0.044	0.041	0.52
	31840	27040	29374.7	0.032	0.060	0.055	0.59
313	7740	5840	6745.5	0.012	0.025	0.022	0.54
	15400	11930	13591.3	0.022	0.050	0.044	0.51
	22830	18270	20465.4	0.031	0.074	0.066	0.46
	31310	24800	27928.7	0.045	0.102	0.091	0.50

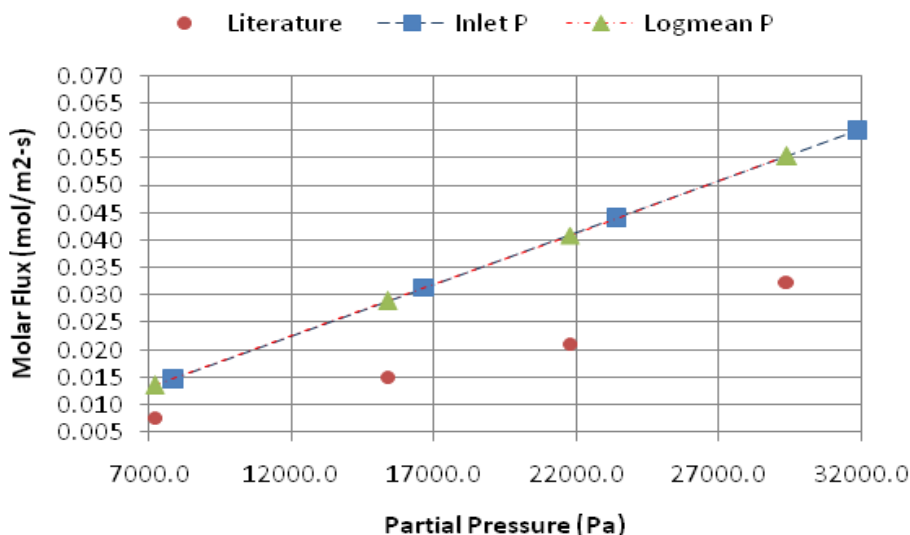


Fig.3: Molar flux as a function of partial pressure of CO<sub>2</sub> at 293K

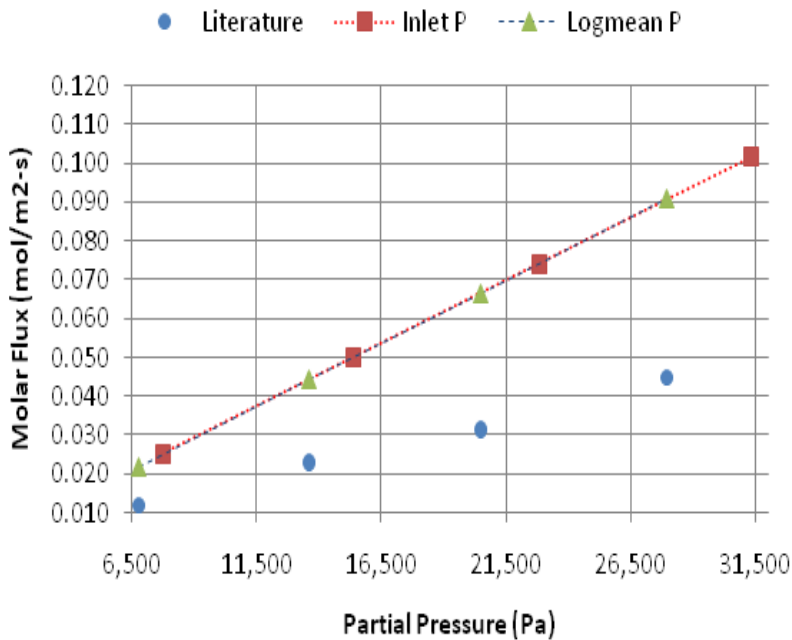


Fig.4: Molar flux as a function of partial pressure of CO<sub>2</sub> at 313K

Pressure has strong relationship to the time exposure and mass transfer. In this paper, inlet partial pressure and log mean partial pressure were applied on the calculation of absorption flux. These values yield mostly the similar results in this scenario. However, when the pressure difference between the gas inlet and gas outlet are significant, the molar fluxes of CO<sub>2</sub> of each scenario are no longer in a compromised status.

$$\begin{aligned} t = 0, y = 0; P = P_0 \\ t > 0, y > 0, P = P_y \end{aligned} \quad (33)$$

Boundary condition, as illustrated in Eq. (33), indicates that the pressure at distance of  $y$  does not return to initial value or inlet pressure. Moreover, the absorbed and reacted gas component into the liquid would decrease the fraction of those in rich gas. According to Dalton's law, partial pressure can be expressed by mole fraction of component in total mixture.

$$p_A = P_{total} y_A \quad (34)$$

The log mean partial pressure was calculated to get the average value that could represent the system in a better way. Based on the simulation results, it is reported that the model outcome is averagely twice of the literature result.

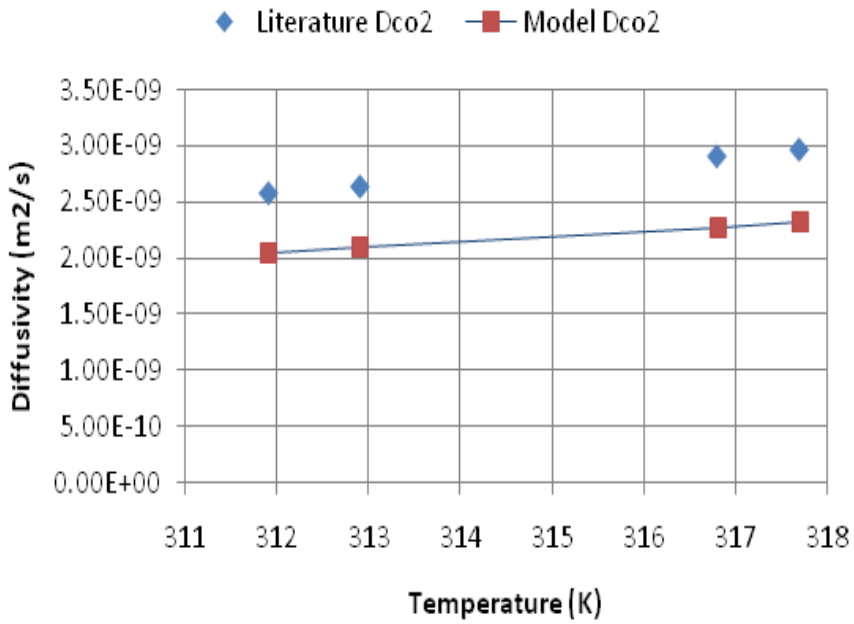


Fig.5: CO<sub>2</sub> Diffusivity as a function of temperature

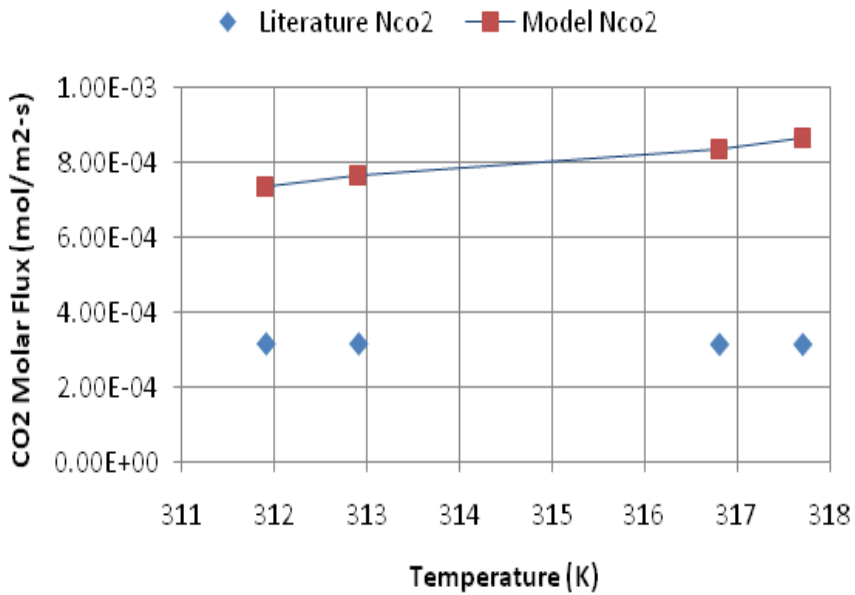


Fig.6: CO<sub>2</sub> molar flux as a function of temperature

### Effects of Temperature

Temperature has a strong relationship with vapour-liquid equilibrium. According to the results from some previous researchers, increases of temperature within a scope will contribute on better absorption (Qin *et al.*, 2010). Carbon dioxide diffusivity calculated from Eq. (25) is plotted in Fig.5 as a function of temperature. Molar carbon dioxide flux from the model as a function of temperature is shown in Fig.6. It can be seen from Fig.6 that the molar carbon dioxide flux increases as the temperature increases. The increase of temperature increases the diffusivity and kinetic rate constant and thereby increasing the molar flux of CO<sub>2</sub>. It can be seen from Fig.5 and Fig.6 that CO<sub>2</sub> diffusivity and flux calculated from the model equation follow the same trend as that of the experimental data.

Aqueous ammonia has a low boiling point. As a result of being high vapour pressure, aqueous ammonia will boil up and undergo vaporization more easily with the lower boiling point. Therefore, it is predicted that the carbon dioxide removal rate will increase until an extent just before the solvent starts boiling off. It will have a significant reduction beyond that temperature. Besides, the account of lowering down the heat of absorption of carbon dioxide, cool or chilled ammonia, which is at low temperature, has mainly been studied (Darde *et al.*, 2009).

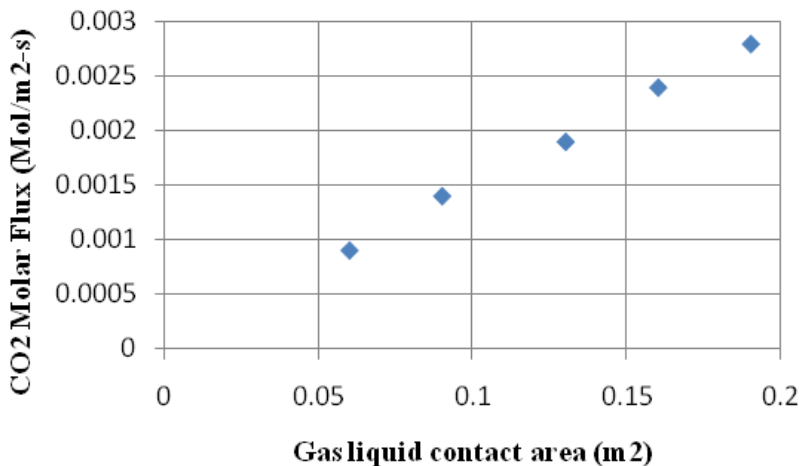


Fig.7: CO<sub>2</sub> molar flux as a function of gas-liquid contact area

### Effects of Contact Area

While the height of the column is increasing, the area of contact will become larger. As a result, it enhances the diffusion of components. Moreover, this result gives a linear expression as shown in Fig.7. Since there has been no current available literature result for the comparison, this relationship is merely based on model prediction. Radius, which is another dimension of area, is kept at constant during the simulation on the account of varying of radius will not give significant effect to the system. Furthermore, the layer that is formed by the falling liquid is negligible. This assumption is made based on the thin film assumption and slow liquid rate which cause a smooth flow.



However, the changes in height will contribute to the pressure loss of solution simultaneously. This is due to the fact that the distance of flow has been extended. As a consequence, the physical properties of the interested solvent such as the density will be varied significantly. Also, higher pressure at the lower stage will induce the phase change and increase the plant cost.

## CONCLUSION

In this paper, a mathematical model is developed based on mass and momentum balance for CO<sub>2</sub> absorption into aqueous ammonia in a wetted wall column. The model is simplified based on the assumption that the CO<sub>2</sub> absorption into aqueous ammonia is a pseudo-first-order reaction. Laplace transform method is applied in order to solve the partial differential model equation. Finally, the CO<sub>2</sub> molar flux is expressed as a function of partial pressure of CO<sub>2</sub>, concentration of aqueous ammonia, temperature and gas-liquid contact area. The molar flux of CO<sub>2</sub> increases as the partial pressure of CO<sub>2</sub> increases. The calculated flux from the model follows the same trend as that of the experimental data. Carbon dioxide flux increases as the temperature increases. CO<sub>2</sub> diffusivity and flux calculated from model equation follow the same trend as that of the experimental data. CO<sub>2</sub> molar flux is also found to increase with increase in gas-liquid contact area. The developed mathematical model is very useful to predict the CO<sub>2</sub> molar flux as a function of the concentration of aqueous ammonia, partial pressure of CO<sub>2</sub>, temperature and gas-liquid contact area.

## ACKNOWLEDGEMENTS

The authors acknowledge the financial support provided by Fundamental Research Grant Scheme (FRGS) of Ministry of Higher Education, Malaysia [JPT.S Jld.13 (28)].

## REFERENCES

- Cullinane, J. T. & Rochelle, G. T. (2004). Carbon dioxide absorption with aqueous potassium carbonate promoted by piperazine. *Chemical Engineering Science*, 59, 3619-3630.
- Darde, V., Thomsen, K., van Well, W. J. M., & Stenby, E. H. (2009). Chilled ammonia process for CO<sub>2</sub> capture. *Energy Procedia*, 1, 1035-1042.
- Darde, V., Thomsen, K., van Well, W. J. M., & Stenby, E. H. S. (2010). Chilled ammonia process for CO<sub>2</sub> capture. *International Journal of Greenhouse Gas Control*, 4, 131-136.
- Dave, N., Do, T., Puxty, G., Rowland, R., Feron, P. H. M., & Attalla M. I. (2009). CO<sub>2</sub> capture by aqueous amines and aqueous ammonia. *Energy Procedia*, 1, 949-954.
- Derks, P. W. J. & Versteeg, G. F. (2009). Kinetics of absorption of carbon dioxide in aqueous ammonia solutions. *Energy Procedia*, 1, 1139-1146.
- Diao, Y. F., Zheng, X. Y., He, B. S., Chen, C. H., & Xu, X. C. (2004). Experimental study on capturing CO<sub>2</sub> greenhouse gas by ammonia scrubbing. *Energy Conversion and Management*, 45, 2283-2296.
- Energy Information Administration (EIA). (2006a). *Annual Energy Outlook 2006*. Retrieved from <http://www.eia.doe.gov/oiaf/aeo>.

- Energy Information Administration (EIA). (2006b). *International Energy Outlook 2006*. Retrieved from <http://www.eia.doe.gov/oiaf/ieo/index.html>.
- Feng, Q., Wang, S. J., Hartono, A., Svendsen, H. F., & Chen, C. H. (2010). Kinetics of CO<sub>2</sub> absorption in aqueous ammonia solution. *International Journal of Greenhouse Gas Control*, 4(5), 729-738.
- Froment, G.F. & Bischoff, K.B. (1979). *Chemical reactor analysis and design*. (2nd Ed.). New Jersey: John Wiley & Sons.
- Ghosh, U. K., Kentish, S. E., & Stevens, G. W. (2009). Absorption of carbon dioxide into aqueous potassium carbonate promoted by boric acid, *Energy Procedia*, 1, 1075-1081.
- Ghosh, U. K. & Yee, S. C. (2013). Modelling and simulation of reaction kinetics of carbon dioxide absorption into aqueous ammonia in a wetted wall column. *International Journal of Environment and Pollution*, 51(1/2), 121-138.
- IPCC (2005). *Carbon Dioxide Capture and Storage*.
- Kim, J. Y., Han, K., & Chun, H. D. (2009). CO<sub>2</sub> absorption with low concentration ammonia liquor. *Energy Procedia*, 1, 757-762.
- Kim, Y. J., You, J. K., & Hong, W. H. (2008). Characteristics of CO<sub>2</sub> absorption into aqueous ammonia. *Separation Science and Technology*, 43, 766-777.
- Kister, H. Z. (1992). *Distillation Design*. New York: McGraw-Hill.
- Kohl, A. L. & Nielsen, R. B. (1997). *Gas Purification* (5th Edn.). Houston: Gulf Publishing.
- Levenspiel, O. (1999). *Chemical reaction engineering* (3rd Edn.). New York: John Wiley & Sons.
- Liu, J., Wang, S., Zhao, B., Tong, H., & Chen C. (2009). Absorption of carbon dioxide in aqueous ammonia. *Energy Procedia*, 1, 933-940.
- Liu, J., Wang, S., Qi, G., Zhao, B., & Chen, C. (2011). Kinetics and mass transfer of carbon dioxide absorption into aqueous ammonia. *Energy Procedia*, 4, 525-532.
- Puxty, G., Rowland, R., & Attalla, M. (2010). Comparison of the rate of CO<sub>2</sub> absorption into aqueous ammonia and monoethanolamine. *Chemical Engineering Science*, 65, 915-922.
- Qin, F., Wang, S., Hartono, A., & Svendsen, H. F. (2010). Kinetics of CO<sub>2</sub> absorption in aqueous ammonia solution. *International Journal of Greenhouse Gas Control*, 4, 729-738.
- Shen, S., Feng, S., Zhao, R., Ghosh, U.K., & Chen, A. (2013). Kinetic study of carbon dioxide absorption with aqueous potassium carbonate promoted by arginine. *Chemical Engineering Journal*, 222, 478-487.
- Smith, K., Ghosh, U., Khan, A., Simioni, M., Endo, K., Zhao, X., Kentish, S., Qader, A., Hooper, B., & Stevens, G. (2009). Recent developments in solvent absorption technologies at the CO<sub>2</sub>CRC in Australia. *Energy Procedia*, 1, 1549-1555.
- Strube, R., Pellegrini, G., & Manfredi, G. (2011). The environment impact of post-combustion CO<sub>2</sub> capture with MEA, with aqueous Ammonia, and with an aqueous ammonia-ethanol mixture for a coal-fired power plant. *Energy*, 36(6), 3763-3770.
- Suda, T., Lijima, M., Tanaka, H., Mitsuoka, S., & Iwaki, T. (1997). Countercurrent Absorption of CO<sub>2</sub> in a real flue gas into aqueous Alkanolamine Solutions in a Wetted Wall Column. *Environmental Progress*, 16(3), 200-207.

- Yeh, A. C. & Bai, H. (1999). Comparison of ammonia and monoethanolamine solvents to reduce CO<sub>2</sub> greenhouse gas emissions. *The Science of the Total Environment*, 228, 121-133.
- Yeh, J. T., Resnik, K. P., Rygle, K., & Pennline, H. W. (2005). Semi-batch absorption and regeneration studies for CO<sub>2</sub> capture by aqueous ammonia. *Fuel Processing Technology*, 86, 1533-1546.
- Zeng, Q., Guo, Y., & Niu, Z. (2011). Experimental studies on removal capacity of carbon dioxide by a packed reactor and a spray column using aqueous ammonia. *Energy Procedia*, 4, 519-524.

## NOMENCLATURE

- $A_c$  contact area (m<sup>2</sup>)
- $C_A$  concentration of carbon dioxide (mol m<sup>-3</sup>)
- $C_{Ai}$  concentration of carbon dioxide at gas-liquid interface (mol m<sup>-3</sup>)
- $D_A$  diffusivity of carbon dioxide (m<sup>2</sup> s<sup>-1</sup>)
- $E$  activation energy for carbon dioxide absorption (kJ mol<sup>-1</sup>)
- $H_A$  Henry's law constant (mol Pa m<sup>-3</sup>)
- $h$  height of wetted wall column (m)
- $J_A$  carbon dioxide absorption rate (mol s<sup>-1</sup>)
- $k_1$  pseudo-first-order rate constant of carbon dioxide absorption (m<sup>3</sup> mol<sup>-1</sup> s<sup>-1</sup>)
- $m_A$  mass rate of carbon dioxide (kg s<sup>-1</sup>)
- $M_A$  molecular weight of carbon dioxide (g mol<sup>-1</sup>)
- $N_A$  carbon dioxide molar flux (mol m<sup>-2</sup> s<sup>-1</sup>)
- $p_A$  partial pressure of carbon dioxide at the bulk gas (Pa)
- $p_{Ai}$  partial pressure of carbon dioxide at gas-liquid interface (Pa)
- $R$  gas constant (J mol<sup>-1</sup> K<sup>-1</sup>)
- $R_A$  reaction rate of carbon dioxide (mol m<sup>-3</sup>s<sup>-1</sup>)
- $r$  radius of wetted wall column (m)
- $s$  coefficient of Laplace transform
- $t$  time (s)
- $v_x$  velocity of gas in x-direction, (m s<sup>-1</sup>)

## **T-DepExp: Simulating Transitive Dependence Based Coalition Formation**

**Billy Pik Lik Lau\*, Ashutosh Kumar Singh and Terence Peng Lian Tan**

*Department of Electrical and Computer Engineering, Curtin University Sarawak, Miri, Malaysia*

### **ABSTRACT**

In this paper, we introduce T-DepExp system to simulate the transitive dependence based coalition formation (CF). It is a multi-agent based simulation (MABS) tool that aims to enhance cooperation between agents through transitive dependence. Previously, the transitive dependence was introduced by An and his colleagues for expressing the indirect dependence between agents in their cooperation. However, it did not receive much attention. Although it has a few problems need to be addressed, we try to propose our own mechanism to increase the efficiency of the transitive dependence based CF. To simulate MAS dependence relationship, we have included two fundamental dependence relationships in this MABS tool, which are AND-Dependence and OR-Dependence. In addition, the architecture of the T-DepExp system is presented and discussed. It allows possible integration of other features such as budget mechanism and trust model. Subsequently, hypothesis for the experiments and experimental setup are explained. The overall system will be demonstrated for its functionality and the experimental results will also be discussed.

*Keywords:* T-DepExp system, coalition formation, multi-agent based simulation, dependence relationship

### **INTRODUCTION**

Multi-agent based simulations (MABS) have become one of the popular tools that help computer scientists to simulate multi-agent systems (MAS) without developing the actual system for simulating certain features. It aims to enhance the performance of MAS in terms of space complexity, time complexity and computational complexity. By defining the performance of MAS, the cooperation between autonomous agents in the society for expressing (Castelfranchi, 1998; Sichman, Conte, Demazeau, & Castelfranchi, 1998) the need of depending on others.

This phenomenon is known as heterogeneous need among autonomous problem solvers in the society that leads to cooperation between agents. The cooperation formed between the agents in a group that are goal directed is known as a coalition.

---

*Article history:*

Received: 27 September 2013

Accepted: 18 January 2014

---

*E-mail addresses:*

[billy.lau@curtin.edu.my](mailto:billy.lau@curtin.edu.my) (Billy Pik Lik Lau)

[ashutosh.s@curtin.edu.my](mailto:ashutosh.s@curtin.edu.my) (Ashutosh Kumar Singh)

[terence.tan@curtin.edu.my](mailto:terence.tan@curtin.edu.my) (Terence Peng Lian Tan)

\*Corresponding Author

Coalition is a goal-directed and short-lived organization and framework for agents to perform problem solving in a distributed manner (Sycara, 1998; Wooldridge, 2009). The cooperation between agents in coalition can be instant and dissolved when there is no common goal. Coalition formation (CF) is often viewed as an optimization problem for the cooperation between agents in problem solving. It offers a quick formation of group for tackling the dynamic environment of MAS. However, coalition suffers some of the limitations such as coalition formation is invisible (An, Shen, Miao, & Cheng 2007), where other agents are not aware of it. In order to address this drawback, social reasoning mechanism (Sichman *et al.*, 1998; Gaspar & Morgado, 2000; Sichman & Demazeau, 2001) has been implemented to aid agents in identifying the social needs of dynamic coalition formation in a real-world agent environment.

The social reasoning mechanism (SRM) (Sichman *et al.*, 1998; Gaspar *et al.*, 2000; Sichman *et al.*, 2001) has opened its way for forming the dynamic coalition by identifying whom a particular agent is going to depend on and vice versa. In addition, it has introduced several types of dependence relationships such as (1) OR-Dependence, (2) AND-Dependence, and (3) CO-Dependence. One of the most significant developments of SRM is the visualization of the dependence network between agents into dependence graph. It offers researchers an easier modelling of the agents' dependence. Utilizing the dependence graph, we can represent the coalition formation in graph and further investigate the relationship and reason of coalition formation fails. Some researchers (e.g. An, Miao, & Cheng, 2005a; An, Miao, Tang, Li, & Cheng, 2005c; An *et al.*, 2007) have also shown a transitive dependence relationship when forming a coalition between agents that can be applied in manufacturing field.

To the authors' knowledge, despite the formalization of transitive dependence, not much research has been done in this field. Furthermore, there is no standard software or tools that support the transitive dependence based coalition formation. To this end, the T-DepExp system has been proposed to simulate the transitive dependence between agents to form coalition. The design of the T-DepExp system is based on the original concept introduced by An and his colleagues (An *et al.*, 2005a; An *et al.*, 2005c; An *et al.*, 2007) and we have introduced the extendibility into the T-DepExp system for future development of mechanism and experiments. The T-DepExp system aims to develop an alternate mechanism for forming transitive dependence based a coalition that encourages the indirect cooperation between agents in problem solving.

The rest of the paper is organized as follows: First, the related work of the T-DepExp system is introduced in Section II. Subsequently in Section III, the concept and architecture of the T-DepExp system are explained for running the experiments on transitive dependence based coalition formation. In Section IV, the experimental setup and results as well as the analysis are presented based on the observation. The conclusion of the T-DepExp system and future works are presented in the last section.

## RELATED WORK

The literature review related to the T-DepExp system is presented in this section. It consists of (1) Coalition formation, (2) social reasoning mechanism based coalition, and (3) transitive dependence.

### Coalition Formation

Coalition is a type of dynamic organization in MAS which is goal-directed group for agents to form cooperation. It is a short-lived group that is formed and dissolved when it is no longer needed (Horling & Lesser, 2004). Coalition Formation (CF) is often viewed by researchers as an optimization problem of MAS' cooperation. The need for forming coalition is based on the limited capability of the agent itself to achieve the required specific goals. Hence, the agent will depend on other agents to fulfil the required capability to achieve its goals. This phenomenon is known as social needs or dependence theories that are presented in some papers (Castelfranchi, 1998; Sichman *et al.*, 1998). An example of the coalition formation is shown in Figure 1.

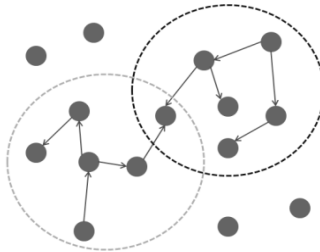


Fig.1: Example of the coalitions in MAS

The dotted circles in Fig.1 represent the coalition boundary, while the bold dots represent agents in the society. One problem of the coalition is that the possibility of overlapping issues occurs during CF, as shown in Fig. 1. This suggests that an agent can join more than one coalition in parallel.

CF is originated from the game theory (Osborne & Rubinstein, 1994) and has been widely studied for its dynamic formation of group. It is also known as coalitional game. Organization such as coalition is suitable for tackling the open multi-agent system (OMAS). OMAS is the MAS societies that have high dynamic elements and they require agents to be hyper-adaptive. There are a few payment configurations developed along with the coalition such as (1) Shapley Value (Shapley, 1953), (2) Kernel (Morton & Michael, 1967), and (3) Core (Klusch & Gerber, 2002). The payment configurations aim to distribute the profit of the coalition to all the agents involved. It may vary depending on the element the payment configuration emphasises on such as fairness, uniqueness, and consistency.

### Social Reasoning Mechanism Based Coalition

Social reasoning mechanism (Sichman *et al.*, 1998; Gaspar *et al.*, 2000; Sichman, *et al.*, 2001) (SRM) was developed to assist an agent to reason about other agents in the MAS society. SRM is based on the dependence theory that proposes the social need of an agent and is required to depend on other agents. The SRM relieves the communication flow between agents by identifying them using the social reasoning. This mechanism helps an agent to achieve a given goal by reasoning about other agents in two different social views (Sichman *et al.*, 2001): (1) Whom do I depend and (2) Who depends on me. The dependence

relationships show the relationship of an agent depending on other agents to achieve its goal using the required capabilities. The dependence relationship formed can be classified into: (1) AND-Dependence, (2) OR-Dependence, and (3) Single-Dependence. The three fundamental dependence relationships in the proposed T-DepExp system are described in Table 1 below:

TABLE 1: Type of the Dependence Relationship

Type of Dependence Relationship	Explanation
OR-Dependence	This relationship indicates that agent has option of choosing agent to cooperate for achieving its goals.
AND-Dependence	This relationship indicates that agent would have to take account all party of agents since all agent are required for achieving the goal.
Single-Dependence	This relationship indicates the agent only has a single option in choosing the partner for achieving its goal.

On the other hands, OR-Dependence, AND-Dependence and Single-Dependence can be expressed in a mathematical form:

- AND-Dependence

$$\begin{aligned}
 AND\_Dep(Agt_j, agt_{p_{qk}}) = & \forall ag_k \in G(agt_k) \neg a_{aut}(agt_i, g_k, p_{qk}) \wedge \forall i_m(p_{qk}) \in I(p_{qk}) a_m \in \\
 & A_n(agt_i, g_k, p_{qk}) (\exists ! Agt_k \in AG | Agt_j = \exists agt_i \in Agt_k) basic\_dep(agt_i, agt_i, g_k, p_{qk}, a_m) \vee \\
 & \exists ! Agt_k \in Ag_j OR\_dep(agt_i, Ag_k, a_m) \wedge \neg \exists AG_m AG_j \subset AG_m AND\_dep(agt_i, AG_m, g_k, p_{qk})
 \end{aligned}
 \tag{1}$$

- OR-Dependence

$$\begin{aligned}
 OR\_Dep(agt_i, Agt_j, g_k, a_m) = & \exists g_k \in G(agt_i) \neg a_{aut}(agt_i, g_k, p_k) \wedge |Agt_j| \wedge \forall Agt_i \\
 & \in Agt_j basic\_dep(agt_i, agt_i, g_k, p_{qk}, a_m) \wedge \neg \exists Agt_m Agt_j \subset Agt_m \\
 & OR\_Dep(agt_i, Agt_m, g_k, p_{qk}, a_m)
 \end{aligned}
 \tag{2}$$

- Single-Relationship

$$\begin{aligned}
 Single\_dep(agt_i, agt_j, p_{qk}, g_k) \equiv & \exists g_k \in (agt_i, g_k, p_{qk}) \wedge \forall Agt_i \in \\
 & Agt_j basic\_dep(agt_i, agt_i, p_{qk}, a_m) \wedge \exists Agt_m Agt_j \subset Agt_m OR\_dep(agt_i, Agt_m, g_k, p_{qk}, a_m)
 \end{aligned}
 \tag{3}$$

Other related works of SRM include identifying four structural viewpoints (Boella, Sauro, & Torre, 2004) of an agent in a coalition such as: (1) power view, (2) mind view, (3) coalition view, and (4) dependence view. SRM also has its place in social exchange (Rodrigues & Costa, 2003; Rodrigues, Costa, & Bordini, 2003) that exchanges value introduced to support the social interactions between agents. It is based on the algebra of exchange values that the structural value of storing and manipulating is done by modifying SRM. In addition, we also reviewed the work of Lau, Singh and Tan (2012) on the dependence graph of agents with SRM in our previous works.



### Transitive Dependence Relationship

The transitive dependence is an indirect dependence between the agents in the society that is introduced by An and his colleagues (An *et al.*, 2005c; An *et al.*, 2007). They have shown a possible indirect dependence relationship between agents using SRM.

The transitive dependence is based on the dependence chain that the starting agent (also known as head) will connect to an ending agent of the chain (known as tail) by a series of connected agents sharing the same goal to achieve. Fig.2 shows the example of the transitive dependence relationship based the coalition formed:

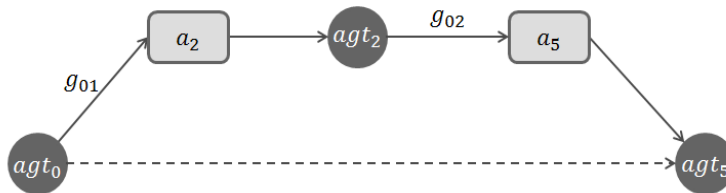


Fig.2: Example of Transitive Dependence

From Fig. 2, the transitive dependence relationship for the agents in the cooperation can be expressed as  $dep = TDep(agt_o, agt_s, depchain)$ , where  $depchain = agt_o \xrightarrow{p_g^{01, a2}} agt_2 \xrightarrow{p_g^{02, a5}} agt_5$ . Transitive dependence relationship is proven (An *et al.*, 2005a; An *et al.*, 2007) to encourage agents to help each other regardless of the profits gained from the direct dependence. The main concept behind the transitive dependence is indirect profitable cooperation that will lead to overall profitable cooperation among the agents.

Other related works of transitive dependence include the application of transitive dependence into virtual organization (An, Miao, Shen, Miao, & Cheng, 2005b). This application includes service discovery and partner-searching features using transitive dependence based reasoning. However, the auto-complete knowledge of an agent in the transitive dependence shows an agent has a complete knowledge regarding itself, which is impractical.

## T-DEPEXP SYSTEM

In this section, we have proposed the T-DepExp system for simulating the transitive dependence between agents in coalition. The concept of the T-DepExp system is explained in the first sub-section. Subsequently, the system design of the T-DepExp system is presented and explained. The parameters for conducting the experiments are explained in the last sub-section.

### Concept of T-DepExp System

T-DepExp system is a MABS software that aims to provide alternate payoff mechanism to CF other than Shapley value, core and kernel. The Shapley value is the most popular payoff mechanism since it offers fair payment to all agents involved in coalition formation. However, the Shapley value (Shapley 1953) has a higher computation complexity since it involves permutation and factorial when calculating payoff (also known as utility) for each

agent. The core (Klusck *et al.*, 2002) suggests that agents do not need to have unique payoff configurations when forming coalition. However, searching for core optimal coalition structure is computationally difficult. The kernel (Morton *et al.*, 1967) introduces stable payment configuration where there is an equilibrium between the agents in the coalition. The main drawback of the kernel is that it cannot guarantee parento optimal condition where all agents are getting equal paid for joining the coalition.

For explanation of the transitive dependence based coalition example, the coalition formed with three agents shown in Fig. 2 is considered. This coalition has a centralized view as we will call agent, *agt<sub>o</sub>*, as a root agent to form coalition and agent *agt<sub>5</sub>* as the leaf agent where there is no more “potential child” to invite for forming a coalition. Similar concepts are applied in the T-DepExp System as the programme reaches leaf agent and when there is no more child to invite to join the coalition, it is considered that no more coalition will be formed. In the T-DepExp System, however, the coalition of *n*-size will be tested that wishes to able to handle larger group of agents.

Together with the T-DepExp system, the authors aimed to create an alternate payoff mechanism based on the concept of budgets. The main purposes of designing encourage the cooperation between the agents. Assume that all the agents in the society are applying the sincerity principles, the agent that has higher cost in the society will have a lower chance of involving into coalition formation. Through the development of budget mechanism, the agents will have equal chance of involving into the coalition to earn profits. If the cost is within the budget requirement, the coalition will then be formed, giving the chance to other agents to involve into the coalition.

The T-DepExp system attempts to address the issue of the transitive dependence based coalition which is useful in three-tier systems. It includes the *n* number of middle-man for forming the cooperation. Most MABS tools available emphasize on direct dependence between agents. The motivation of the T-DepExp System is an attempt to address indirect dependence between the agents. This enables them to have a larger perspective of their cooperation instead of their first-person’s view.

### *The Proposed T-DepExp System Architecture*

In this sub-section, the architecture of the T-DepExp Systems is proposed. It shares some common features of the ASIC Model (Boissier & Demazeau, 1994) proposed by Boissier and his colleagues. The fundamental composition of this architecture is the external description of the agents. By introducing the external description, we can address our agent architecture using belief, desire and intention (BDI) architecture (Wooldridge, 2009). The BDI architecture which represents the agents in the MAS society are able to reason, have their own trust towards other entities and goals to achieve. Fig.3 shows the architecture of the T-DepExp system.

The T-DepExp system is constructed with the external mechanism for assisting the agent to make a better decision and give reasoning about the environment and social status. The main focus of the T-DepExp system is simulating the transitive type dependence during CF. Hence, SRM and social evaluation module play an important role here for the agents to analyze their social status.

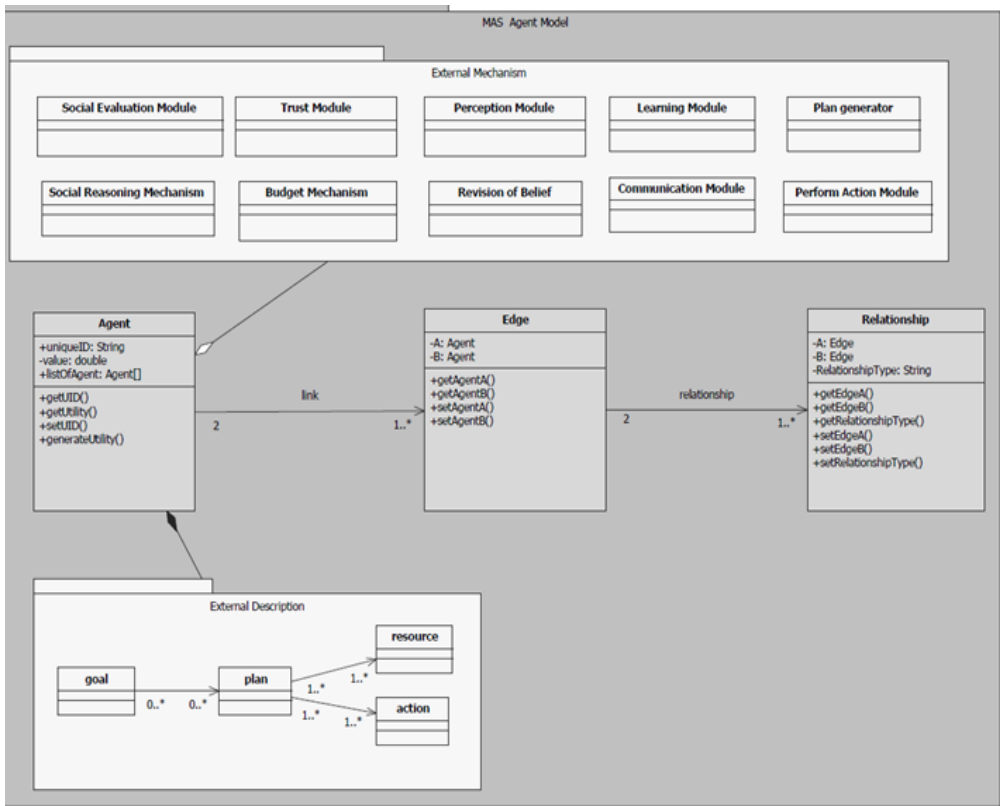


Figure 3: The architecture of the T-DepExp Systems

The T-DepExp system has a robust learning module that learns based on the outcome of their decision. It will learn based on the outcome of the transitive dependence based coalition. The plan generator will generate plan for the agent after the learning module is invoked. Meanwhile, the communication module serves as a medium for the agents to communicate among themselves. The T-DepExp system architecture consists of trust module, where credibility of the agent is given attention here. It is to mitigate any malicious agent to cheat on the agents' profit. Nonetheless, it is not guaranteed that the agent will avoid the cheating issue completely. Hence, the trust model implemented here is using the reputation and confidence (Ramchurn, Sierra, Godó, & Jennings, 2003). The Reputation model suggests that the agent will gain trust if friends of an ally have received positive feedbacks from other agents.

The T-DepExp systems was developed using JAVA programming language. It offers cross-platform compatibility to execute the programme. Hence, it has become the choice of the programming language. It was designed with object-oriented concept in mind incorporate iterative waterfall model lifecycle. One major focus of this program is the extendibility of the new mechanism implementation. The mechanism that uses external description will run well with the T-DepExp system.

*Parameters Input and Hypothesis*

The T-DepExp System requires certain input for generating the outcome of CF. The society of MAS is randomized based on the setting for getting un-bias results. For the experimental setup in this study, Table 2 depicts the parameters to be input for running the simulation of transitive dependence based CF:

TABLE 2: Parameters for Inputing into Simulations

Parameters	Descriptions
$n$	Number of agents in the society
$P_a$	Probability / Ratio of agent having an action to achieve the goal assigned.
$P_{and}$	AND Ratio of the relationship occurred when requiring the action/resource from other agents.
$P_{or}$	OR Ratio of the relationship occurred when requiring the action/resource from other agents.
$v$	Budget value that are allocated for coalition formation.
$i$	The payout for accepting the coalition invitation
$i_{max}$	The maximum payout for agent to propose for the value per each action.
$i_{min}$	The minimum payout for agent to propose for the value per each action.

The T-DepExp system emphasizes on the searching ideal amount of budget for an agent to form transitive dependence coalition. Below are the hypotheses for the experiments conducted with the T-DepExp System to adapt budget mechanism and calculate a suitable budget for forming a feasible coalition.

- Hypothesis 1: Optimal amount of budget encourage the cooperation of the agent to form coalition (until an optimal budget is reached).

The amount of budget serves as a threshold to the size of coalition that an agent wants to perform. If the amount of budget is optimal, the coalition can be formed regardless of the number of agents in the coalition. It ensures that every agent in the coalition will obtain profit through the cooperation with other agents. Hence, it is believed that the optimal amount of budget will encourage the cooperation of agents in the transitive dependence based coalition.

- Hypothesis 2: Bad planning (relationship ratio increase) will decrease cooperation between agents.

The incremental of the relationship ratio suggests the dependence relationship between agents in the coalition increases. It increases the computational time to traverse through the dependence relationship. In addition, the coalition value will increase and tend not to meet the allocated budget for CF. Hence, the rate of the cooperation will go down. Hypothesis 2 is indirectly opposite of Hypothesis 1 for the rate of cooperation. Hence, the incremental of the relationship ratio will decrease the rate of cooperation between the agents.

- Hypothesis 3: Higher OR-Dependence ratio will decrease the computational time of CF in the T-DepExp system.

The ratio of the OR-Dependence will have an impact on the CF computational time. It is believed that a higher ratio of OR-Dependence will yield more alternate choices for agents to choose. This is in contrast with the AND-Dependence ratio, where the agent is not required to consider all the agents in the dependence relationship. Hence, it is assumed that a higher ratio of the OR-Dependence will form the transitive dependence based coalition in a shorter computation time than the AND-Dependence.

## EXPERIMENTAL RESULTS

In this section, the experiment of the T-DepExp system is conducted and the analysis of the results is discussed based on the observation. The performance measurement of the experiments is discussed in the first sub-section. Subsequently, the results of the experiments are displayed. Lastly, the last sub-section includes the discussion on the results and observation.

### *Performance Measurements*

For the T-DepExp system, the authors have included their own measurements for the CF in the T-DepExp system. It aims to test the efficiency of the new implementation of the mechanism and algorithm for future upgrades. The performance measure for conducting this experiment is shown in Table 3 below.

TABLE 3: Performance Measurement

Measurements	Descriptions
$N_{total}$	The number of coalition that is successfully formed per simulation.
$B_{total}$	The budget in term of utility for forming coalition.
$V_c$	The value for the coalition formation.
$V_{average}$	The average of the coalition formation for multiple simulations.
$R_c$	The profit that gained for forming the coalition.

**RESULTS**

The simulation of the T-DepExp System was conducted using the computer with the specifications of Intel Xeon processor and 16GB RAM. The dataset to be inputted into the simulation were randomly generated during initialization of the simulation. The focus of the simulation was to obtain a suitable budget for supporting budget mechanism in forming transitive based coalition. Also, the cooperation rate between agents was also tested in the simulations of the T-DepExp system. Table 4 shows the results of the simulation.

TABLE 4: Result for Simulating for Agent Size of 10

$P_{and}$ \ $P_a$	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
0.0	29.0	21.4	17.8	29.8	40.8	30.0	7.6	24.6	-	11.0	-	10.2	26.2	-	9.6	11.8	10.4	9.8	-	-
0.1	42.4	9.4	29.2	34.8	17.0	47.4	26.6	31.0	30.6	6.4	11.2	18.6	8.0	22.8	21.2	9.4	-	-	33.4	-
0.2	38.8	44.0	46.6	19.2	47.4	16.8	17.8	23.0	9.2	11.8	20.0	21.4	11.8	31.8	-	-	-	43.2	43.2	-
0.3	50.8	50.2	45.0	34.6	24.4	26.2	40.6	10.8	8.8	33.0	31.8	-	9.0	40.0	21.6	-	52.6	9.8	-	10.2
0.4	44.8	32.0	25.0	41.2	16.4	41.8	-	11.2	16.8	25.0	31.6	33.2	28.6	56.4	-	-	-	-	-	-
0.5	11.4	27.0	42.8	27.6	34.2	11.6	9.0	26.0	17.6	9.2	10.6	-	-	-	-	29.2	-	-	-	-
0.6	26.8	43.6	35.0	32.4	8.8	42.8	13.6	33.0	-	25.6	22.4	9.0	-	-	-	-	11.0	-	-	11.0
0.7	21.4	50.2	41.4	27.4	19.2	26.0	12.0	30.8	11.4	18.4	11.8	-	34.8	-	22.0	-	21.2	11.2	24.0	25.0
0.8	46.2	19.4	27.4	37.2	21.0	25.0	9.8	17.6	-	17.8	-	-	-	-	-	19.8	-	-	-	-
0.9	42.2	36.4	42.6	36.4	15.0	30.8	8.8	16.2	18.2	10.4	-	-	-	-	-	-	-	-	-	11.0
1.0	28.2	47.6	34.6	8.6	-	44.2	31.0	29.8	8.2	-	19.4	-	-	-	-	-	-	-	-	-

As the relationship ratio goes higher, agents tend to have dependence chain that ends up in a loop (dead lock) where the coalition formation is not feasible. The increase in the AND-Dependence ratio does not affect the feasibility of the coalition formation much, except for computation time. Fig. 4 shows the total value of the coalition formed with a society size of 10 agents and the basic payout of 40 and 60.

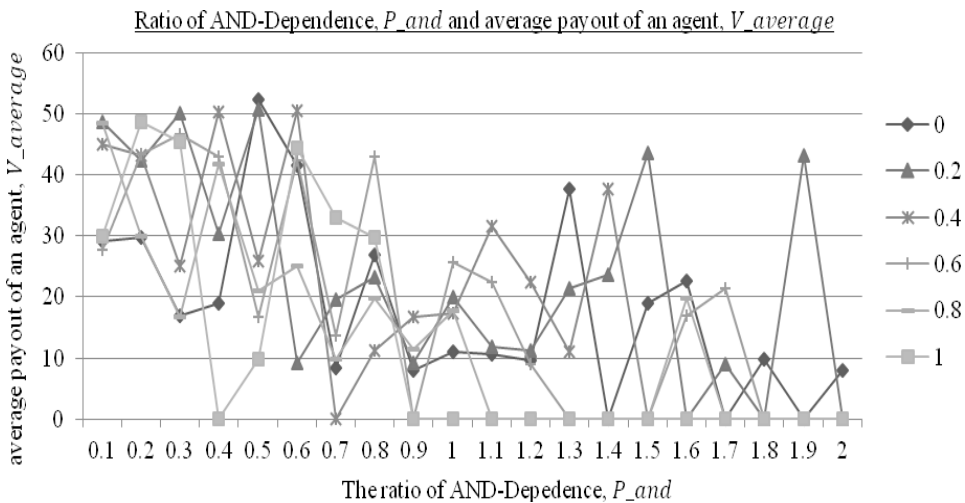


Fig.4: Ratio of AND-Dependence,  $P_{and}$  and average payout of an agent  $V_{average}$

There is some noise during the process of CF as there may be some “deadlock” issues. The main reason is the data for this experiment are generated randomly. The authors intentionally include this particular constraint in the experiment as it will add a dynamic element to the simulation. The graph in Figure 4 shows a running series of the simulation that considers multiple randomized datasets. Based on the simulation results, a few observations can be deduced, as follows:

- Observation 1: The increment in the AND-Dependence ratio  $P_{\text{and}}$  causes the coalition formation to fail easily.

The increment of the AND-Dependence ratio  $P_{\text{and}}$  shows that the agent has to consider all the agents engaged in the dependence relationship. There are two fail outcomes of CF which include: (1) insufficient budget to form coalition and (2) agents refuse to cooperate and there are no alternative options. The AND-Dependence relationship has a strict condition for the dependence relationship that all agents in the dependence relationship have to agree to join the coalition. If one of the agents rejects the offer, the CF will fail easily. The budget  $v$  has a major influence on CF as it holds the threshold for it. If the budget  $v$  is insufficient, CF will fail instantly. Fig. 4 and Table 4 have shown the increment of the AND-Dependence ratio  $P_{\text{and}}$  will cause CF to fail easily. This observation has been shown in Hypothesis 2.

- Observation 2: The increment of the relation ratio  $P_a$  causes CF to fail easily.

The increment of the relation ratio  $P_a$  indicates the number of dependence relationships in the coalition increases. The relationship includes the number of AND-Dependence and OR-Dependence in the process of CF. The increase in the dependence relationships indicates that the coalition is much harder to form due to the complexity of the relationship. Hence, the CF process has a tendency to fail. An observation of Table 4 shows that the relation ratio  $P_a = 2.0$  consists of eight failed attempts of CF. By comparing the relation ratio  $P_a = 2.0$  and relation ratio  $P_a = 1.0$ , the failure rate can be easily distinguished based on the relation ratio. By concluding Observation 2, Hypothesis 1 has shown the influence of the relation ratio  $P_a$  towards successful CF.

- Observation 3: The ratio of OR-Dependence  $P_{\text{or}}$  encourages the coalition formation in the society.

The ratio of OR-Dependence  $P_a$  shows increasing chances of an agent to choose an optimal partner. The increment of the OR-Dependence ratio  $P_a$  shows that the ratio of AND-Dependence  $P_{\text{and}}$  decreases. As the ratio of AND-Dependence  $P_{\text{and}}$  increases in Figure 4, CF tends to fail easily. This situation can be denoted as the AND-Dependence consume majority of the budget  $v$  to maintain the stability of the coalition. Due to limited budget, the CF will fail as the budget for the allocation is insufficient. This is on the contrary to the AND-Dependence scenario, where the increment of the OR-Dependence ratio  $P_{\text{or}}$  has a higher rate of CF. Agents



can solely depend on the most convenient agent for CF. Hence, the computational complexity of the OR-Dependence will be low as compared to the AND-Dependence. Based on the analysis above, we can denote that Hypothesis 3 is proven.

## CONCLUSION

T-DepExp system has become the framework for developing the budget mechanism in providing a better mechanism for transitive based coalition formation. It has been proven to generate feasible coalition with various numbers of budgets, where traditional method such as the Shapley value does not perform well in large-scale society. In searching of an ideal formula for expressing the required budget for the transitive dependence based coalition, various types of simulation and extensions will be implemented for future work.

In future agenda, the T-DepExp system will simulate CF based on an optimal budget in order to form feasible coalitions. The authors will define the calculation of the cost for each action requiring other agents' capabilities. Furthermore, algorithm that enables the T-DepExp system to adapt to dynamic environment can be implemented anytime in the simulation.

## REFERENCES

- An, B., Miao, C., & Cheng, D. (2005a). A Coalition Formation Framework Based on Transitive Dependence. *IEICE - Trans. Inf. Syst.*, E88-D, 2672-2680.
- An, B., Miao, C., Shen, Z., Miao, Y., & Cheng, D. (2005b). Transitive Dependence Based Formation of Virtual Organizations. In Y. Hao, J. Liu, Y. Wang, Y.-m. Cheung, H. Yin, L. Jiao, J. Ma, & Y.-C. Jiao (Eds.), *Computational Intelligence and Security (Vol. 3801)* (pp. 375-380). Springer Berlin Heidelberg.
- An, B., Miao, C., Tang, L., Li, S., & Cheng, D. (2005c). Toward Transitive Dependence in MAS. *Proceedings of the 6th international conference on Intelligent Data Engineering and Automated Learning*, 486-493.
- An, B., Shen, Z., Miao, C., & Cheng, D. (2007). Algorithms for Transitive Dependence-Based Coalition Formation. *IEEE Transactions on Industrial Informatics*, 3, 234-245.
- Boella, G., Sauro, L., & Torre, L. v. d. (2004). Social Viewpoints on Multiagent Systems. *Proceedings of the Third International Joint Conference on Autonomous Agents and Multiagent Systems - Volume 3*, 1358-1359.
- Boissier, O. & Demazeau, Y. (1994). Mavi: A Multi-Agent System for Visual Integration. In *Multisensor Fusion and Integration for Intelligent Systems, 1994. IEEE International Conference on MFI '94*, pp. 731-738.
- Castelfranchi, C. (1998). Modelling Social Action for Ai Agents. *Artificial Intelligence*, 103, 157-182.
- Gaspar, G. & Morgado, L. (2000). A Social Reasoning Mechanism Based on a New Approach for Coalition Formation. *Technical Report 41740360*. Faculdade de Ciências da Universidade de Lisboa.
- Horling, B. & Lesser, V. (2004). A Survey of Multi-Agent Organizational Paradigms. *Knowl. Eng. Rev.*, 19, 281-316.
- Klusck, M. & Gerber, A. (2002). Dynamic Coalition Formation among Rational Agents. *Intelligent Systems, IEEE*, 17, 42-47.

- Lau, B. P. L., Singh, A. K., & Tan, T. P. L. (2012). A Review on Dependence Graph in Social Reasoning Mechanism. *Artificial Intelligence Review*, 1-14.
- Morton, D. & Michael, M. (1967). The Structure of the Kernel of a Cooperative Game. *SIAM Journal on Applied Mathematics*, 15, 569-604.
- Osborne, M. J. & Rubinstein, A. (1994). *A Course in Game Theory* (1st Edn.). London, England: The MIT Press.
- Ramchurn, S., Sierra, C., Godó, L., & Jennings, N. R. (2003). A Computational Trust Model for Multi-Agent Interactions Based on Confidence and Reputation. *Proceedings of 6th international workshop of deception, fraud and trust in agent societies*, 69-75.
- Rodrigues, M. R. & Costa, A. C. d. R. (2003). Using Qualitative Exchange Values to Improve the Modelling of Social Interactions. In *Multi-Agent-Based Simulation Iii 4th International Workshop, Mabs 2003, Melbourne, Australia, July 14, 2003. Revised Papers* (Vol. 2927), Springer Berlin Heidelberg, pp. 57-72.
- Rodrigues, M. R., Costa, A. C. d. R., & Bordini, R. H. (2003). A System of Exchange Values to Support Social Interactions in Artificial Societies. *Proceedings of the Second International Joint Conference on Autonomous Agents and Multiagent Systems*, 81-88.
- Shapley, L. S. (1953). A Value for N-Person Games. *Annals of Mathematical Studies* v, 2, 1-13.
- Sichman, J. S., Conte, R., Demazeau, Y., & Castelfranchi, C. (1998). A Social Reasoning Mechanism Based on Dependence Networks. In N. H. Michael and P. S. Munindar (Eds.), *Readings in Agents* (pp. 416-420). Morgan Kaufmann Publishers Inc.
- Sichman, J. S. & Demazeau, Y. (2001). On Social Reasoning in Multi-Agent Systems. Technical.
- Sycara, K. P. (1998). Multiagent Systems. *AI Magazine*, 19, 79-92.
- Wooldridge, M. (2009), *An Introduction to Multiagent Systems* (2nd Edn.). John Wiley & Sons.



## Synthesis of Nanoparticle-based Binary Oxide Electrode $\text{TiO}_2\text{-ZrO}_2$ with Carrot-derived Natural Dye Extract for Dye Sensitized Solar Cell (DSSC) Application

S. Y. Win<sup>1\*</sup>, T. T. Win<sup>1</sup>, Y. M. Maung<sup>1</sup>, K. K. K. Soe<sup>2</sup>, T. T. Kyaw<sup>3</sup>, C. K. Tan<sup>4</sup>,  
S. Rajalingam<sup>4</sup> and Z. Oo<sup>4</sup>

<sup>1</sup>Department of Physics, University of Yangon (YU), Yangon, Myanmar, Yangon

<sup>2</sup>Yangon Institute of Education, Yangon, Myanmar

<sup>3</sup>Department of Chemical Engineering, Thanlyin Technological University, Yangon, Myanmar

<sup>4</sup>Department of Electrical and Computer Engineering, Curtin University, Sarawak, Malaysia

### ABSTRACT

Dye-sensitized solar cell (DSSC) is the third generation of thin film solar cell. In this work, carrot fruit dye was prepared and used in DSSC as a sensitizer.  $\text{TiO}_2\text{-ZrO}_2$  fine binary oxide was mechanochemically prepared and made paste.  $\text{TiO}_2\text{-ZrO}_2$  paste (colloidal) was deposited onto FTO/glass in two ways, i.e. as single and double coatings by rolling method. It was immersed in the carrot solution to get dyed cell. The dyed  $\text{TiO}_2\text{-ZrO}_2\text{-FTO/glass}$  cell was offset with the FTO/glass cell coated with adhesive carbon paste. Photovoltaic properties of prepared  $\text{TiO}_2\text{-ZrO}_2$  DSSC cell were measured. Results showed that the efficiency of double coating cell was greater than that of the single coating cell. According to the fill factor from the experiments, both the DSSC cells were acceptable for industrial requirement. Hence, it can be concluded that the results obtained were acceptable in the use of cost-effective and eco-favourable dye-sensitized solar cell.

**Keywords:** Mechanochemical milling, FTO/glass, carbon counter electrode, photovoltaic properties dye-sensitized solar cells

#### Article history:

Received: 10 August 2013

Accepted: 18 January 2014

#### E-mail addresses:

87.kitkit@gmail.com (S. Y. Win),

thannthannwinn@gmail.com (T. T. Win),

dryinmgmg@gmail.com (Y. M. Maung),

tinakyaw@gmail.com (T. T. Kyaw),

dr.kokokyawsoe@gmail.com (K. K. K. Soe),

drtanck@curtin.edu.my (C. K. Tan),

rajalingam@curtin.edu.my (Rajalingam S),

zeya.oo@curtin.edu.my (Z. Oo)

\*Corresponding Author

### INTRODUCTION

Photoelectrochemical application based on dye-sensitized nanostructured  $\text{TiO}_2$  solar cell has attracted much attention as a low cost alternative to conventional silicon solar cell. In 1991, dye-sensitized solar cell (DSSC) based on liquid electrolyte with an efficiency of about 11% was first reported by O' Regan and Gratzel (Buradah *et al.*, 2011;

Nupearachchi *et al.*, 2011; Zhou *et al.*, 2011). DSSCs, which are also known as Gratzel cells, are new invention in thin film solar cell. The DSSCs are currently attracting extensive academic and industrial interests envisioning this technology as a powerful and promising way to generate electricity from the sun (Flores *et al.*, 2007; Fujihara *et al.*, 2007; Ali & Nayan, 2010; Kakuta *et al.*, 2012; Ekanayake *et al.*, 2011).

The main principal use of these DSSCs is the dye-sensitization of wide band gap semiconductors such as  $\text{TiO}_2$ ,  $\text{ZnO}$ ,  $\text{SnO}_2$ , etc., by suitable regenerative dyes which ultimately convert solar irradiation into electricity (Win *et al.*, 2012).  $\text{TiO}_2$  is a wide band gap oxide and it has been used as photoelectrode in DSSCs because of its high specific surface area that allows absorption of a large number of dye molecules.  $\text{TiO}_2$  has been proven to be one of the most promising materials for various applications including solar energy conversion, fuel cells, paints and photocatalysts, due to its high chemical stability, availability and low cost. In DSSCs,  $\text{TiO}_2$  only absorbs UV and does not absorb other wavelengths. Therefore, the energy conversion efficiency is increased by adding a dye that absorbs light with wavelengths in the visible light range of the solar spectrum (Neppolian *et al.*, 2007; Mane *et al.*, 2005; Gratzel, 2004; Gratzel, 2003; Kim *et al.*, 2005; Park *et al.*, 2003; Win *et al.*, 2012).  $\text{ZrO}_2$  has been investigated for its catalytic properties with organic compounds. In addition,  $\text{ZrO}_2$  has been used not only as a support for  $\text{TiO}_2$  but also with  $\text{TiO}_2$  as a binary oxide catalyst since  $\text{ZrO}_2$  itself as a photocatalyst (Wongcharee *et al.*, 2006). The ability of sensitizers in the natural dye is linked to Anthocyanin properties. Anthocyanin molecules in the forms of carbonyl and hydroxyl which occur naturally in fruit, leaf and flowers are responsible to show types and colour pigments in visible red-to-blue spectrum. Natural dyes have wider absorption spectra compared to chemical synthesis dyes due to the more various constituents in the natural dyes (Lin *et al.*, 2007; Okoli *et al.*, 2011; Abeygunawardhana *et al.*, 2011). In DSSCs, natural dyes can help to expand their absorption spectra. In this work, carrot solution was used as a natural dye sensitizer.

## MATERIALS AND METHOD

### *Preparation of Mixed Binary Oxide $\text{TiO}_2$ - $\text{ZrO}_2$*

Titanium dioxide ( $\text{TiO}_2$ ) (BDH Chemical) was used in this work. The  $\text{TiO}_2$  nano particle was prepared by using a mortar and a pestle, mesh-sieving and ball-milling method. Firstly, the  $\text{TiO}_2$  powder was ground for 1h before sieving it with 3-step meshes and milling it with the ball-milling machine for 20h to get nano particle grain size. Meanwhile, 9 ml of ethanol ( $\text{C}_2\text{H}_5\text{OH}$ ) was added into the  $\text{TiO}_2$  powder as a binding agent. This powder was continuously stirred by using a magnetic stirrer for 2h to be homogeneous. Then, it was dried at room temperature for 24h. Eventually, the homogeneous  $\text{TiO}_2$  powder was obtained. Zirconium dioxide ( $\text{ZrO}_2$ ) (AnalaR-grade) was used in the preparation of the homogeneous  $\text{ZrO}_2$  powder following the same procedure as  $\text{TiO}_2$ . Then,  $\text{TiO}_2$  (95%mol) and  $\text{ZrO}_2$  (5%mol) were mixed thoroughly in 9ml of ethanol ( $\text{C}_2\text{H}_5\text{OH}$ ) and stirred for 2h. The mixture powder was annealed at four different temperatures of 450°C, 500°C, 600°C and 700°C for 1h in oxygen ambient. Crystal structure of mixed binary oxide  $\text{TiO}_2$ - $\text{ZrO}_2$  was then analyzed by using X-ray diffraction (XRD), as shown in Fig.5.

### *TiO<sub>2</sub>-ZrO<sub>2</sub> Paste Preparation*

$\text{TiO}_2\text{-ZrO}_2$  powder was dissolved in acetylacetone and water mixed solution. During this preparation, detergent was added into it as a surfactant. It was coated onto clean FTO/glass substrate using the rolling method so as to obtain the single layer cell and double layer cell. After air drying, it was sintered at  $400^\circ\text{C}$  for 1 h. Both films were immersed in 0.1 M HCL for 1 h and washed with DIW maintained 1 h for surface treatment. Finally,  $\text{TiO}_2\text{-ZrO}_2$  film (active area =  $1\text{ cm} \times 0.5\text{ cm}$ ) was formed on FTO/glass substrate.

### *Preparation of Dye Sensitizer*

Commercial Carrot (*Daucus carota* L.) was used as a dye. Firstly, the carrot sticks were cured in boiled water for 45 min to attain softer and enhanced colour. The outside layer of the carrot skin was peeled off and sliced into several pieces. Secondly, the pieces of carrot was packed in a piece of thin cloth and cured in ethanol. Ethanol changed its colour into orange. After cooling, pH was measured to be 6. Later, some powder was acidified with 1%  $\text{H}_2\text{SO}_4$ , mixed with ethanol and annealed at  $80^\circ\text{C}$  for 1 h. After cooling, the pH level was found to be 8. The solutions obtained from two different methods were mixed and pH9 was obtained. The KOH base was added to get the natural carrot solution. Fig.1 shows the carrot pieces and carrot solution.



Fig.1. Carrot pieces and carrot solution

### *Preparation of Carbon Catalyst*

First of all, KOH (16 ml) and ethanol (8 ml) were mixed together. Then, carbon powder and black carbon powder were dispersed into this mixture solution. After dispersion, carboxymethylcellulose (0.24 g) was also added and adhesive carbon paste was formed. It was coated onto FTO/glass substrate (active area =  $1\text{ cm} \times 0.5\text{ cm}$ ) by rolling and annealing it at  $180^\circ\text{C}$  for 1 h.

### *Preparation of FTO/glass*

FTO powder was prepared by the solution method. Firstly, tin (IV) chloride (10.5g) was

added to 150ml ethanol and mixed in a sealed glass vial for 5h. In another sealed glass vial, ammonium fluoride (1.86g) was added into DIW (5.04ml) and mixed for 5h. The fluoride solution was added into the glass vial containing the tin chloride solution while in a water bath at 60°C temperature. Finally, the FTO powder was obtained. Then, it was coated onto the glass by spinning method.

### *DSSC Prototype Preparation*

The TiO<sub>2</sub>-ZrO<sub>2</sub> coated electrodes were immersed in the carbon solution for 15 h and annealed at 100°C for 1 h. Fig.2 shows the carbon coated and TiO<sub>2</sub>-ZrO<sub>2</sub> coated electrodes.

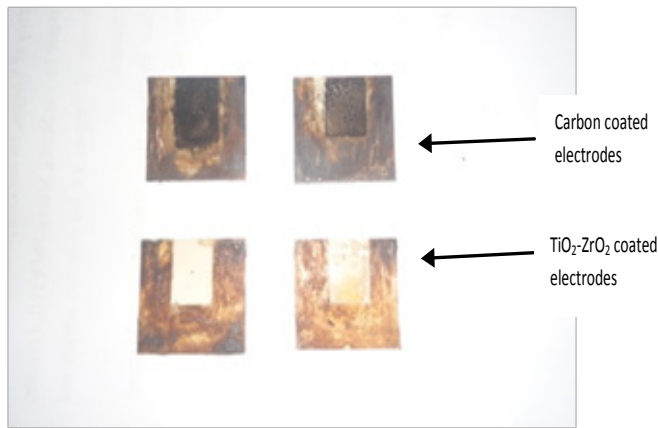


Fig.2: Carbon coated and TiO<sub>2</sub>-ZrO<sub>2</sub> coated electrodes

When the preparation of the positive and negative electrodes was completed, 1-2 drops of iodine were placed on the negative electrode. Two prepared glass slides were set together and the sandwiching of the two plates was offset so that each one had a small position exposed so that an alligator clamp could be attached as indicated in Fig.3.

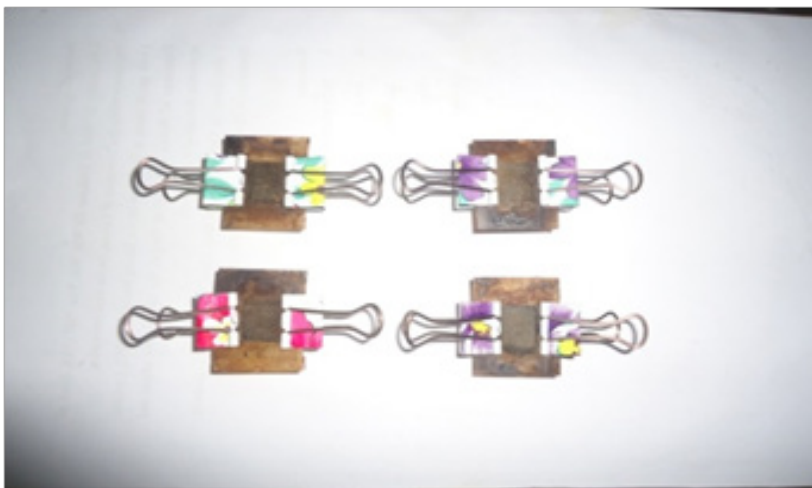


Fig.3: DSSCs with binder clips



## RESULTS AND DISCUSSIONS

### *Characterization of $\text{TiO}_2\text{-ZrO}_2$ Binary Oxide Power*

On the XRD pattern of  $\text{TiO}_2\text{-ZrO}_2$  binary oxide power ten peaks were clearly observed. The most dominant peak occurred at (101) peak shown  $\text{TiO}_2$  Anatase structure. The lattice distortion (or) lattice strain of other peaks after annealing indicates the good crystalline nature. Meanwhile,  $600^\circ\text{C}$  is shown to be the best temperature for this purpose. Fig.4 shows the XRD pattern of  $\text{TiO}_2\text{-ZrO}_2$  binary oxide at  $600^\circ\text{C}$ .

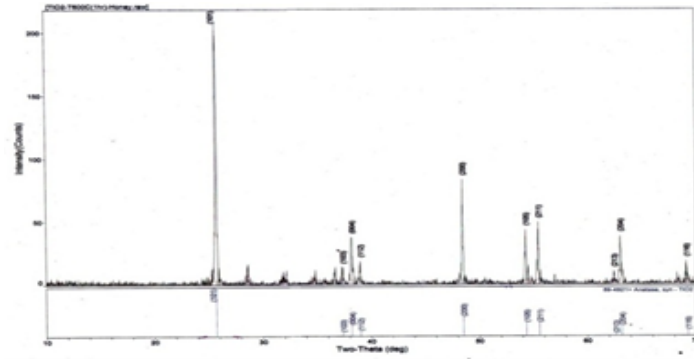


Fig.4: The XRD pattern of  $\text{TiO}_2\text{-ZrO}_2$  binary oxide at  $600^\circ\text{C}$

### *Solar Cell Evolution*

Fig.5 shows the change in photocurrent as a function of voltage with carrot solution. Some solar cell parameters such as conversion efficiency and fill factor were evaluated and listed in Table 1 and Table 2.

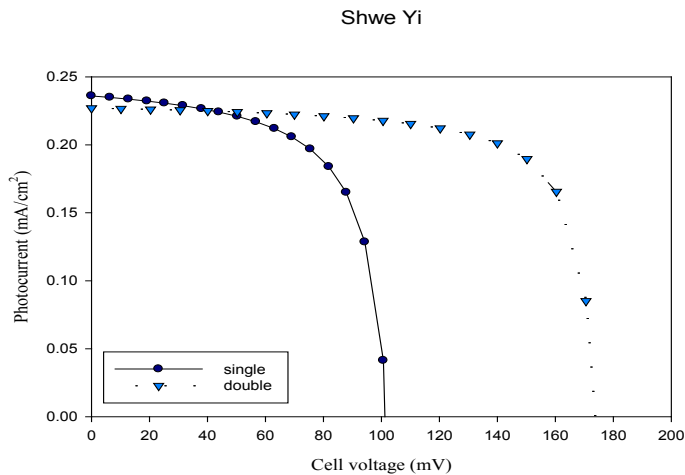


Fig.5: Current-voltage curves for Carrot sensitized solar cell

TABLE 1: Solar cell parameters of the cells with natural dye

TiO <sub>2</sub> -ZrO <sub>2</sub>	Im (mA)	Vm (mV)	Isc (mA)	Voc (mV)
Single	29.3	75.4	35.4	10.3
Double	28.6	150.0	34.1	17.4

TABLE 2: Efficiency and fill factor of the cells with natural dye

TiO <sub>2</sub> -ZrO <sub>2</sub>	Efficiency (%)	Fill Factor
Single	0.015	0.61
Double	0.030	0.72

## CONCLUSION

Preparation of TiO<sub>2</sub>-ZrO<sub>2</sub> binary oxide electrode (single & double layer coatings) with carrot extract was implemented in this study. The conversion efficiency of TiO<sub>2</sub>-ZrO<sub>2</sub> (double coating) (0.030%) was found to be higher than that of binary oxide at single coating (0.015%). The increase in efficiency was found to be due to the film thickness of coating. The fill factor of both the DSSC films was found to be within the range of accepted value for industrial purposes.

## ACKNOWLEDGEMENTS

The authors thank the Department of Physics, University of Yangon, Myanmar and Department of Electrical and Computer Engineering, Curtin University Sarawak Malaysia for the support rendered to this study.

## REFERENCES

- Abeygunawardhana, P., Palamakubura, S., Thotawattage, C. A., Dissanayake, M. A. K. L., & Senadeera, G. K. R. (2011). Nanocrystalline TiO<sub>2</sub> photo-sensitized with natural dyes. *Solar Asia 2011 International Conference*, pp. 229-235.
- Ali, R. A. M. & Nayan, N. (2010). Fabrication and analysis of dye-sensitized solar cell using natural dye extracted from dragon fruit. *International Journal of Integrated Engineering*, 55-62.
- Buradah, M. H., Teo, L. P., Yusuf, S. N. F., Noor, M. M., Careem, M. A., Majid, S. R., & Arof, A. K. (2011). *Chitosan-based Polymer Electrolyte For Dye-Sensitized Solar Cell*. Solar Asia 2011 International Conference.
- Ekanayake, P., Zain, R., Iskandar, M., Tennakoon, K., Yoshikawa, S., & Senadeera, R. (2011). Evaluation of dye from *Melastroma Melabathricum*: a native plant of Borneo, as potential natural colour for dye-sensitized solar cell. *Solar Asia 2011 International Conference*, 246-250.
- Flores, C., de Freitas, J. N., Longo, C., De Paoli, M. A., Winnischofer, H., & Nogueira, A. F. (2007). Dye-sensitized solar cells based on TiO<sub>2</sub> nanotubes and a solid-state electrolyte. *Journal of Photochemistry and Photobiology*, 189, 153-160.

- Fujihara, K., Kumar, A., Jose, R., Ramakrishna, S., & Uchida, S. (2007). Spray deposition of electrospun TiO<sub>2</sub> nanorods for dye-sensitized solar cell. *Nanotechnology*, 18, 1-5.
- Gratzel, M. (2003). Dye-sensitized solar cell. *Journal of Photochemistry and Photobiology C: Photochemistry Reviews*, 4, 145-153.
- Gratzel, M. (2004). Conversion of sunlight to electric powder by nanocrystalline dye-sensitized solar cells. *Journal of Photochemistry and Photobiology A: Chemistry*, 164, 3-14.
- Kakuta, N., Oku, T., Suzuki, A., Kikuchi, K., & Kikuchi, S. (2012). Effect of an amorphous TiO<sub>2</sub> addition on dye-sensitized solar cells with organic dyes. *Journal of Ceramic Processing Research*, 13(1), 28-31.
- Kim, S. S., Yum, J. H., & Sung, Y. E. (2005). Flexible dye-sensitized solar cells using ZnO coated TiO<sub>2</sub> nanoparticles. *Journal of Photochemistry and Photobiology A: Chemistry*, 269-273.
- Lin, T. W., Lin, J. R., Tsai, S. Y., Lee, J. N., & Ting, C. C. (2007). Absorption Spectra Analysis of Natural Dyes for Applications in Dye-sensitized Nano Solar Cell. The 32nd National Conference on Theoretical and Applied Mechanics, 21-22.
- Mane, R. S., Lee, W. J., Pathan, H. M., & Han, S. H. (2005). Nanocrystalline TiO<sub>2</sub>/ZnO thin films: fabrication and application to dye-sensitized solar cells. *J. Phys. Chem.*, 24254-24259.
- Neppolian, B., Wang, Q., Yamashita, H., & Choi, H. (2007). Synthesis and characterization of ZrO<sub>2</sub>-TiO<sub>2</sub> binary oxide semiconductor nanoparticles: Application and interparticle electron transfer process. *Applied Catalysis*, 333, 264-271.
- Nupearachchi, C. N., Wijayarathna, T. R. C. K., & Perera, V. P. S. (2011). *Utilization of natural pigment extracted from Henna leaf in combination with gelatine as a sensitizer in photoelectrochemical solar cell*. Solar Asia 2011 International Conference, pp. 28-30.
- Okoli, L. U., Ekpunobi, A. J., & Ozuomba, J. O. (2011). A comparative study of the performance of dye-sensitized solar cells based on antocyanin local dye and ruthenium dye. *Digest Journal of Nanomaterials and Biostructures*, 6, 1929-1934.
- Park, N. G., Kang, M. G., Ryu, K. S., Kim, K. M., & Chang, S. H. (2003). Photovoltaic characteristics of dye-sensitized surface-modified nanocrystalline S<sub>n</sub>O<sub>2</sub> solar cells. *Journal of Photochemistry and Photobiology A: Chemistry*, 1-6.
- Win, T. T., Maung, Y. M., & Soe, K. K. K. (2012). Characterization of Nano-sized ZnO Electrodes with Curcumin-derived Natural Dye Extract for DSSC Application. *American Journal of Materials Science and Technology*, 28-33.
- Win, T. T., Maung, Y. M., & Soe, K. K. K. (2012). Fabrication of TiO<sub>2</sub>-ZrO<sub>2</sub> Binary Oxide Electrode with Natural Dye (Rose) for Dye Sensitized Solar Cell Application. *Advanced Materials Research Journal*, 550-553, 2036-2039.
- Wongcharee, K., Meeyoo, V., & Chavadej, S. (2006). Dye-sensitized solar cell using natural dye extracted from rosella and blue pea flowers. *J. Solmat*, 11.
- Zhou, H., Wu, L., Gao, Y., & Ma, T. (2011). Dye sensitized solar cell using 20 natural dyes as sensitizers. *Journal of Photochemistry and Photobiology A: Chemistry*, 219, 188-194.



## **Information Technology: Impacts on Environment and Sustainable Development**

**Adib Kabir Chowdhury\* and Veeramani Shanmugan**

*Department of Electrical and Computer Engineering, Curtin University, Sarawak, Miri, Malaysia*

---

### **ABSTRACT**

In this modern world, Information Technology gives impacts on society, countries, economy, and environment. This paper discusses the positive, negative, direct and indirect impacts of IT on environmental issues. A strategy for sustainable development in ICT and its future demand are also proposed. Apart from that, a research was also done to find a quantitative indicator to show the relationship between demand in IT industry and impacts to the environment. By using a mathematical formula, an estimation of the effect to the environment can be found. By using the indicator, it is hoped that society and the IT industry will become more aware of their action to the environment.

*Keywords:* Environment, impact, information technology, sustainable development.

---

### **INTRODUCTION**

Information technology (IT) is one of the important aspect that makes the world as it is now. The role of IT in our daily life is very important as our quality of lives and the way we live tremendously depend on IT. This happens especially due to the rapid development of IT and its products. It has become essential in our daily life, and the IT industry has given significant impacts to our technical development. Most of the impacts to the environment are negative. In Information Technology, we will discuss in details the effects of Information Technology towards the environment.

As IT and the effects to environment are interconnected in many ways, society has to learn how to change this negative relationship into a positive one. Hence, the study proposes sustainability development that can help to balance and offset the bad effects of IT industry on the environment. In addition, the meaning of sustainable development and the challenges to be overcome to sustainability in IT industry will also be discussed in Environmental Impacts of Information Technology. After that, an approach to discuss further how the qualitative effect of the environment will also be suggested by using the formula and method

---

*Article history:*

Received: 7 October 2013

Accepted: 18 January 2014

---

*E-mail addresses:*

[s.veeramani@curtin.edu.my](mailto:s.veeramani@curtin.edu.my) (V. Shanmugan)

[adib.kabir@curtin.edu.my](mailto:adib.kabir@curtin.edu.my) (A.K. Chowdhury)

\*Corresponding Author

derived. The formula will later be proven by using a set of data, which depict the relationship between demand (for the purpose of this paper, demand indicate demand of electricity), gain and loss of a certain processes, and these will be discussed in Sustainable Development. Finally, some effective ways to reduce the environmental impacts will be put forward in *Sustainable Development in ICT*.

## **INFORMATION TECHNOLOGY**

The phrase Information Technology (IT) refers to an entire industry. The phrase information technology carries the definition of the use of computers and other gadgets (such as phones) and software to manage information. In some companies, this is referred to as Management Information Services (MIS) or simply as Information Services (IS). The information technology department of a large company is responsible for storing information, protecting information, processing the information, transmitting the information as necessary, and later retrieving information as necessary (Schneider, n.d.).

## **ENVIRONMENTAL IMPACTS OF INFORMATION TECHNOLOGY**

Information technology like many other creations, gives impacts to the society, economy and most importantly, the environment. The impacts information technology has can either be positive or negative and direct or indirectly harm effects to the surrounding. Below are the impacts of Information Technology.

### *First Order Impact*

The first order impacts of Information Technology mostly give direct effects towards the surrounding. Among the impacts that are rated as the first order are the manufacture of IT equipment such as computers, mobile phones, peripheral devices and satellites. Inside these products, there are various additional components used to produce IT equipments. Most manufacturing processes of these components pollute the environment. One of the examples of the pollution is the production of semiconductors that releases dangerous gases to the atmosphere such as acid fumes (Berkhout & Hertin, 2001). According to Hilty and Ruddy (2000) in their paper entitled, 'Towards a Sustainable Information Society', only 2% of the materials used in the production of personal computers become parts of the product. The remaining (98%) are dumped as wastes.

The second direct impact that is rated as the first order impact is the transportation of components and products of IT. Most of the components used for production of IT equipment come from all over the world. These components are imported to an assembly centre to assemble the products. After the production is done, the final IT products are exported to other places. The transportation process of IT equipment production will leave a significant carbon foot print that harms the environment.

Another direct first order impact is the consumption of energy by the ICT equipment. The increasing demand and supply for ICT devices increase electrical consumption. The increase in power consumption can cause more carbon foot print to the environment.

Last but not least, the direct impact of IT is the ever increasing amount of electronic waste (e-waste) that comprises old and considered outdated electronic devices. These devices are disposed off when the owners buy new and more advance equipment. Improper e-waste management will lead to pollution due to leak of lead, mercury and other toxic materials from the e-waste to the landfill. For example, cathode ray tubes if leaked will release heavy metal leaching to the ground water and harm the water source.

### *Second Order Impact*

The second order impacts of ICT industry are mostly positive to the surrounding. Most probably come with the fact how ICT development is managed to increase the economy via the use of information technology. The growth in economy is due to the change to utilise ideas compared to energy and material (Kelly, 1999). For example, the growth of economy in the United States in 1995-1998 was because of IT related businesses (Kelly, 1999). Other than that, IT also managed to change the way product and service is designed, produced, distributed and operated. The technology managed to do a simulation of these processes and thus give insights into the end results of the processes even before they are started. Via the usage of IT, the cost to complete these processes can be reduced significantly. Below are some detailed examples of how ICT can improve the processes of making products:

- Intelligent production processes: Through careful computer-aided design of production facilities and precise control of operations during production made possible by extensive sensors and automated controls.
- Intelligent design and operation of products: enabled by computer-aided, simulations of product performance result in 'lighter' products that use less materials to make them operate more efficiently; efficient sensors and controls ensure services/ functions are delivered efficiently when and where they are required.
- Reorganisation of supply chains and business organisation: E-commerce leads to the closure of retails outlets, more efficient inventory and chain management supply, and the rise of tele-working.
- The process of e-materialisation: The substitution of tangible goods for intangible services (for instance, the purchase of e-book rather than book or the purchase of music online rather than music CDs).

In conclusion, the IT industry has many impacts on the environment. Unfortunately, none of them gives a qualitative indicator that is used to evaluate the relationship between the demand and the impact of IT on the environment. This finally brings to this research which is intended to find a relationship between the three aspects and to provide a qualitative indicator on how the demand of IT industry affects the environment. With this clear, concise qualitative indicator, it is hoped that the industry will respond better to numerical indicators in terms of realising the importance of sustainable development in the IT industry.



## **SUSTAINABLE DEVELOPMENT**

There are many definitions of sustainable development, including this landmark one which first appeared in 1987:

*“Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”*

This was taken from the World Commission on Environment and Development’s report entitled, ‘Our Common Future’, which is also known as the Brundtland Report (United Nations, 1997).

Sustainable development is development that meets the needs of the present without compromising the ability of the future generations to meet their own. It contains within it two key concepts, namely:

- The concept of ‘needs’, in particular, the essential needs of the world’s poor, to which overriding priority should be given; and
- The idea of limitations imposed by the state of technology and social organization on the environment’s ability to meet the present and future needs.

Thus, the goals of economic and social development must be defined in terms of sustainability in all countries - developed or developing, market-oriented or centrally planned. Interpretations definitely vary but they must share certain general features and flow from a consensus on the basic concept of sustainable development and a broad strategic framework for achieving it. Development involves a progressive transformation of economy and society. A development path that is sustainable in a physical sense could theoretically be pursued even in a rigid social and political setting. Physical sustainability, however, cannot be secured unless development policies pay attention to such considerations such as changes in access to resources and in the distribution of costs and benefits. Even the narrow notion of physical sustainability implies a concern for social equity between generations, a concern that must logically be extended to equity within each generation.

## **CONCEPT OF SUSTAINABLE DEVELOPMENT**

According to the Brundtland Report, sustainable development aims to meet the basic needs of all people and provide all opportunities to everyone so that they can satisfy their aspiration for better life. This is because the main objective of development is to satisfy the basic human need. The basic needs especially in the developing countries are food, clothing, shelter and jobs, satisfaction of human needs and aspirations in the major objective of development. The report also claimed that a world in which poverty and inequity are endemic is susceptible to be ecological and other crises (United Nations, 1997). Below are detailed explanations of sustainable development concept adapted from Brundtland Report:

- Living standards that go beyond the basic minimum are sustainable only if consumption standards everywhere have regard for long-term sustainability. To achieve sustainable development, society has to promote consumption standard that are within the limit of ecological possible and to which all can reasonably aspire.
- Sustainable development will compete to make sure that societies meet human needs both by increasing productive potential and by ensuring or providing equitable opportunities for all.
- Sustainable development can only be pursued if demographic developments are in harmony with the changing productive potential of the ecosystem.
- To achieve sustainable development, human activities at minimum must not endanger the natural systems that support life on Earth: the atmosphere, the waters, the soils, and the living beings.
- The accumulation of knowledge and the development of technology can enhance the carrying capacity of the resource base. But ultimate limits there are, and sustainability requires that long before these are reached, the world must ensure equitable access to the constrained resource and reorient technological efforts to relieve the presume.

\* The points discussed above are taken and adapted from the Brundtland Report.

## **SUSTAINABLE DEVELOPMENT IN ICT**

Sustainable development has increasingly become important to all sectors especially business. Overuse of natural resources to meet ever increasing demands has shown its toll to the world we are living in right now. The rapid depletion of resources, as well as the negative impacts as a result of the need to fulfil demand of societies, has made the societies and corporate sector realise the importance of sustainability in their own industry. As such, more recently, a perspective has emerged that defines sustainability to include three components, namely, the natural environment, society, and economic performance. These components are mostly known as the triple bottom line (TBL). The TBL approach proposes that besides economic performance, organizations need to be aware of their act in activities that will give positive effect to the environment and the society. This TBL approach is a crucial to be used in all industries, especially in ICT (Dao, Langella, & Carbo, 2001).

Parallel to the new technology being introduced to our lives, the ICT sector has managed to give a big impact and change the way we live, communicate, work, learn and play. From mobile phones, tablets and micro-computer chips to the internet, ICT has successfully provided us with innovative products and services that are now becoming parts of everyday life. Unfortunately, the ever growing quantities of these innovative IT products and peripherals have made more wastes resulted from discards of old, broken IT products. As the demand for IT products and services increases, the data will also increase. This data and information require physical storage and hence access to reliable electricity to power up the servers that keep the data. These data centres have grown in number due to increasing demands hence making the data centres as the ‘factories’ of this century [1]. Fortunately, these ‘data factories’ do have a

choice to power the centres unlike the factories during the Industrial Revolution that relied heavily on coal-source energy generation. The ICT companies can opt to determine the kind of energy they use to power up their data centres.

## **CHALLENGES OF SUSTAINABILITY IN ICT INDUSTRY**

As many other good things in the world, there are many challenges to be faced in order to achieve sustainable development in the ICT industry. Below are some of explanations of these challenges.

### *Bad Decision Making Favouring Profit over Effects to the Environment*

With the development of technology, people can opt to keep their data online rather than wasting more money to keep them using their own storing devices. This step helps to reduce the additional need for peripherals such as flash drives or hard disk drives. Unfortunately, the step that is hoped to reduce significant usage of the IT products that may lead to less amount of e-waste produced will also have effects in increasing the energy used to power the data centres as more people keep their data online. The term cloud, or cloud computing, used as a metaphor for the internet, is based on an infrastructure and business model, whereby rather than being stored in your own devices - data, entertainment, news and other products and services are delivered to your device, in real time, from the Internet (Kelly, 1999).

As mentioned above, powering these massive storage facilities requires huge amounts of energy. Fortunately, with the technology that we have now, the energy source to power these data centres can come from a greener, renewable energy source. However, the decisions on how the cloud will be built are being made by business leaders who are more concerned with the higher cost of using renewable energy rather than the effects of using dirty energy that they prefer using on the environment. In January 2010, for example, Facebook built a new data centre in Oregon which is powered by PacificCorp, a utility that gets the majority of its energy from coal-fired power stations, the United States' largest source of greenhouse gas emissions (Greenpeace International, 2010). This act is one of the proofs how some IT companies are more concerned about money than the environment when they choose to power up their data centres with the cheapest electricity means available, which in many countries means dirty coal. Below are the data for carbon footprint produced by data centres that uses dirty energy (see Fig. 1).

In the graph above, it is clear that if cloud computing is a country, it would have been the fifth highest country in the world with high electricity consumption, making it one of the highest contributors of carbon footprint. In conclusion, the IT companies play a vital role and have to live up with it to reduce their carbon footprint in the ICT industries by making a wiser decision that will mostly benefit the world and the environment in the long run.

### *Lack of Awareness in the Society*

Another challenge towards sustainable development in the ICT industry is the lack of awareness in a society. This happens when the society especially the consumers do not care enough about

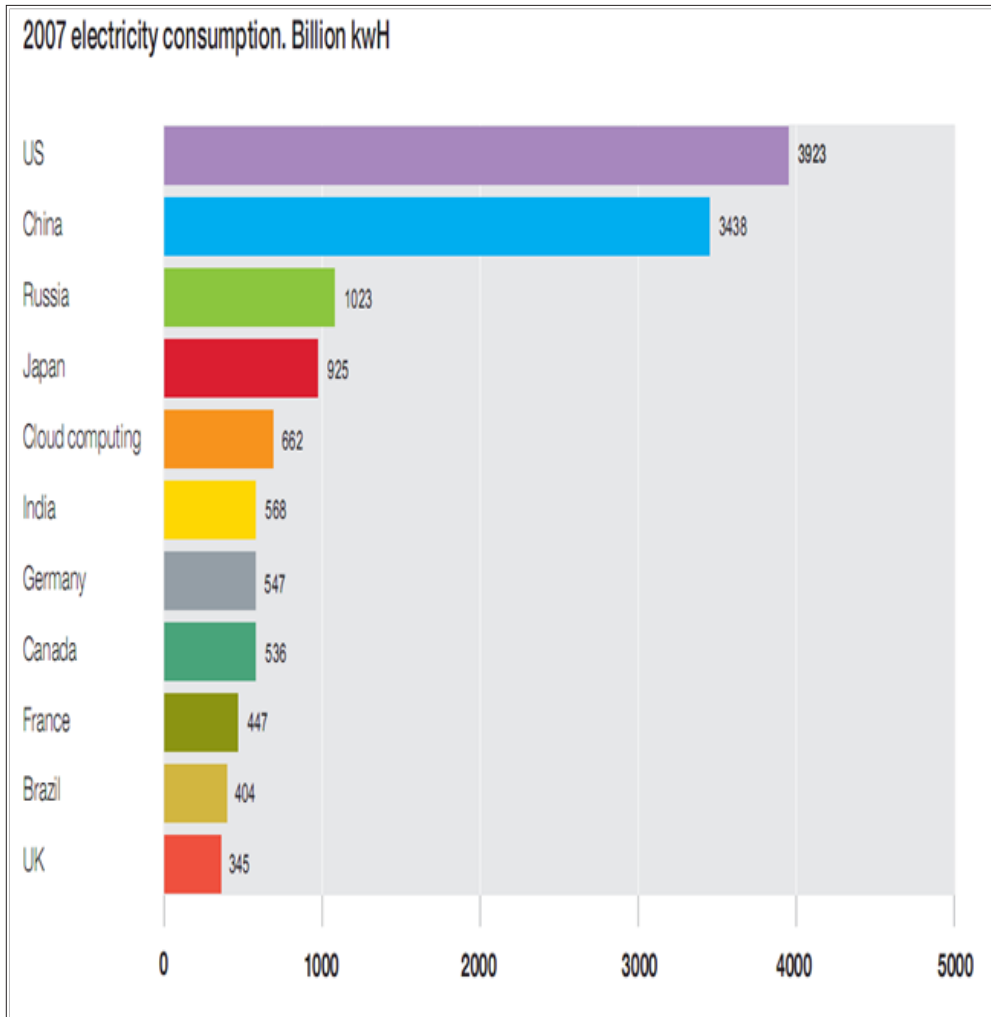


Fig.1: 2007 Electricity Consumption,billion kWh (Greenpeace International, 2011)

the consequences of the excess usage of IT products and peripherals, as well as the excessive usage of energy to power them. This can be overcome when the society is educated about the dangers and the effects of the problem mentioned above. The society must realise that everytime they change to the latest gadgets, the act will lead to increases of e-waste. Hence, the government and private bodies have to educate the people about this danger.

## DISCUSSION AND SUGGESTIONS

As explained earlier on, human activities and industries, such as the IT industry, give impact to the environment. In the case of the IT industry, there is not much we can do to eliminate all the impacts on the environment. As a responsible society, however, we should at least try our best to minimise the effects of our everyday activities while using and managing information and IT devices. In this section, we will try to look at the energy purchased by IT companies to manage their data centres.

While some companies opt to make good decisions by using renewable energy, there are many other IT companies that prefer to save their money by using dirty energy powered by coal burning. To see how certain acts of these companies benefit the quality of environment, a new formula is derived. The formula is  $E=(d*g)/l$ , where E refers to quality of the environment, d refers to demand of the IT industry (in this case, only the electric demand to power data centres is considered), g refers to gain added to the benefit of the environment (here, g refers to clean energy used to power the data centres) and l refers to the loss that impacts the environment (here, l means the dirty energy used to power data centres). The derivation of this formula is shown in details as follows:

#### Derivation of the Formula

$$E = 1/(NR) \quad [1]$$

$$E = x / (NR) \quad [2]$$

From the equation above, “x” considered to be the constant, which is considered to be the gain of the system. In this case, gain refers to the per unit consumption of the entity, namely, electricity, without causing any harm on the environment. As indicated earlier, the source of clean energy is considered to be the clean energy, assuming the source used is hydro electricity, which does not cause immediate harm to the environment. “NR” is considered to be a natural resource, using which we generate the electricity. If we consider ‘x’ to be our gain, the equation can then be rewritten as:

$$E = g / NR \quad [3]$$

$$E / g = 1 / (NR) \quad [4]$$

On the other hand, from the equation above “y” is considered to be the constant, which is the loss of the system. Here, loss refers to the per unit consumption of the entity, i.e. electricity, with causing any direct harm towards the environment. The source of dirty energy is known and considered as the non-environmentally friendly energy, assuming the source of electricity used is coal/petroleum/nuclear, etc., which cause immediate harm to the environment. “NR” is considered to be the natural resource, using which the electricity is generated. If ‘y’ is considered as our loss, the equation can therefore be rewritten as:

$$d = 1/NR \quad [5]$$

$$d = y / NR \quad [6]$$

If ‘y’ is considered as our loss, the equation can thus be rewritten as:

$$d = 1 / NR \quad [7]$$

$$d / L = 1 / NR \quad [8]$$

From equations 8 and 4, we can conclude that:

$$d / l = 1 / NR = E / g \quad [9]$$

The equation can be rewritten and represented as follows:

$$E / g = d / l \tag{10}$$

Hence, the formula is:

$$E = (d.g) / l \tag{11}$$

As the quality of environment, E, is proportionate to both gain added to the environment, g, and the demand, attempt to reduced the demand must be done (Table 1).

TABLE 1: Demand of electricity for various companies

Companies	Demand of Electricity, d(*MW)	Dirty Energy Used, l(*MW)	Clean Energy Used, g(*MW)
Amazon	98.05	84.41	13.64
Apple	146	134.79	11.21
Dell	12	5.24	6.76
Facebook	307	196.61	110.39
Google	564	341.87	222.13
Hp	172	148.03	23.97
IBM	99.5	88.09	11.41
Microsoft	252	177.43	74.57
Oracle	19	17.74	1.26
Rackspace	44	30.49	13.51
Salesforce	11.5	11.04	0.46
Twitter	7	5.51	1.494
Yahoo	74.2	35.07	39.13

## RESULTS

Below is a graph depicting the trend of electricity demand and also the trend of the uses of clean and dirty energy. As shown below, the trend of dirty energy used to fulfil the demand of electricity is higher than the trend of the clean energy used (Fig. 2).

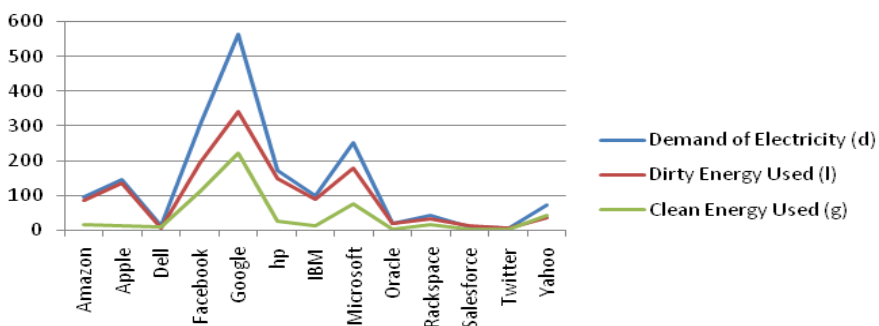


Fig.2: Demand of Electricity and Trend on Type of Energy Used

Next, depicted below is the result of effect on the environment with respect to demand. What can be seen is the higher the demand, the higher the effect will be on the environment. E is an indicator that can be used by companies to measure how much or how high they can affect the environment. Hence, to reduce the effect to environment, the demand of electricity must also be reduced. Below is the calculation of  $E=dg/l$  based on demand (Table 2).

TABLE 2: Calculation of  $E=dg/l$  based on demand

Companies	Demand of Electricity /MW	Effect to Environment
Amazon	98.05	15.84
Apple	146	12.14
Dell	12	5.24
Facebook	307	172.37
Google	564	366.46
hp	172	27.85
IBM	99.5	12.89
Microsoft	252	108.98
Oracle	19	1.35
Rackspace	44	19.5
Salesforce	11.45	0.48
Twitter	7	1.9
Yahoo	74.2	19.32

The graph below is a representation of the trend in the demand for electricity and its effects on the environment. The graph is the results generated from Table 3. Here, it can be clearly observed that the effect to environment follows the same trend as the demand for electricity. This further clarifies the relationship between them (Fig. 3).

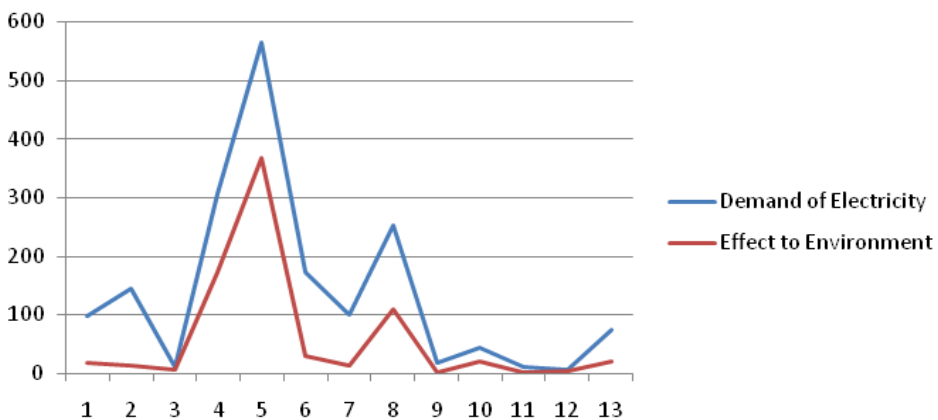


Fig.3: Trend of demand of electricity and its effect to environment

Figure 4 is a representation of the graph based on the relationship of the demand for electricity and its effect on the environment. Figure 5 depicts the relationship between the two variables, with the demand of electricity as the independent variable and the effect to the environment as the dependent variable. It can be seen that the effect on the environment increases linearly with respect to the demand for electricity.

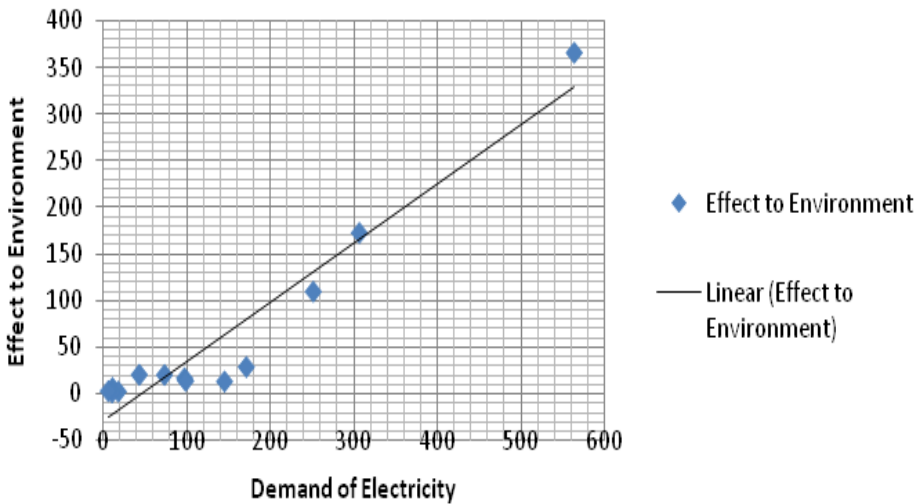


Fig.4: Relationship between Demand Of Electricity and Effect to Environment

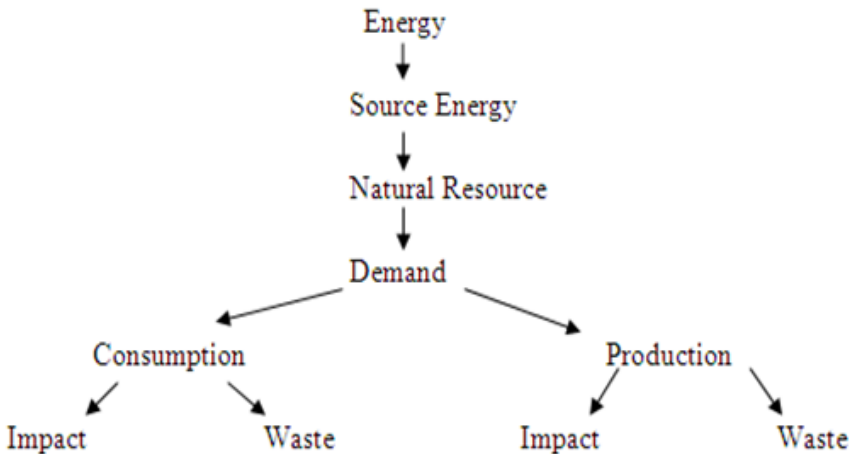


Fig.5: The Representation of Energy Distribution, Recycling and Production of Resources

Lastly, the chart provides a flow of relation between the demand and its impact, particularly to the environment. As shown, the demand leads to production and consumption of a product.



As explained earlier, the products here mean the ICT devices and peripherals plus energy used in the production, consumption and managing the wastes of the ICT industry. As a result of the demand, more products are made, leading to more effects to environment. Hence, it is important to emphasize once again that by decreasing demand, the impacts on the environment can be reduced to achieve sustainability.

## CONCLUSION

From the data gathered in the previous section, the demand can be clearly and quantitatively shown to have a significant relation with the impact to the environment. Hopefully by using the formula discussed above, the result (i.e. E) can be used as an indicator to signify how much a company in the IT industry affects the environment. It is also hoped that the companies and particularly the consumers can reduce their demands so as to reduce the effects on the environment as the relationship between these two elements has quantitatively been proven in this research.

Besides that, an awareness toward the direct impacts of this relationship should exist in the society. The society, as well as the ICT companies, should make their choice wisely in using resources so that it will be easier to achieve sustainability of the environment. When smart decisions are made, it is possible to reduce the demand for IT products, while sustainable development and progress in the ICT industry can be achieved at the same time.

## REFERENCES

- Berkhout, F. & Hertin, J. (2001). *Impacts of Information and Communication Technologies on Environmental Sustainability: Speculations and Evidence*. Report to the OECD, Frans Berkhout and Julia Hertin, University of Sussex, United Kingdom.
- Dao, V., Langella, I., & Carbo, J. (2001). From Green to Sustainability: Information Technology and an Integrated Sustainable Framework. *The Journal of Strategic Information Systems*, 20(1), 63-79.
- Greenpeace International. (2010, March). *Make IT Green: Cloud Computing and Its Contribution to Climate Change*. Retrieved July 6, 2012, from <http://www.greenpeace.org/international/Global/international/planet-2/report/2010/3/make-it-green-cloud-computing.pdf>
- Greenpeace International. (2011, April). *How Dirty is Your Data*. Retrieved July 6, 2012, from <http://www.greenpeace.org/international/Global/international/publications/climate/2011/Cool%20IT/dirty-data-report-greenpeace.pdf>
- Greenpeace International. (2012, April). *How Clean is Your Cloud*. Retrieved July 7, 2012, from <http://www.greenpeace.org/international/Global/international/>
- Hilty, L. & Ruddy, T. (2000). Towards a Sustainable Information Society. *Informatik / Informatique*, 4, 2-9.
- Kelly, H. (1999). *Information Technology and the Environment: Choices and Opportunities*. Retrieved July 13, 2012, from [www.cisp.org](http://www.cisp.org)
- Pinto, V. (2008). E-Waste Hazard: The Impending Challenge. *Indian Journal of Occupational and Environmental Medicine*, 12(2), 65-70.

Schneider, L. (n.d.). *IT Definition*. Retrieved July 13, 2012, from <http://jobsearchtech.about.com/od/careersintechnology/p/ITDefinition.html>

United Nations. (1997). *Our Common Future*. Oxford University Press.



## Experimental Study on Mixed Convection Heat Transfer in a Square Duct with Varying Inclination Angles

G. Rajamohan<sup>1\*</sup>, R. Narayanaswamy<sup>2</sup> and P. Kumar<sup>3</sup>

<sup>1</sup>Department of Mechanical Engineering, Curtin University, CDT 250, 98009 Miri, Sarawak, Malaysia

<sup>2</sup>Department of Mechanical Engineering, Curtin University, GPO Box U 1987, Perth WA 6845, Australia

<sup>3</sup>Department of Chemical Engineering, Curtin University, CDT 250, 98009 Miri, Sarawak, Malaysia

### ABSTRACT

This study analysed mixed convection heat transfer for thermally developing flow in a side heated square duct with varying inclination angles. The test section consists of one-side heated isothermal wall and three adiabatic walls. The inclination angle varied from 0° to 20°, with hot wall temperature ranging from 30°C to 100°C, and heat flux ranging from 252 W/m<sup>2</sup> to 872 W/m<sup>2</sup>. Reynolds number was varied from 858 to 1788 and the wall surface emissivity was considered to be 0.05 and 0.85. Flow visualizations were carried out to obtain the flow structure of natural convection and mixed convection for three inclination angles. The variation of surface temperature along the length of the test section was studied to calculate the convective Nusselt number. The result showed that the heat transfer enhancement and convective Nusselt number was significantly affected by the variations of inclination angle, flow velocity, Reynolds number, and the surface radiation. It was also observed that the increase in the inclination angle improved convection rate and hence significantly enhanced heat transfer.

*Keywords:* Mixed convection, Square duct, Thermally developing, Radiation effects

### INTRODUCTION

Heat transfer phenomenon in which natural and forced convection mechanisms interact is termed 'combined' or mixed convection. The performance of thermal energy conversion devices depends on the energy exchange that takes place through various heat and fluid flow processes prevailing in these devices. A better understanding of fluid flow and heat transfer helps in a better design of energy conversion devices.

The rate and the amount of heat transfer by the working fluid depend on certain factors such as the geometry, type of flow, and the thermal boundary conditions. Due to well-known advantages, air is a common working

---

#### Article history:

Received: 7 November 2013

Accepted: 18 January 2014

---

#### E-mail addresses:

[rajamohan.g@curtin.edu.my](mailto:rajamohan.g@curtin.edu.my) (G. Rajamohan)

\*Corresponding Author

fluid in electronic equipment. A closer look at the literature shows that more experimental work is needed to examine the characteristics of the transport mechanisms due to the interaction between surface radiation and mixed convection in horizontal and vertical ducts. The radiative interaction between the walls of the duct and its effects on mixed convection heat transfer are of great importance in the design of these systems. Therefore, more research on flow and heat transfer through ducts is needed.

The emissivity of the walls of the duct and the surface radiation from the walls of the duct will affect the overall heat transfer coefficient in duct flows.

In the case of enclosures and cavities, even at moderate temperatures, surface radiation does significantly affect free convection heat transfer rates. Radiation and convection effects, without considering their interaction, lead to significant errors as radiation and convection effects are competingly important. The importance of the surface radiation effects is identified in this research, and accounted for, in the analysis of flow and heat transfer involving horizontal and vertical ducts.

A wide range of both experimental and numerical studies on mixed convection heat transfer in horizontal and vertical flows with radiation effects has been presented for both developed and thermally developing flow (Jackson *et al.*, 1989; Yan & Li, 2001; Chandratilleke *et al.*, 2010; Rajamohan *et al.*, 2011; Barletta *et al.*, 2003; Barletta *et al.*, 2005; Gao *et al.*, 2000; Yang *et al.*, 2009; Maughan & Incropera, 1987; Maughan & Incropera, 2009; Ramesh & Venkateshan, 2001; Chang & Lin 1997; Dogan *et al.*, 2005; Rajamohan *et al.*, 2011). It can be inferred from these works that the Nusselt number depends on flow regime and also on the radiation effects. A closer look at the published literature reveals that no experimental studies have been done on mixed convection heat transfer in a square duct with inclined walls and heated from the side wall. It can also be observed that no experimental study has so far considered the analysis of mixed convection in horizontal and vertical ducts provided with differentially heated walls.

## EXPERIMENTAL METHODOLOGY

The experimental apparatus consists of an air blower with speed-controller, portable test section, measuring probes, data logger and a power supply unit (see Fig.1). The blower provided air through the test section from the inlet of the test section to the exit, with an operating range of 3 -12 V DC, and had a diameter of 36 mm. The blower was connected to the laboratory DC power supply with a regulator to provide the desired voltage. The flow rate was measured by using an anemometer (Testo 425) with an accuracy of  $\pm 1.5$  %. The anemometer probe was inserted from a small hole of 7 mm diameter located on the top side of the test section to measure the airflow velocity within the duct. Table 1 shows the dimensions of the test section and flow conditions (Coleman & Steele, 1989).

TABLE 1: Dimensions of the Test Section

AR	W (mm)	H (mm)	L (mm)	Dh (mm)	U (m/s)	Re
1	54	54	270	54	0.24	858
1	54	54	270	54	0.50	1788

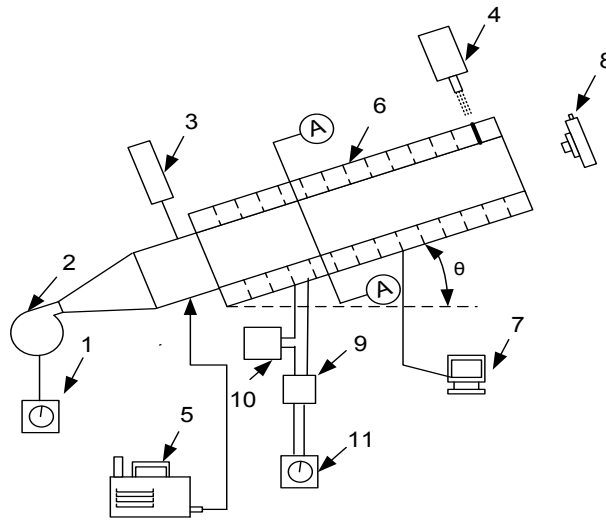


Fig.1: A schematic view of the experimental rig (1 & 11). Power supply, 2. Centrifugal Blower, 3. Anemometer, 4. Illuminator, 5. Smoke generator, 6. Test section, 7. Data logger, 8. Camera, 9. Voltmeter, 10. Ammeter.).

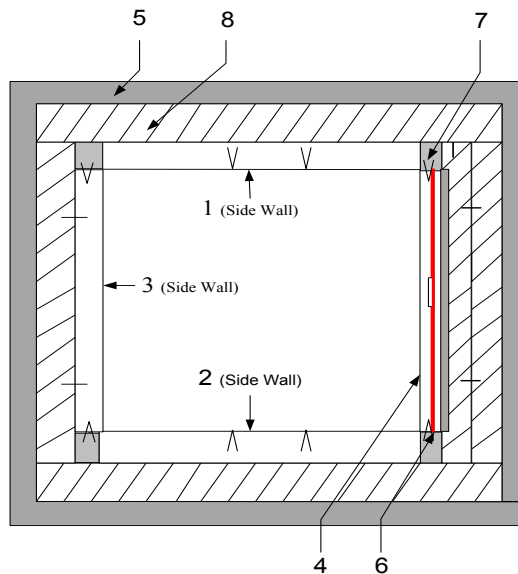


Fig.2: A sectional (A-A) view of the square test cell (54 mm x 54 mm) (1, 2 and 3. Adiabatic walls, 4. Isothermal hot walls, 5. Insulation, 6. Electric heater, 7. Thermocouples, 8. Wood ).

Fig.2 shows the schematic view of the test section which consists of differentially heated isothermal wall and three adiabatic walls. Other details pertaining to experimental set up and

procedure can be found elsewhere (Rajamohan *et al.*, 2011). The walls made of Perspex were milled based on the design requirement. In assembling the test section, one of the most important considerations was to make sure that there was no physical contact between the walls. Slots were provided at all corners of the test section such that there was no conduction heat transfer across the walls. Glass-wool was used as the insulation material to avoid air circulation in the slots. For temperature measurement, thermocouples were embedded in the top and bottom walls at various locations. The distance between the two neighbouring thermocouple rows was 15 mm, while the spacing between the neighbouring columns was 54 mm, with a total of 6 thermocouples fixed in each row. Black paint was applied on the side walls in order to obtain a surface emissivity of about 0.85 or provided with very thin aluminium foil so as to obtain a surface of emissivity of about 0.05 (Coleman & Steele, 1989). Details of the experimental procedure can be found elsewhere (Rajamohan *et al.*, 2011).

## EXPERIMENTAL UNCERTAINTY

The accuracy of experimental results depends on the accuracy of the individual measuring instruments. An uncertainty analysis was conducted on all the measured quantities calculated from the measured results. The procedure suggested by Coleman and Steele (Coleman & Steele, 1989) was used in the analysis. The overall uncertainty was found to be  $\pm 3\%$  for Nusselt number.

## RESULTS AND DISCUSSION

This study covered flow variables in the range of Reynolds number  $Re = 858$  and  $1788$ , heat  $253 \text{ W/m}^2$  to  $872 \text{ W/m}^2$ , and hot wall temperature from  $40^\circ\text{C}$  to  $100^\circ\text{C}$ .

The convection heat transfer from the hot wall surface was calculated as:

$$Q_{\text{conv}} = Q_t - Q_{\text{cond}} \quad (1)$$

Where,  $Q_{\text{cond}}$  is the heat loss by conduction along the heat. Conduction heat transfer rate across was found to be negligible in all the cases. The convection heat flux was calculated as follows:

$$q_{\text{conv}} = Q_{\text{conv}} / A_s \quad (2)$$

is the heat loss by conduction along the heated wall  
where  $A_s = H \times L$

$$Nu = q_{\text{conv}} D_h / (T_h - T_m) k_m \quad (3)$$

where,

$$T_m = (T_{in} + T_{ow}) / 2 \quad (4)$$

$T_h$  is hot wall temperature. Surface temperature depends on heat flux, emissivity of walls, Reynolds number, the flow entrance condition and the length of the entrance section. In this work, the effect of inclination angle was studied. The surface temperature profile on the duct walls is shown in Fig.3 and Fig.4.

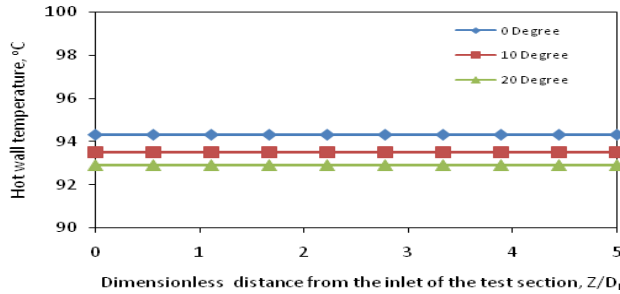


Fig.3: Heat wall surface temperature profiles

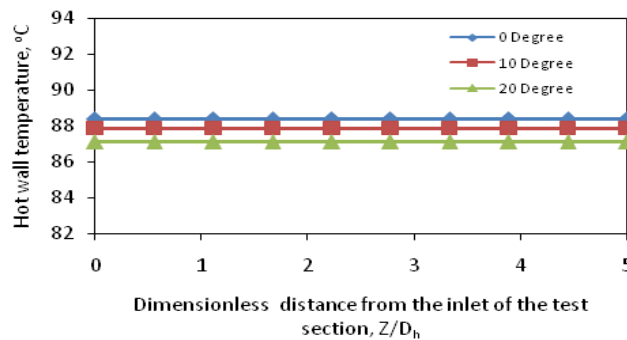


Fig.4: Heat wall surface temperature profiles

Fig.3 and Fig.4 show the surface temperature profile on the heated wall with weak ( $\epsilon = 0.05$ ) and strong ( $\epsilon = 0.85$ ) radiation for  $Re = 1788$ . It can be observed that the surface temperature was uniform along the length of the cell. Moreover, the increase in inclination angle results in the decrease of temperature.

Fig.5 through Fig.8 show the difference of the both (top and bottom) wall inside temperature from the inlet of the test section to the exit for a Reynolds number of 1788. Fig.5 shows that the maximum top wall average surface temperature of  $66.1^\circ\text{C}$ , which was obtained for the case of a duct having highly polished surface ( $\epsilon = 0.05$ ) with heat flux  $862 \text{ W/m}^2$  and  $42.1^\circ\text{C}$  was obtained for the case of a duct having black surface ( $\epsilon = 0.85$ ) with heat flux  $728 \text{ W/m}^2$ . Fig.7 shows that the highest bottom wall average surface temperature of  $46.1^\circ\text{C}$ , which was obtained for the case of a duct having highly polished surface ( $\epsilon = 0.05$ ) with heat flux  $862 \text{ W/m}^2$  and  $32.4^\circ\text{C}$  obtained for the case of a duct having black surface ( $\epsilon = 0.85$ ) with heat flux  $728 \text{ W/m}^2$ . In this case, low inclination angle was maintained higher top wall temperature than higher inclination angle.



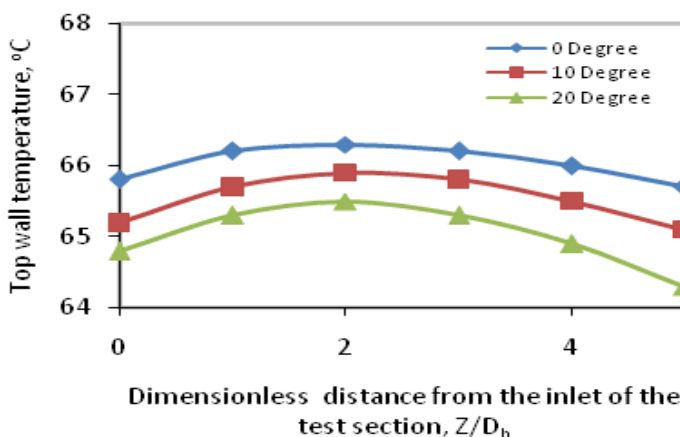


Fig.5. Top wall surface temperature profile

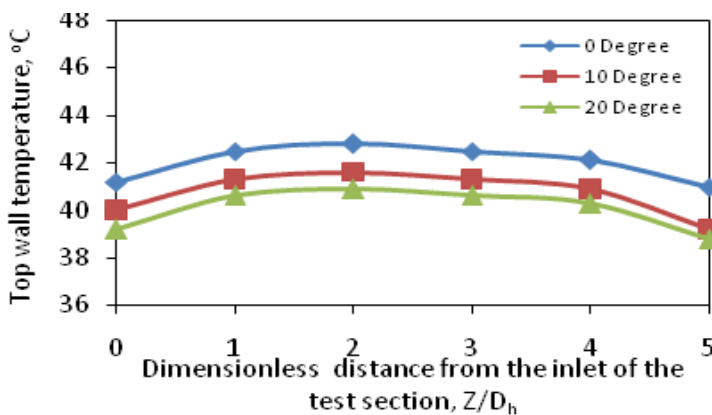


Fig.6. Top wall surface temperature profile

In addition, for a low hot wall temperature, the average top and bottom wall temperature was found to be unaffected by the surface emissivity of the duct walls. For a specific value of the input wall heat flux, the temperature drop per unit length of the test section was found to be the same for all the cases. The differences in the top and bottom wall temperatures are due to the result of interaction of mixed convection and surface radiation. For mixed convection cases due to strong natural convection, the average top wall temperature is always higher than the bottom wall temperature. The effect of surface radiation along the inside surfaces of the walls is brought in through the wall emissivity. Surface radiation affects the overall heat transfer rate. It was observed that radiation has a multiple effect of contributing to the overall heat transfer enhancement and decrease of the convective component.

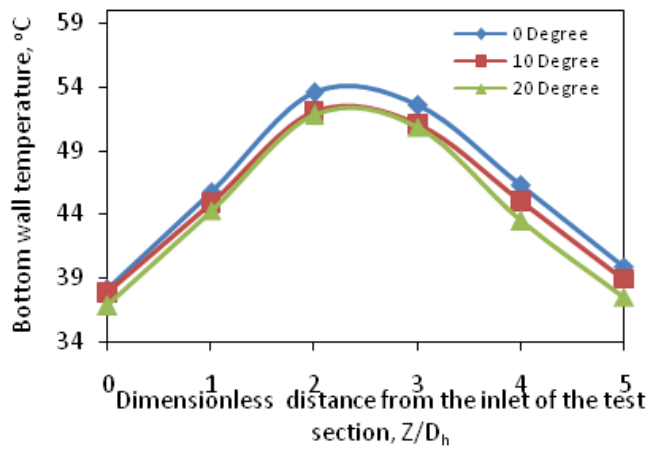


Fig.7. Bottom wall surface temperature profile

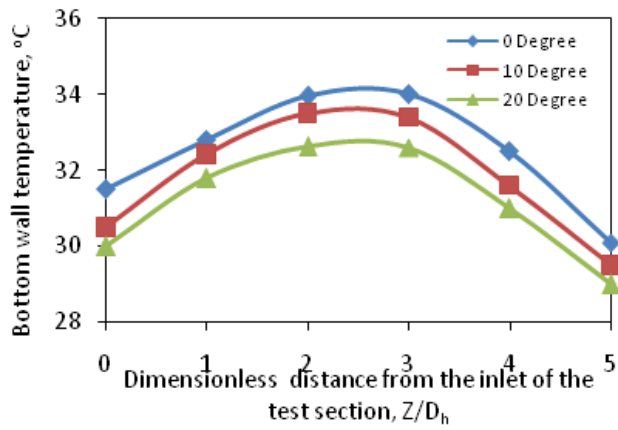


Fig.8. Bottom wall surface temperature profile

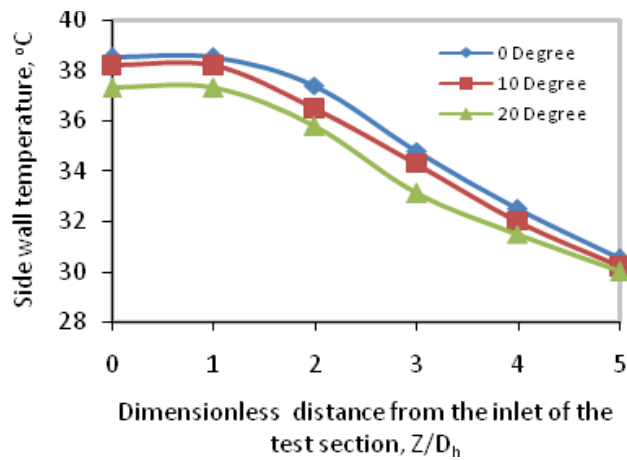


Fig.9. Side wall surface temperature profile

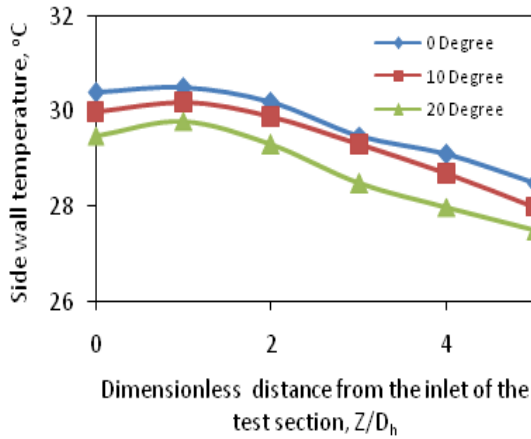


Fig.10. Side wall surface temperature profile

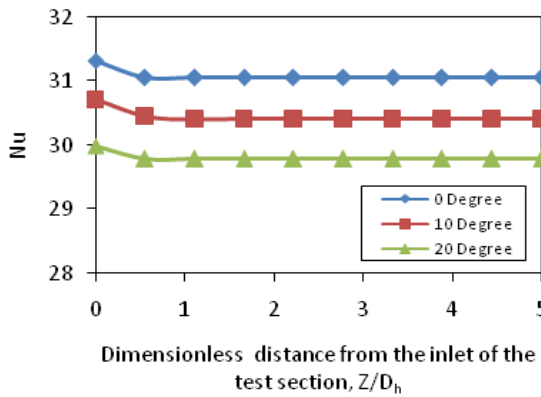


Fig.11. Local convective Nusselt number profile with varying inclination angles.

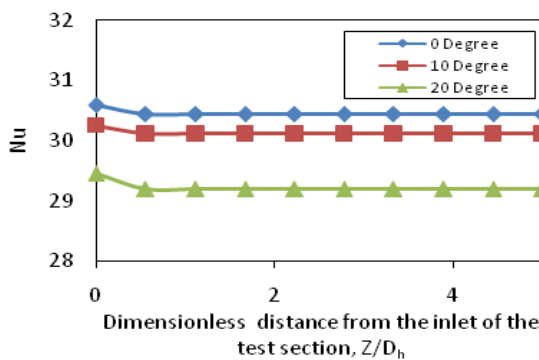


Fig.12. Local convective Nusselt number profile with varying inclination angles

Figures 9 and 10 show the side wall surface temperature profile. The side wall temperature was maintained lower than the bottom wall. Figures 11 and 12 present the variation of local average convective Nusselt number at the heated wall with different emissivity of high heat flux for Reynolds number ( $Re = 1788$ ). The pattern of the graphs shows that the Nusselt number

values for both emissivity cases, 0.05 and 0.85, are of the same order. However, the temperature range is higher for polished than black surface. Considering the effect of inclination angle, the local average convective Nusselt number for high heat flux with higher inclination angle was found to be 31.1 and 30.5 for the polished and black surface, respectively. The local average convective Nusselt number for the polished surface is 4.2 % higher for higher inclination angle than lower inclination angle. Similarly, the local average convective Nusselt number for black surface is 4.3% higher for higher inclination angle than lower inclination angle.

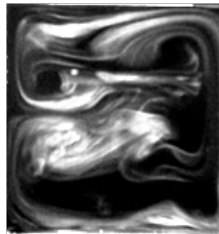


Fig.13. Mixed convection flow pattern in the square duct (inclination 0°).

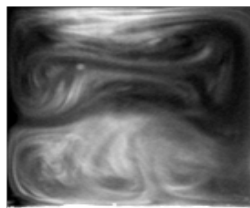


Fig.14. Mixed convection flow pattern in the square duct (inclination 10°)

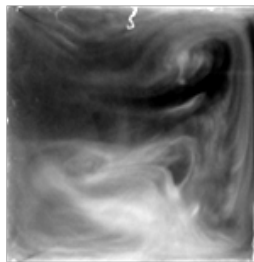


Fig.15. Mixed convection flow pattern in the square duct (inclination 20°)

Figures 13 to 15 show the mixed convection flow structure for the square duct with varying divergent angles. The flow visualization result shows that the polished surface heated wall temperature is always higher than black surface. The above figures (13 to 15) show that the flow moves upward and accumulates near the top wall adjacent to the hot wall of the duct and circulated to the cold wall on the opposite side. This flow further moves downward and gets as close as to the bottom of the duct depending on the heat flux value. The accumulated flow is thermally stable. The stable conditions can reduce the heat transfer enhancement because of the buoyancy force. It can be seen that the flow pattern is dissimilar for each angle due to the variation of inclination angle.

## CONCLUSION

The variation of the surface temperature was found to be significantly affected by the inclination angle. As the inclination angle increased, the heated wall temperature decreased. It was observed that the convective Nusselt number increased when the inclination angle of the test section increased. Polished surface emissivity appears to have higher convective Nusselt number compared to the black surface emissivity. It could be seen that the convective Nusselt number appeared to be higher for high Reynolds number. Meanwhile, flow visualisation results showed that the hot fluid transfers upward and gathers near the top wall. As a result, the top wall causes higher average temperatures than other adiabatic walls.

## ACKNOWLEDGMENTS

This work was funded by Curtin Sarawak, Malaysia.

## REFERENCES

- Barletta, A., Magyari, E., & Keller, B. (2005), Combined forced and free flow in a vertical rectangular duct with prescribed wall heat flux. *International Journal of Heat and Mass transfer*, 24, 874-887.
- Barletta, A., Rossi, D. S. E., & Zanchini, E. (2003). Combined forced and free flow in a vertical rectangular duct with prescribed wall heat flux. *International Journal of Heat and Fluid Flow*, 24, 874-887.
- Chandratilleke, T. T., Ramesh, N., & Wangdham-koom, P. (2010). *Convective heat transfer in airflow through a duct with thermal radiation*. IOP Conference Series 10 Materials Science and Engineering, 012026.
- Chang, M. Y. & Lin, T. F. (1997). Experimental study of aspect ratio effects on longitudinal vortex flow in mixed convection of air in a horizontal rectangular duct. *International Journal of Heat and Mass Transfer*, 41, 719-733.
- Coleman, H. W. & Steele Jr, W. G. (1989), *Experimentation and Uncertainty Analysis for Engineers* (2nd ed.), New York: John Wiley & Sons.
- Dogan, A., Sivrioglu, M., & Baskaya, S. (2005), Experimental investigation of mixed convection heat transfer in a rectangular channel with discrete heat sources at the top and at the bottom. *International Communications in Heat and Mass Transfer*, 32, 1244-1252.
- Gau, C., Jeng, Y. C., & Liu, C. G. (2000). An experimental study on mixed convection in a horizontal rectangular channel heated from a side. *Transactions of the ASME Journal of Heat Transfer*, 122, 701-707.
- Jackson, J. D., Cotton, M. A., & Axcell, B. P. (1989). Studies of mixed convection in vertical tubes. *International Journal of Heat and Fluid Flow*, 10, 1-15.
- Maughan, J. R. & Incropera, F.P. (1987). Experiments on mixed convection heat transfer for airflow in a horizontal and inclined channel. *International Journal of Heat and Mass Transfer*, 30, 1307-1318.
- Maughan, J. R. & Incropera, F.P. (1990). Regions of heat transfer enhancement for laminar mixed convection in a parallel plate channel. *International Journal of Heat and Mass Transfer*, 33, 555-570.
- Rajamohan, G., Ramesh, N., & Kumar, P. (2011). Study on Mixed Convection Heat Transfer in Vertical Ducts with Radiation Effects. *World Academy of Science, Engineering and Technology*, 81, 2070-3740.

- Rajamohan, G., Ramesh, N., Alexander, G., & Kumar, P. (2011). *Experimental study on mixed convection heat transfer for thermally developing flow in horizontal ducts with radiation effects*. ASME/JSME 8th Thermal Engineering Joint Conference, 44174.
- Ramesh, N. & Venkateshan, S. P. (2001). Experimental study of natural convection in a square enclosure using differential interferometer. *International Journal of Heat and Mass Transfer*, 44, 1107-1117.
- Yan, W. M. & Li, H. Y. (2001). Radiation Effects on Mixed convection heat transfer in a vertical square ducts. *International Journal of Heat and Mass Transfer*, 44, 1401-1410.
- Yang, C. S., Liu, C. G., & Gau, C. (2009), Study of channel divergence on the flow and heat transfer in horizontal ducts heated from a side. *International Journal of Thermal Sciences*, 48, 105-113.



## Microstructure Analysis, Physical and Thermal Properties of Al<sub>2</sub>O<sub>3</sub>-Al<sub>2</sub>TiO<sub>5</sub> Functionally Graded Ceramics for the Application of Car Brake Rot

Rong Kimberly, F. P.<sup>2</sup>, Oo, Z.<sup>1\*</sup> and Sujan, D.<sup>2</sup>

<sup>1</sup>Department of Electrical and Computer Engineering, School of Engineering and Science, Curtin University, Sarawak Malaysia, CDT 250, Senadin, Miri, Malaysia

<sup>2</sup>Department of Mechanical Engineering, School of Engineering and Science, Curtin University, Sarawak Malaysia, CDT 250, Senadin, Miri, Malaysia

### ABSTRACT

Aluminium titanate (AT) (Al<sub>2</sub>TiO<sub>5</sub>) is a promising engineering material because of its low thermal expansion coefficient, excellent thermal shock resistance, good refractoriness and non-wetting with most metals. Functionally graded material (FGM) is generally a particulate composite with continuously varying volume fractions. FGMs are alternative materials for dental implants, building materials and ballistic protection. It has been of great interest to future engines, internal combustion engines, metal cutting and other high temperature engineering application. There has been a demand for an adequate disc brake that requires less maintenance in the automotive manufacturing industry. FGM, the next evolution of layered structure, consists of graded compositions that are dispersed across the ceramic which produces a gradual improvement in the properties across the ceramic at a steady pace.

*Keywords:* Functional Graded Materials, Aluminium titanate, refractory, excellent thermal shock resistance

### INTRODUCTION

AT, with the pseudo-brookite structure, is the only compound in the alumina-titania system. It is an excellent refractory and thermal shock resistant material due to its relatively low thermal expansion coefficient ( $1 \times 10^{-6} \text{ }^\circ\text{C}^{-1}$ ), thermal conductivity (0.9 to 1.5 W/m.K) and

high melting point (1860°C) (Kato *et al.*, 1980). Due to the effects of atmosphere and annealing time on the thermal stability of Al<sub>2</sub>TiO<sub>5</sub>- based, Al<sub>2</sub>TiO<sub>5</sub> is stable with no apparent phase decomposition for up to 5h at 1100°C in air and becomes unstable between 1100-1280°C when it undergoes a eutectoid-

#### Article history:

Received: 7 November 2013

Accepted: 18 January 2014

#### E-mail addresses:

[zeya.oo@curtin.edu.my](mailto:zeya.oo@curtin.edu.my) (Oo, Z.)

[d.sujan@curtin.edu.my](mailto:d.sujan@curtin.edu.my) (Sujan, D.)

[kimbuali@gmail.com](mailto:kimbuali@gmail.com)(Rong Kimberly, F. P)

\*Corresponding Author



like decomposition to  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> and TiO<sub>2</sub> (rutile) (Oo, 2012). The process of decomposition in Al<sub>2</sub>TiO<sub>5</sub> is reversible at above 1350°C (Oo, 2012). Currently, the braking system is the most important thing for the transportation affairs in the world. The traditional disc brake rotors in use today are fabricated by gray cast iron (Borgiolo *et al.*, 2004). Jun Qu and co-workers (2009) presented the feasibility of using excellent coefficient friction level (0.35-0.50) by using oxygen-diffused titanium a candidate brake rotor material. High density, thermal conductivity and specific heat capacity of gray cast iron are 7.6 g/cm<sup>3</sup>, 47.3 W/m°C and 0.498 J/g. K, respectively (Kimberly *et al.*, 2011). Till now, the best candidate brake rotor material for the future generation replacement of the car brake rotors in terms of the relationship between high speed and less coefficient of friction is still unsatisfactory yet. Therefore, it is anticipated that Al<sub>2</sub>TiO<sub>5</sub> FGM ceramics may replace conventional gray cast iron for better thermal performance in car brake rotor. Moreover, due to its low density compared to gray cast iron, Al<sub>2</sub>TiO<sub>5</sub> FGM ceramics, it is a fuel saving option for car brake rotor (Sujan *et al.*, 2012). At present, there has been no significant research performed on the application of FGM in the car brake rotor manufacturing. In this paper, an assessment of the microstructure analysis and a preliminary investigation of the physical and thermal properties of FGM Al<sub>2</sub>O<sub>3</sub>- Al<sub>2</sub>TiO<sub>5</sub> (AT) are presented.

## MATERIALS AND METHODS

### *Sample Preparation*

Al<sub>2</sub>TiO<sub>5</sub> (AT) Aluminium titanate was synthesized by molar ratio method, using one mole of Al<sub>2</sub>O<sub>3</sub> and one mole of TiO<sub>2</sub>. Two different FGM samples group preparations were introduced. The first sample group preparation, based on the creation of thin interface of graded (A, B, and C) three batches of Al<sub>2</sub>O<sub>3</sub>/Al<sub>2</sub>TiO<sub>5</sub> composite without layers, was sandwiched between an outer layer of 100%Al<sub>2</sub>O<sub>3</sub> and 100%AT with the thickness range from 0.3cm, 0.4 cm and 0.5 cm, respectively. The second sample group preparation provided the FGM samples with the sandwich, graded (D, E, F, and G) four batches layers of 50%Al/50%AT, 75%Al 25%AT, 25% AT and 25%Al/75% AT, with the thickness range from 0.3cm to 0.5 cm, respectively. The samples were uniaxial die-pressed at 5000 PSI for 20 seconds by a Blackhawk Uniaxial Press to allow solidification. The FGM samples were sintered at 1200°C for an hour by using LENTON AWF 12/12.

### *Radial Shrinkage*

Radial shrinkages were measured for all the seven batches of the FGM samples using Vernier Caliper. The diameters of the FGM samples were measured from the top surface (Al<sub>2</sub>O<sub>3</sub> layer) with percentage increments until the bottom surface (Al<sub>2</sub>TiO<sub>5</sub> layer). The radial shrinkage (S<sub>r</sub>) was calculated using equation (1).

$$S_r = \frac{D - D_{\text{measured}}}{D} \times 100 \quad (1)$$

D = diameter (cm),

D<sub>measured</sub> = measured diameter (cm)

### Density and Porosity

The FGM samples 100%Al<sub>2</sub>O<sub>3</sub>/100%Al<sub>2</sub>TiO<sub>5</sub>, with the thickness of 0.4 cm and 0.5 cm, 50%Al<sub>2</sub>O<sub>3</sub>/50% Al<sub>2</sub>TiO<sub>5</sub> sandwich layers thickness of 0.3 cm and 0.4 cm were utilized and measured for the density and porosity test. Firstly, the dry, sintered and cooled samples were weighed using a digital weighing scale with an uncertainty of ± 0.01g. Secondly, the samples were soaked in water for approximately 24 hours before being they were weighed again, suspended in air as well as suspended in de-ionized water. Finally, bulk density ( $D_b$ ), apparent solid density ( $D_{as}$ ) and apparent porosity ( $P_a$ ) were then calculated using the formulas:

$$D_b = \frac{m_D}{m_s - m_i} \times D_i$$

$$D_{as} = \frac{m_D}{m_D - m_i} \times D_i \quad (2)$$

$$P_a = \frac{m_s - m_D}{m_s - m_i} \times 100$$

$m_D$  = Mass of dry sample (g)

$m_i$  = Mass of sample saturated with and suspended in water (g)

$m_s$  = Mass of sample saturated with water and suspended in air (g)

$D_i$  = Density of water (1 g m<sup>-3</sup>)

### Thermal Conductivity

The FGM samples 50%Al<sub>2</sub>O<sub>3</sub>/50%Al<sub>2</sub>TiO<sub>5</sub> (thickness=0.5 cm) and 75%Al<sub>2</sub>O<sub>3</sub> + 25% Al<sub>2</sub>TiO<sub>5</sub> (thickness=0.3cm) /25%Al<sub>2</sub>O<sub>3</sub> + 75%Al<sub>2</sub>TiO<sub>5</sub> (thickness=0.3 cm) were used to test for the thermal conductivity by using the Graded Heat Flow method.

### Scanning Electron Microscopy

Scanning Electron Microscopy (SEM) has been used for analyzing the surface imaging of samples, mostly showing the cross-sectional microstructure of the materials. Due to the type of signals produced by backscattered electrons (BSE), the decomposition characteristics of Al<sub>2</sub>TiO<sub>5</sub> at 1100°C for coarse grain, medium grain and fine grain are shown in Figures 4 (a-c).

## RESULTS AND DISCUSSION

### Radial Shrinkage

Radial shrinkage (%) with percentage distance for all FGM seven groups are shown in Figures 1-3. It is very evident that the FGM samples have undergone non-uniform shrinkage. One of the factors that leads to the non-uniformly shrinkage is the porosity of both Al<sub>2</sub>O<sub>3</sub> and Al<sub>2</sub>TiO<sub>5</sub>.

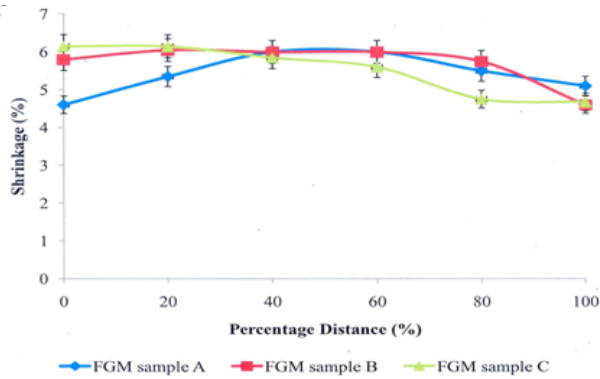


Fig.1. Shrinkage (%) vs. percentage distance for A, B, and C, FGM layers

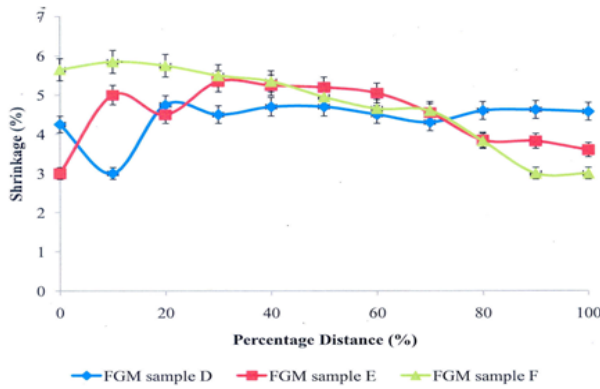


Fig.2. Shrinkage (%) vs. percentage distance for D, E and F, FGM layers

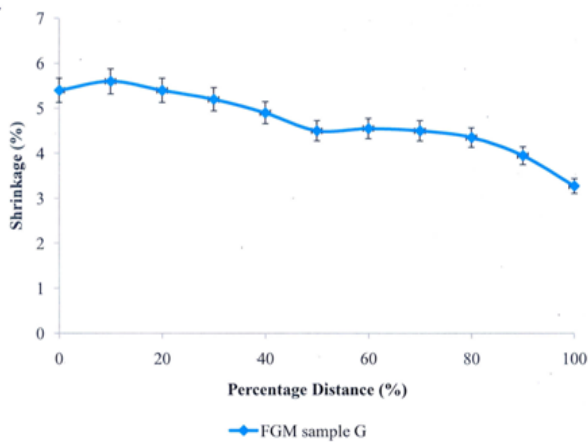


Fig 3. Shrinkage (%) vs. percentage distance for FGM – G

Shrinkage plays an important role in the suppression of defect forming during sintering. When a ceramic is sintered, it shrinks and experiences a reduction of porosity and an improvement in mechanical integrity. These changes occur due to the coalescence of the powder particles into a dense mass, where the reduction in total particle surface area is caused by surface energies being larger in magnitude than grain boundary energies. Necks are formed along the contact regions between adjacent particles during the initial sintering stage. Grain boundary then forms within each neck and every interstice between the particles becomes a pore (Callister, 2003). Shrinkage was measured for all the samples in the first group A, B, and C (sintered at 1200°C for 1 hour) and second group, D, E, and F (sintered at 1200°C for 1 hour), averaged and then grouped into three groups, depending on the thickness of the outermost alumina layer and the temperature they were sintered at 1200°C. The results were then graphed using the surface of the alumina layer as the starting point (Figures 1-3).

The effect is due to the fact that the two materials of alumina and aluminium titanate have vastly differing coefficients of thermal expansion and porosity. Thus, their shrinkage rates would be vastly different. The aluminium titanate is vastly more porous than the alumina, and thus does not incur shrinkage at the rate that the alumina would because it possesses greater pore size that will take longer to reduce in size. The large difference in thermal expansion coefficients also depicts the difference in dimensional change with temperature variations, in such that alumina dimensions will change at a rate of approximately eight times more than that of aluminium titanate. The effects of non-uniform shrinkage could be lessened by introducing more discrete steps across the cross-section of the sample of the sample.

### *Density and Porosity*

The FGM samples B, C, D and F were tested for their density and porosity. The calculated bulk density and apparent porosity are tabulated in Table 1.

TABLE 1: Bulk Density and porosity values for the FGM samples (Tatt, 2010)

FGM sample	Bulk Density ( $\rho_s$ g/cm <sup>3</sup> )	Apparent Porosity (%)
B	15.7	21.9
C	15.1	23.4
D	9.76	38.4
E	10.1	38.6

The results that can be observed are the bulk density decreases while the apparent porosity increases with the introduction of the intermediate functionally graded layer (50% Al<sub>2</sub>O<sub>3</sub> + 50% Al<sub>2</sub>TiO<sub>5</sub>). This may be the influence of Al<sub>2</sub>TiO<sub>5</sub> on the FGM samples as a whole as Al<sub>2</sub>TiO<sub>5</sub> is less dense than Al<sub>2</sub>O<sub>3</sub>. Al<sub>2</sub>TiO<sub>5</sub> has a very low coefficient of thermal expansion and a low bulk density compared to Al<sub>2</sub>O<sub>3</sub> and thus a build-up of residual stress will occur during sintering, which tends to hinder densification due to debonding between the grains of Al<sub>2</sub>O<sub>3</sub> and Al<sub>2</sub>TiO<sub>5</sub>.

Another factor is that  $Al_2TiO_5$  has large pores; therefore, there are many larger interstices between the particles which create larger pores that need to be reduced. This results in the lowering of the overall density of the material. Still, the  $Al_2O_3$  layer and the  $Al_2TiO_5$  layer would not see much of a reduction in density compared to their stand alone counterparts.

### Thermal Conductivity

From the second group of FGM, the F and G samples were tested for the thermal conductivity by using the graded heat flow method (see Fig.4), in which the temperatures from both  $Al_2O_3$  (alumina) side (heat source) and the  $Al_2TiO_5$  (AT) side was measured. The results are shown in Table 2.

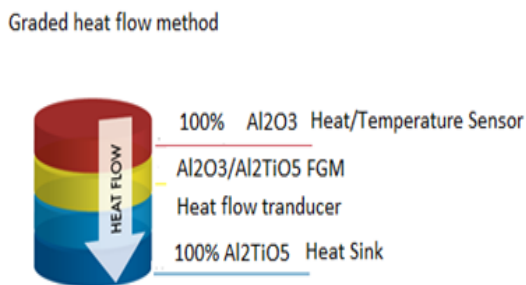


Fig. 4. Thermal conductivity tested by using the Graded heat flow method (Adopted from <http://www.Thermalphysics.com>)

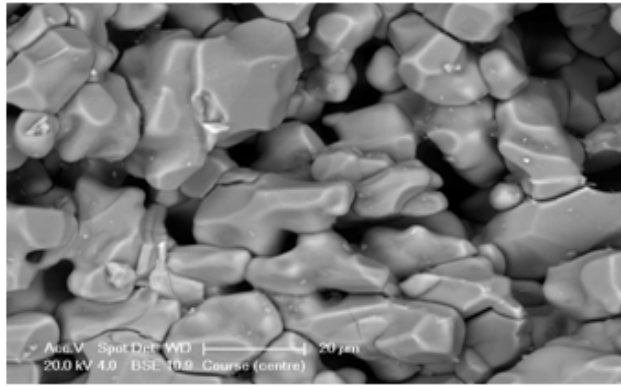
Table 2: Bulk Density and porosity values for the FGM samples

FGM samples	Thermal conductivity, k (W/m. K)
F	267.29 ± 0.02
G	256.33 ±0.02

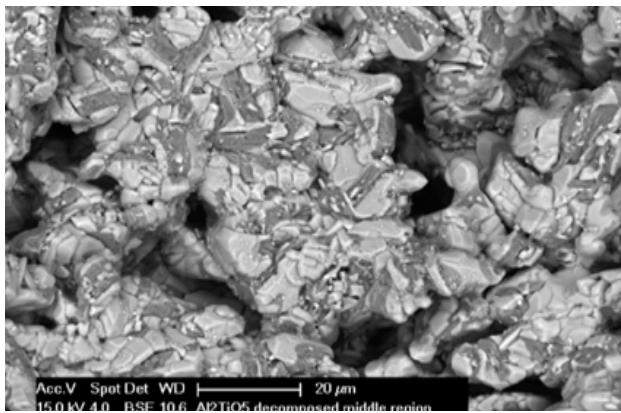
The resulting thermal conductivity is significantly higher compared to stand alone alumina and  $Al_2TiO_5$  (AT). It is clear that the influence of alumina on the FGM samples as a whole is greater than  $Al_2TiO_5$  (AT). In addition,  $Al_2TiO_5$  (AT) also increased due to the FGM arrangement.

### Scanning Electron Microscopy Analysis

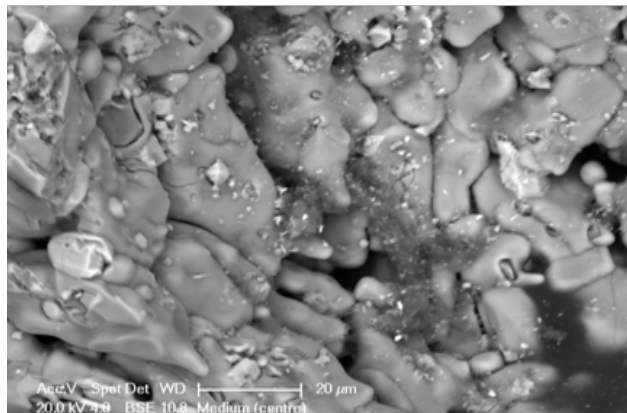
The microstructure of as-sintered  $Al_2TiO_5$  sample is shown in Fig.4 (a, b and c) where relatively large and smooth grains of 10-20  $\mu m$  formed with occasional appearance. When this sample was isothermally decomposed at 1100°C for 22 h, finer grains of rutile (white) and  $\alpha-Al_2O_3$  (dark) can be seen to form in-situ within the original  $Al_2TiO_5$  (light gray) grain as shown in Figures 4 (a) and (b). The microstructure of the as-sintered  $Al_2TiO_5$  sample is shown in Fig. 4 (a, b and c), where relatively large and smooth grains of 10-20  $\mu m$  formed with occasional appearance.



(a)



(b)



(c)

Fig. 4 (a-c). Back-scattered electron micrographs showing the microstructure of (a) as sintered  $\text{Al}_2\text{TiO}_5$  coarse grain size and (b) isothermally decomposed  $\text{Al}_2\text{TiO}_5$  fine grain size at  $1100^\circ\text{C}$  for 22 h. (c)  $\text{Al}_2\text{TiO}_5$  medium grain size decomposed at  $1100^\circ\text{C}$  for 22 h Legend: White phase is rutile ( $\text{TiO}_2$ ), light gray is  $\text{Al}_2\text{TiO}_5$ , dark gray is  $\alpha$ - $\text{Al}_2\text{O}_3$  and black are pores and cracks (Adopted from Oo, 2012).

When this sample was isothermally decomposed at 1100°C for 22 h, finer grains of rutile (white) and  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> (dark) can be seen to form in-situ within the original Al<sub>2</sub>TiO<sub>5</sub> (light gray) grain as shown in Fig. 4(a) and 4(b) (Oo, 2012). This physical separation or decomposition of Al<sub>2</sub>TiO<sub>5</sub> into finer grains of alumina and rutile has not resulted in observable shrinkage or disintegration of the decomposed sample. In fact, the decomposed sample appears to be harder and stronger due to the presence of alumina and rutile in the microstructure. However, the development of secondary intragranular porosity can be seen in the decomposed microstructure which concurs with the work of Henniecke and Lingenberg (Manurung, 2001).

## CONCLUSION

On the basis of the above finding, the following are the physical and thermal properties of Al<sub>2</sub>O<sub>3</sub>-Al<sub>2</sub>TiO<sub>5</sub> main points that can be summarized. The radial shrinkages of FGM Al<sub>2</sub>O<sub>3</sub>-Al<sub>2</sub>TiO<sub>5</sub> were observed by using the defects concepts due to the sintering process. Meanwhile, the density, porosity and thermal conductivity of FGM Al<sub>2</sub>O<sub>3</sub>-Al<sub>2</sub>TiO<sub>5</sub> were studied and the influence of Al<sub>2</sub>TiO<sub>5</sub> is the most significant for decomposition at 1100°C. Hence, the microstructure evaluation for the combination of 50% Al<sub>2</sub>O<sub>3</sub> and 50% Al<sub>2</sub>TiO<sub>5</sub>, 75% Al<sub>2</sub>O<sub>3</sub> and 25% Al<sub>2</sub>TiO<sub>5</sub>, 25% Al<sub>2</sub>O<sub>3</sub> and 75% Al<sub>2</sub>TiO<sub>5</sub> were observed and verified the results of physical properties.

Isothermally decomposition of Al<sub>2</sub>TiO<sub>5</sub> was confirmed by Scanning-Electron Microscope. The typical microstructure of as-sintered coarse-grained Al<sub>2</sub>TiO<sub>5</sub> prior to thermal ageing can be attributed to the pronounced thermal expansion anisotropy of Al<sub>2</sub>TiO<sub>5</sub> during cooling from an elevated temperature. The presence of these microcracks is believed to impart a low fracture strength but high thermal shock resistance to Al<sub>2</sub>TiO<sub>5</sub> (Oo, 2012). Following isothermal-ageing in air at 1000°C for 14 h, both needle-like and angular particles could be seen to form on the surface of Al<sub>2</sub>TiO<sub>5</sub> grains. Those nano-sized particles were identified alpha-Al<sub>2</sub>O<sub>3</sub> and TiO<sub>2</sub> at the edge and centre of the coarse, medium and fine grained samples of isothermally decomposed Al<sub>2</sub>TiO<sub>5</sub> during 10 h (Oo, 2012). It should be noted that the decomposition characteristics of Al<sub>2</sub>TiO<sub>5</sub>-based ceramics at 1100°C is highly significant. On the other hand, an appropriate coefficient of friction level, wear volume and wear rate of Al<sub>2</sub>O<sub>3</sub>-Al<sub>2</sub>TiO<sub>5</sub> FGM car brake rotor still need to be studied for the commercial brake system.

## ACKNOWLEDGEMENTS

This project was funded by the Curtin Sarawak Collaboration Research (CSCR), Approval number 4011, 2010-2012. The authors would like to thank to Mr Jonathan Yong Chung Tatt, Tokuyama (Malaysia) Sdn Bhd., B.E. (Mechanical Engineer 2010), for his contribution in conducting experimentation on the density, porosity and thermal conductivity of FGM.

## REFERENCES

- Borgioli, E., Galvanetto, E., Fossati, A., & Pradelli, G. (2004). Glow-Discharge and Furnace Treatments of Ti-6Al-4V, *Surface Coating Technology*, 184, 255-262.
- Callister, W. D. (2003). *Materials Science and Engineering, An Introduction* (6th edition). New York: John Wiley & Sons, Inc.

- Kato, E., Daimon, K., & Takahashi, K. 1980. Decomposition Temperature of beta-Al<sub>2</sub>TiO<sub>5</sub>. *Journal of the American Ceramic Society*, 63, 355-356.
- Kimberly, F. P. R., Gorin, A., Sujan, D., & Oo, Z. (2012). On the Problem of Novel Composite Materials Development for Car Brake Rotor. *International Journal of Engineering and Physical Sciences*, 6, 333-336.
- Manurung, P. (2001). *Microstructural Design and Characterisation of Alumina/Aluminium Titanate Composites*. (PhD Thesis). Curtin University, Australia.
- Oo, Z. (2012). *Characterisation of Thermal Stability, Microstructures and Properties of Al<sub>2</sub>TiO<sub>5</sub>- and Ti<sub>3</sub>SiC<sub>2</sub>-based Ceramics*. (Ph D Thesis). Curtin University. Australia.
- Qu, J., Blau, P. J., & Jolly, B. C. (2009). Oxygen-Diffused Titanium as a Candidate Brake Rotor Material, *Wear*, 267, 818-822.
- Sujan, D., Oo, Z., Hahman, M. E., Maleque, M. A., & Tan, C. K. (2012). Physio-mechanical Properties of Aluminium Metal Matrix Composites Reinforced with Alumina and Silicon Carbide. *International Journal of Engineering and Applied Sciences*, 6, 288-291.
- Tatt, Y. C. (2010). Fabrication and Mechanical Properties of Functionally Graded Ceramics Al<sub>2</sub>O<sub>3</sub>-Al<sub>2</sub>TiO<sub>5</sub>. *Final Year Project Report*, Curtin University Sarawak Malaysia.





## REFEREES FOR THE PERTANIKA JOURNAL OF SCIENCE AND TECHNOLOGY

VOL. 23(1) JAN. 2015

The Editorial Board of the Journal of Science and Technology wishes to thank the following for acting as referees for manuscripts published in this issue of JST.

Abd Manan Samad  
*(UiTM, Malaysia)*

Abdul Aziz Abdul Rahman  
*(UM, Malaysia)*

Abdul Jalil Abdul Kader  
*(USIM, Malaysia)*

Abdul Manaf Bohari  
*(UUM, Malaysia)*

Abu Abdullah  
*(UTeM, Malaysia)*

Aida Hanum Ghulam Rasool  
*(USM, Malaysia)*

Ashish M. Gujarathi  
*(Sultan Qaboos University, Oman)*

Azlin Baharudin  
*(UKM, Malaysia)*

Barsoum Nader  
*(UMS, Malaysia)*

Bassim H. Hameed  
*(USM, Malaysia)*

Biswa Mohan Biswal  
*(USM, Malaysia)*

Biswajeet Prahdan  
*(UPM, Malaysia)*

C. S. Kannan  
*(The Petroleum Institute Abu Dhabi, UAE)*

Che Hassan Che Haron  
*(UKM, Malaysia)*

Hatta Sidi  
*(UKM, Malaysia)*

Hejar Abdul Rahman  
*(UPM, Malaysia)*

Idawaty Ahmad  
*(UPM, Malaysia)*

Mohd Sanusi S. Ahamad  
*(USM, Malaysia)*

Moola Mohan Reddy  
*(Curtin University Sarawak, Malaysia)*

Myo Min Than  
*(Yangon Technological University, Myanmar)*

Norsa'adah Bach  
*(USM, Malaysia)*

Ong Puay Hoon  
*(UMS, Malaysia)*

Papita Das  
*(National Institute of Technology Durgapur, India)*

Rajamohan Ganesan  
*(Curtin University Sarawak, Malaysia)*

S. Jayashri  
*(Adhiparasakthi Engineering College, India)*

Than Zaw Htwe  
*(Yangon Technological University, Myanmar)*

Yin Maung Maung  
*(Yangon University, Myanmar)*

---

UPM- Universiti Putra Malaysia

USM- Universiti Sains Malaysia

UM- Universiti Malaya

UKM- Universiti Kebangsaan Malaysia

UiTM- Universiti Teknologi MARA Malaysia

UUM- Universiti Utara Malaysia

UMS- Universiti Malaysia Sabah

USIM- Universiti Sains Islam Malaysia

UTeM- Universiti Teknikal Malaysia Melaka

---

While every effort has been made to include a complete list of referees for the period stated above, however if any name(s) have been omitted unintentionally or spelt incorrectly, please notify the Chief Executive Editor, *Pertanika* Journals at [nayan@upm.my](mailto:nayan@upm.my).

Any inclusion or exclusion of name(s) on this page does not commit the *Pertanika* Editorial Office, nor the UPM Press or the University to provide any liability for whatsoever reason.



# *Pertanika*

*Our goal is to bring high quality research to the widest possible audience*

## **Journal of Science & Technology**

### **INSTRUCTIONS TO AUTHORS**

(Manuscript Preparation & Submission Guidelines)

Revised: June 2014

*We aim for excellence, sustained by a responsible and professional approach to journal publishing.  
We value and support our authors in the research community.*

Please read the guidelines and follow these instructions carefully; doing so will ensure that the publication of your manuscript is as rapid and efficient as possible. The Editorial Board reserves the right to return manuscripts that are not prepared in accordance with these guidelines.

#### **About the Journal**

*Pertanika* is an international peer-reviewed journal devoted to the publication of original papers, and it serves as a forum for practical approaches to improving quality in issues pertaining to tropical agriculture and its related fields. *Pertanika* began publication in 1978 as Journal of Tropical Agricultural Science. In 1992, a decision was made to streamline *Pertanika* into three journals to meet the need for specialised journals in areas of study aligned with the interdisciplinary strengths of the university. The revamped Journal of Science and Technology (JST) is now focusing on research in science and engineering, and its related fields. Other *Pertanika* series include Journal of Tropical Agricultural Science (JTAS); and Journal of Social Sciences and Humanities (JSSH).

JST is published in **English** and it is open to authors around the world regardless of the nationality. It is currently published two times a year i.e. in **January** and **July**.

#### **Goal of *Pertanika***

Our goal is to bring the highest quality research to the widest possible audience.

#### **Quality**

We aim for excellence, sustained by a responsible and professional approach to journal publishing. Submissions are guaranteed to receive a decision within 12 weeks. The elapsed time from submission to publication for the articles averages 5-6 months.

#### **Indexing of *Pertanika***

*Pertanika* is now over 33 years old; this accumulated knowledge has resulted in *Pertanika* JST being indexed in SCOPUS (Elsevier), EBSCO, Thomson (ISI) Web of Knowledge [CAB Abstracts], DOAJ, Google Scholar, ERA, ISC and MyAIS.

#### **Future vision**

We are continuously improving access to our journal archives, content, and research services. We have the drive to realise exciting new horizons that will benefit not only the academic community, but society itself.

We also have views on the future of our journals. The emergence of the online medium as the predominant vehicle for the 'consumption' and distribution of much academic research will be the ultimate instrument in the dissemination of the research news to our scientists and readers.

#### **Aims and Scope**

*Pertanika* Journal of Science and Technology aims to provide a forum for high quality research related to science and engineering research. Areas relevant to the scope of the journal include: *bioinformatics, bioscience, biotechnology and bio-molecular sciences, chemistry, computer science, ecology, engineering, engineering design, environmental control and management, mathematics and statistics, medicine and health sciences, nanotechnology, physics, safety and emergency management*, and related fields of study.

#### **Editorial Statement**

*Pertanika* is the official journal of Universiti Putra Malaysia. The abbreviation for *Pertanika* Journal of Science & Technology is *Pertanika J. Sci. Technol.*

## Guidelines for Authors

### Publication policies

*Pertanika* policy prohibits an author from submitting the same manuscript for concurrent consideration by two or more publications. It prohibits as well publication of any manuscript that has already been published either in whole or substantial part elsewhere. It also does not permit publication of manuscript that has been published in full in Proceedings. Please refer to *Pertanika*'s **Code of Ethics** for full details.

### Editorial process

Authors are notified on receipt of a manuscript and upon the editorial decision regarding publication.

*Manuscript review:* Manuscripts deemed suitable for publication are sent to the Editorial Board members and/or other reviewers. We encourage authors to suggest the names of possible reviewers. Notification of the editorial decision is usually provided within to eight to ten weeks from the receipt of manuscript. Publication of solicited manuscripts is not guaranteed. In most cases, manuscripts are accepted conditionally, pending an author's revision of the material.

*Author approval:* Authors are responsible for all statements in articles, including changes made by editors. The liaison author must be available for consultation with an editor of *The Journal* to answer questions during the editorial process and to approve the edited copy. Authors receive edited typescript (not galley proofs) for final approval. Changes **cannot** be made to the copy after the edited version has been approved.

### Manuscript preparation

*Pertanika* accepts submission of mainly four types of manuscripts. Each manuscript is classified as **regular** or **original** articles, **short communications**, **reviews**, and proposals for **special issues**. Articles must be in **English** and they must be competently written and argued in clear and concise grammatical English. Acceptable English usage and syntax are expected. Do not use slang, jargon, or obscure abbreviations or phrasing. Metric measurement is preferred; equivalent English measurement may be included in parentheses. Always provide the complete form of an acronym/abbreviation the first time it is presented in the text. Contributors are strongly recommended to have the manuscript checked by a colleague with ample experience in writing English manuscripts or an English language editor.

Linguistically hopeless manuscripts will be rejected straightaway (e.g., when the language is so poor that one cannot be sure of what the authors really mean). This process, taken by authors before submission, will greatly facilitate reviewing, and thus publication if the content is acceptable.

The instructions for authors must be followed. Manuscripts not adhering to the instructions will be returned for revision without review. Authors should prepare manuscripts according to the guidelines of *Pertanika*.

#### 1. Regular article

*Definition:* Full-length original empirical investigations, consisting of introduction, materials and methods, results and discussion, conclusions. Original work must provide references and an explanation on research findings that contain new and significant findings.

*Size:* Should not exceed 5000 words or 8-10 printed pages (excluding the abstract, references, tables and/or figures). One printed page is roughly equivalent to 3 type-written pages.

#### 2. Short communications

*Definition:* Significant new information to readers of the Journal in a short but complete form. It is suitable for the publication of technical advance, bioinformatics or insightful findings of plant and animal development and function.

*Size:* Should not exceed 2000 words or 4 printed pages, is intended for rapid publication. They are not intended for publishing preliminary results or to be a reduced version of Regular Papers or Rapid Papers.

#### 3. Review article

*Definition:* Critical evaluation of materials about current research that had already been published by organizing, integrating, and evaluating previously published materials. Re-analyses as meta-analysis and systemic reviews are encouraged. Review articles should aim to provide systemic overviews, evaluations and interpretations of research in a given field.

*Size:* Should not exceed 4000 words or 7-8 printed pages.

#### 4. Special issues

*Definition:* Usually papers from research presented at a conference, seminar, congress or a symposium.

*Size:* Should not exceed 5000 words or 8-10 printed pages.

#### 5. Others

*Definition:* Brief reports, case studies, comments, Letters to the Editor, and replies on previously published articles may be considered.

*Size:* Should not exceed 2000 words or up to 4 printed pages.

With few exceptions, original manuscripts should not exceed the recommended length of 6 printed pages (about 18 typed pages, double-spaced and in 12-point font, tables and figures included). Printing is expensive, and, for the Journal, postage doubles when an issue exceeds 80 pages. You can understand then that there is little room for flexibility.

Long articles reduce the Journal's possibility to accept other high-quality contributions because of its 80-page restriction. We would like to publish as many good studies as possible, not only a few lengthy ones. (And, who reads overly long articles anyway?) Therefore, in our competition, short and concise manuscripts have a definite advantage.

#### Format

The paper should be formatted in one column format with at least 4cm margins and 1.5 line spacing throughout. Authors are advised to use Times New Roman 12-point font. Be especially careful when you are inserting special characters, as those inserted in different fonts may be replaced by different characters when converted to PDF files. It is well known that 'µ' will be replaced by other characters when fonts such as 'Symbol' or 'Mincho' are used.

A maximum of eight keywords should be indicated below the abstract to describe the contents of the manuscript. Leave a blank line between each paragraph and between each entry in the list of bibliographic references. Tables should preferably be placed in the same electronic file as the text. Authors should consult a recent issue of the Journal for table layout.

Every page of the manuscript, including the title page, references, tables, etc. should be numbered. However, no reference should be made to page numbers in the text; if necessary, one may refer to sections. Underline words that should be in italics, and do not underline any other words.

We recommend that authors prepare the text as a **Microsoft Word** file.

1. Manuscripts in general should be organised in the following order:

- o **Page 1: Running title.** (Not to exceed 60 characters, counting letters and spaces). This page should **only** contain the running title of your paper. The running title is an abbreviated title used as the running head on every page of the manuscript.

In addition, the **Subject areas** most relevant to the study **must be indicated on this page**. Select the appropriate subject areas from the Scope of the Journals provided in the Manuscript Submission Guide.

**A list of number of black and white / colour figures and tables should also be indicated on this page.** Figures submitted in color will be printed in colour. See "5. Figures & Photographs" for details.

- o **Page 2: Author(s) and Corresponding author information.** This page should contain the **full title** of your paper with name(s) of all the authors, institutions and corresponding author's name, institution and full address (Street address, telephone number (including extension), hand phone number, fax number and e-mail address) for editorial correspondence. The names of the authors **must** be abbreviated following the international naming convention. e.g. Salleh, A.B., Tan, S.G., or Sapuan, S.M.

**Authors' addresses.** Multiple authors with different addresses must indicate their respective addresses separately by superscript numbers:

George Swan<sup>1</sup> and Nayan Kanwal<sup>2</sup>

<sup>1</sup>Department of Biology, Faculty of Science, Duke University, Durham, North Carolina, USA.

<sup>2</sup>Office of the Deputy Vice Chancellor (R&I), Universiti Putra Malaysia, Serdang, Malaysia.

- o **Page 3:** This page should **repeat the full title** of your paper with only the **Abstract** (the abstract should be less than 250 words for a Regular Paper and up to 100 words for a Short Communication). **Keywords** must also be provided on this page (Not more than eight keywords in alphabetical order).
- o **Page 4 and subsequent pages:** This page should begin with the **Introduction** of your article and the rest of your paper should follow from page 5 onwards.

**Abbreviations.** Define alphabetically, other than abbreviations that can be used without definition. Words or phrases that are abbreviated in the introduction and following text should be written out in full the first time that they appear in the text, with each abbreviated form in parenthesis. Include the common name or scientific name, or both, of animal and plant materials.

**Footnotes.** Current addresses of authors if different from heading.

- 2. **Text.** Regular Papers should be prepared with the headings **Introduction, Materials and Methods, Results and Discussion, Conclusions** in this order. Short Communications should be prepared according to "8. Short Communications." below.
- 3. **Tables.** All tables should be prepared in a form consistent with recent issues of *Pertanika* and should be numbered consecutively with Arabic numerals. Explanatory material should be given in the table legends and footnotes. Each

table should be prepared on a separate page. (Note that when a manuscript is accepted for publication, tables must be submitted as data - .doc, .rtf, Excel or PowerPoint file- because tables submitted as image data cannot be edited for publication.)

4. **Equations and Formulae.** These must be set up clearly and should be typed triple spaced. Numbers identifying equations should be in square brackets and placed on the right margin of the text.
5. **Figures & Photographs.** Submit an original figure or photograph. Line drawings must be clear, with high black and white contrast. Each figure or photograph should be prepared on a separate sheet and numbered consecutively with Arabic numerals. Appropriate sized numbers, letters and symbols should be used, no smaller than 2 mm in size after reduction to single column width (85 mm), 1.5-column width (120 mm) or full 2-column width (175 mm).
6. Failure to comply with these specifications will require new figures and delay in publication. For electronic figures, create your figures using applications that are capable of preparing high resolution TIFF files acceptable for publication. In general, we require **300 dpi or higher resolution for coloured and half-tone artwork** and **1200 dpi or higher for line drawings**. For review, you may attach low-resolution figures, which are still clear enough for reviewing, to keep the file of the manuscript under 5 MB. Illustrations may be produced at extra cost in colour at the discretion of the Publisher; the author could be charged Malaysian Ringgit 50 for each colour page.
7. **References.** Literature citations in the text should be made by name(s) of author(s) and year. For references with more than two authors, the name of the first author followed by 'et al.' should be used.

Swan and Kanwal (2007) reported that ...

The results have been interpreted (Kanwal *et al.* 2009).

- o References should be listed in alphabetical order, by the authors' last names. For the same author, or for the same set of authors, references should be arranged chronologically. If there is more than one publication in the same year for the same author(s), the letters 'a', 'b', etc., should be added to the year.
  - o When the authors are more than 11, list 5 authors and then et al.
  - o Do not use indentations in typing References. Use one line of space to separate each reference. The name of the journal should be written in full. For example:
    - Jalaludin, S. (1997a). Metabolizable energy of some local feeding stuff. *Tumbuh*, 1, 21-24.
    - Jalaludin, S. (1997b). The use of different vegetable oil in chicken ration. *Malayan Agriculturist*, 11, 29-31.
    - Tan, S. G., Omar, M. Y., Mahani, K. W., Rahani, M., & Selvaraj, O. S. (1994). Biochemical genetic studies on wild populations of three species of green leafhoppers *Nephotettix* from Peninsular Malaysia. *Biochemical Genetics*, 32, 415 - 422.
  - o In case of citing an author(s) who has published more than one paper in the same year, the papers should be distinguished by addition of a small letter as shown above, e.g. Jalaludin (1997a); Jalaludin (1997b).
  - o Unpublished data and personal communications should not be cited as literature citations, but given in the text in parentheses. 'In press' articles that have been accepted for publication may be cited in References. Include in the citation the journal in which the 'in press' article will appear and the publication date, if a date is available.
8. **Examples of other reference citations:**
- Monographs:** Turner, H. N., & Yong, S. S. Y. (2006). *Quantitative Genetics in Sheep Breeding*. Ithaca: Cornell University Press.
- Chapter in Book:** Kanwal, N. D. S. (1992). Role of plantation crops in Papua New Guinea economy. In Angela R. McLean (Ed.), *Introduction of livestock in the Enga province PNG* (p. 221-250). United Kingdom: Oxford Press.
- Proceedings:** Kanwal, N. D. S. (2001). Assessing the visual impact of degraded land management with landscape design software. In Kanwal, N. D. S., & Lecoustre, P. (Eds.), *International forum for Urban Landscape Technologies* (p. 117-127). Lullier, Geneva, Switzerland: CIRAD Press.
9. **Short Communications** should include **Introduction, Materials and Methods, Results and Discussion, Conclusions** in this order. Headings should only be inserted for Materials and Methods. The abstract should be up to 100 words, as stated above. Short Communications must be 5 printed pages or less, including all references, figures and tables. References should be less than 30. A 5 page paper is usually approximately 3000 words plus four figures or tables (if each figure or table is less than 1/4 page).

\*Authors should state the total number of words (including the Abstract) in the cover letter. Manuscripts that do not fulfill these criteria will be rejected as Short Communications without review.

## STYLE OF THE MANUSCRIPT

Manuscripts should follow the style of the latest version of the Publication Manual of the American Psychological Association (APA). The journal uses American or British spelling and authors may follow the latest edition of the Oxford Advanced Learner's Dictionary for British spellings.

## SUBMISSION OF MANUSCRIPTS

All articles should be submitted electronically using the ScholarOne web-based system. ScholarOne, a Thomson Reuters product provides comprehensive workflow management systems for scholarly journals. For more information, go to our web page and click "**Online Submission**".

Alternatively, you may submit the electronic files (cover letter, manuscript, and the **Manuscript Submission Kit** comprising *Declaration* and *Referral* forms) via email directly to the Executive Editor. If the files are too large to email, mail a CD containing the files. The **Manuscript Submission Guide** and **Submission Kit** are available from the *Pertanika*'s home page at <http://www.pertanika.upm.edu.my/> or from the Executive Editor's office upon request.

All articles submitted to the journal **must comply** with these instructions. Failure to do so will result in return of the manuscript and possible delay in publication.

Please do **not** submit manuscripts to the editor-in-chief or to any other office directly. All manuscripts must be **submitted through the executive editor's office** to be properly acknowledged and rapidly processed at the address below:

Dr. Nayan KANWAL  
Chief Executive Editor  
*Pertanika* Journals, UPM Press  
Office of the Deputy Vice Chancellor (R&I)  
IDEA Tower II, UPM-MTDC Technology Centre  
Universiti Putra Malaysia  
43400 UPM, Serdang, Selangor  
Malaysia

E-mail: [nayan@upm.my](mailto:nayan@upm.my); [journal.officer@gmail.com](mailto:journal.officer@gmail.com); tel: + 603-8947 1622.  
or visit our website at <http://www.pertanika.upm.edu.my/> for further information.

Authors should retain copies of submitted manuscripts and correspondence, as materials can not be returned. Authors are required to inform the Executive Editor of any change of address which occurs whilst their papers are in the process of publication.

### Cover letter

All submissions must be accompanied by a cover letter detailing what you are submitting. Papers are accepted for publication in the journal on the understanding that the article is original and the content has not been published or submitted for publication elsewhere. This must be stated in the cover letter.

The cover letter must also contain an acknowledgement that all authors have contributed significantly, and that all authors are in agreement with the content of the manuscript.

The cover letter of the paper should contain (i) the title; (ii) the full names of the authors; (iii) the addresses of the institutions at which the work was carried out together with (iv) the full postal and email address, plus facsimile and telephone numbers of the author to whom correspondence about the manuscript should be sent. The present address of any author, if different from that where the work was carried out, should be supplied in a footnote.

As articles are double-blind reviewed, material that might identify authorship of the paper should be placed on a cover sheet.

### Peer review

*Pertanika* follows a **double-blind peer-review** process. Peer reviewers are experts chosen by journal editors to provide written assessment of the **strengths** and **weaknesses** of written research, with the aim of improving the reporting of research and identifying the most appropriate and highest quality material for the journal.

In the peer-review process, three referees independently evaluate the scientific quality of the submitted manuscripts. Authors are encouraged to indicate in the **Referral form** using the **Manuscript Submission Kit** the names of three potential reviewers, but the editors will make the final choice. The editors are not, however, bound by these suggestions.

Manuscripts should be written so that they are intelligible to the professional reader who is not a specialist in the particular field. They should be written in a clear, concise, direct style. Where contributions are judged as acceptable for publication on the basis of content, the Editor reserves the right to modify the typescripts to eliminate ambiguity and repetition and improve communication between author and reader. If extensive alterations are required, the manuscript will be returned to the author for revision.



### The Journal's review process

What happens to a manuscript once it is submitted to *Pertanika*? Typically, there are seven steps to the editorial review process:

1. The executive editor and the editorial board examine the paper to determine whether it is appropriate for the journal and should be reviewed. If not appropriate, the manuscript is rejected outright and the author is informed.
2. The executive editor sends the article-identifying information having been removed, to three reviewers. Typically, one of these is from the Journal's editorial board. Others are specialists in the subject matter represented by the article. The executive editor asks them to complete the review in three weeks and encloses two forms: (a) referral form B and (b) reviewer's comment form along with reviewer's guidelines. Comments to authors are about the appropriateness and adequacy of the theoretical or conceptual framework, literature review, method, results and discussion, and conclusions. Reviewers often include suggestions for strengthening of the manuscript. Comments to the editor are in the nature of the significance of the work and its potential contribution to the literature.
3. The executive editor, in consultation with the editor-in-chief, examines the reviews and decides whether to reject the manuscript, invite the author(s) to revise and resubmit the manuscript, or seek additional reviews. Final acceptance or rejection rests with the Editorial Board, who reserves the right to refuse any material for publication. In rare instances, the manuscript is accepted with almost no revision. Almost without exception, reviewers' comments (to the author) are forwarded to the author. If a revision is indicated, the editor provides guidelines for attending to the reviewers' suggestions and perhaps additional advice about revising the manuscript.
4. The authors decide whether and how to address the reviewers' comments and criticisms and the editor's concerns. The authors submit a revised version of the paper to the executive editor along with specific information describing how they have answered the concerns of the reviewers and the editor.
5. The executive editor sends the revised paper out for review. Typically, at least one of the original reviewers will be asked to examine the article.
6. When the reviewers have completed their work, the executive editor in consultation with the editorial board and the editor-in-chief examine their comments and decide whether the paper is ready to be published, needs another round of revisions, or should be rejected.
7. If the decision is to accept, the paper is sent to that Press and the article should appear in print in approximately three months. The Publisher ensures that the paper adheres to the correct style (in-text citations, the reference list, and tables are typical areas of concern, clarity, and grammar). The authors are asked to respond to any queries by the Publisher. Following these corrections, page proofs are mailed to the corresponding authors for their final approval. At this point, only essential changes are accepted. Finally, the article appears in the pages of the Journal and is posted on-line.

### English language editing

*Pertanika* **emphasizes** on the linguistic accuracy of every manuscript published. Thus all authors are required to get their manuscripts edited by **professional English language editors**. Author(s) **must provide a certificate** confirming that their manuscripts have been adequately edited. A proof from a recognised editing service should be submitted together with the cover letter at the time of submitting a manuscript to *Pertanika*. **All costs will be borne by the author(s)**.

This step, taken by authors before submission, will greatly facilitate reviewing, and thus publication if the content is acceptable.

### Author material archive policy

Authors who require the return of any submitted material that is rejected for publication in the journal should indicate on the cover letter. If no indication is given, that author's material should be returned, the Editorial Office will dispose of all hardcopy and electronic material.

### Copyright

Authors publishing the Journal will be asked to sign a declaration form. In signing the form, it is assumed that authors have obtained permission to use any copyrighted or previously published material. All authors must read and agree to the conditions outlined in the form, and must sign the form or agree that the corresponding author can sign on their behalf. Articles cannot be published until a signed form has been received.

### Lag time

A decision on acceptance or rejection of a manuscript is reached in 3 to 4 months (average 14 weeks). The elapsed time from submission to publication for the articles averages 5-6 months.

### Hardcopies of the Journals and off prints

Under the Journal's open access initiative, authors can choose to download free material (via PDF link) from any of the journal issues from *Pertanika*'s website. Under "Browse Journals" you will see a link entitled "Current Issues" or "Archives". Here you will get access to all back-issues from 1978 onwards.

The **corresponding author** for all articles will receive one complimentary hardcopy of the journal in which his/her articles is published. In addition, 20 off prints of the full text of their article will also be provided. Additional copies of the journals may be purchased by writing to the executive editor.

## Why should you publish in *Pertanika*?

### BENEFITS TO AUTHORS

**PROFILE:** Our journals are circulated in large numbers all over Malaysia, and beyond in Southeast Asia. Our circulation covers other overseas countries as well. We ensure that your work reaches the widest possible audience in print and online, through our wide publicity campaigns held frequently, and through our constantly developing electronic initiatives such as Web of Science Author Connect backed by Thomson Reuters.

**QUALITY:** Our journals' reputation for quality is unsurpassed ensuring that the originality, authority and accuracy of your work is fully recognised. Each manuscript submitted to *Pertanika* undergoes a rigid originality check. Our double-blind peer refereeing procedures are fair and open, and we aim to help authors develop and improve their scientific work. *Pertanika* is now over 35 years old; this accumulated knowledge has resulted in our journals being indexed in SCOPUS (Elsevier), Thomson (ISI) Web of Knowledge [BIOSIS & CAB Abstracts], EBSCO, DOAJ, Google Scholar, AGRICOLA, ERA, ISC, Citefactor, Rubriq and MyAIS.

**AUTHOR SERVICES:** We provide a rapid response service to all our authors, with dedicated support staff for each journal, and a point of contact throughout the refereeing and production processes. Our aim is to ensure that the production process is as smooth as possible, is borne out by the high number of authors who prefer to publish with us.

**CODE OF ETHICS:** Our Journal has adopted a Code of Ethics to ensure that its commitment to integrity is recognized and adhered to by contributors, editors and reviewers. It warns against plagiarism and self-plagiarism, and provides guidelines on authorship, copyright and submission, among others.

**PRESS RELEASES:** Landmark academic papers that are published in *Pertanika* journals are converted into press releases as a unique strategy for increasing visibility of the journal as well as to make major findings accessible to non-specialist readers. These press releases are then featured in the university's UK-based research portal, ResearchSEA, for the perusal of journalists all over the world.

**LAG TIME:** The elapsed time from submission to publication for the articles averages 4 to 5 months. A decision on acceptance of a manuscript is reached in 3 to 4 months (average 14 weeks).



An  
**Award-Winning**  
International-Malaysian  
Journal  
—MAY 2014

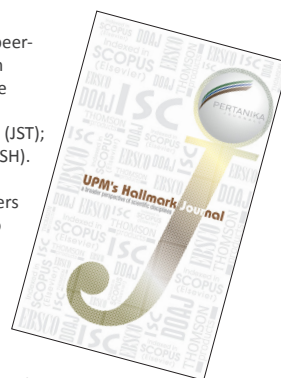
## About the Journal

*Pertanika* is an international multidisciplinary peer-reviewed leading journal in Malaysia which began publication in 1978. The journal publishes in three different areas — Journal of Tropical Agricultural Science (JTAS); Journal of Science and Technology (JST); and Journal of Social Sciences and Humanities (JSSH).

**JTAS** is devoted to the publication of original papers that serves as a forum for practical approaches to improving quality in issues pertaining to **tropical agricultural research**- or related fields of study. It is published four times a year in **February, May, August and November**.

**JST** caters for **science and engineering research**- or related fields of study. It is published twice a year in **January and July**.

**JSSH** deals in **research or theories in social sciences and humanities research**. It aims to develop as a flagship journal with a focus on emerging issues pertaining to the social and behavioural sciences as well as the humanities, particularly in the Asia Pacific region. It is published four times a year in **March, June, September and December**.



## Call for Papers 2015-16 now accepting submissions...

*Pertanika* invites you to explore frontiers from all key areas of **agriculture, science and technology to social sciences and humanities**.

Original research and review articles are invited from scholars, scientists, professors, post-docs, and university students who are seeking publishing opportunities for their research papers through the Journal's three titles; JTAS, JST & JSSH. Preference is given to the work on leading and innovative research approaches.

*Pertanika* is a fast track peer-reviewed and open-access academic journal published by **Universiti Putra Malaysia**. To date, *Pertanika* Journals have been indexed by many important databases. Authors may contribute their scientific work by publishing in UPM's hallmark SCOPUS & ISI indexed journals.

Our journals are open access - international journals. Researchers worldwide will have full access to all the articles published online and be able to download them with **zero subscription fee**.

*Pertanika* uses online article submission, review and tracking system for quality and quick review processing backed by Thomson Reuter's ScholarOne™. Journals provide rapid publication of research articles through this system.

For details on the Guide to Online Submissions, visit  
[http://www.pertanika.upm.edu.my/guide\\_online\\_submission.php](http://www.pertanika.upm.edu.my/guide_online_submission.php)

Questions regarding submissions should only be directed to the **Chief Executive Editor**, *Pertanika* Journals.

Remember, *Pertanika* is the resource to support you in strengthening research and research management capacity.



Address your submissions to:  
**The Chief Executive Editor**  
Tel: +603 8947 1622  
[nayan@upm.my](mailto:nayan@upm.my)

Journal's profile: [www.pertanika.upm.edu.my](http://www.pertanika.upm.edu.my)



**Selected Articles from CUTSE International Conference 2012  
(Engineering Goes Green)**

**Guest Editor:** Muhammad Ekhlaur Rahman

**Guest Editorial Board:** M. V. Prasanna, Hannah Ngu Ling Ngee, Zeya Oo and Rajamohan Ganesan

- T-DepExp: Simulating Transitive Dependence Based Coalition Formation 105  
*Billy Pik Lik Lau, Ashutosh Kumar Singh and Terence Peng Lian Tan*
- Synthesis of Nanoparticle-based Binary Oxide Electrode  $\text{TiO}_2\text{-ZrO}_2$  with Carrot-derived Natural Dye Extract for Dye Sensitized Solar Cell (DSSC) Application 119  
*S. Y. Win, T. T. Win, Y. M. Maung, K. K. K. Soe, T. T. Kyaw, C. K. Tan, S. Rajalingam and Z. Oo*
- Information Technology: Impacts on Environment and Sustainable Development 127  
*Adib Kabir Chowdhury and Veeramani Shanmugan*
- Experimental Study on Mixed Convection Heat Transfer in a Square Duct with Varying Inclination Angles 141  
*G. Rajamohan, R. Narayanaswamy and P. Kumar*
- Microstructure Analysis, Physical and Thermal Properties of  $\text{Al}_2\text{O}_3\text{-Al}_2\text{TiO}_5$  Functionally Graded Ceramics for the Application of Car Brake Rot 153  
*Rong Kimberly, F. P., Oo, Z. and Sujan, D.*

## Contents

<b>Foreword</b>	i
<i>Nayan Deep S. Kanwal</i>	
<b>Editorial</b>	
Integration of Science, Technology and Entrepreneurship to Capture the Power of the Nanoengineering Wave	i
<i>Vijay K. Arora</i>	
<b>Review Article</b>	
Applications of <sup>18</sup> (F) FDG PET/CT in Oncology	1
<i>AS Fathinul Fikri, AJ Nordin, YK Cheah and FN Ahmad Saad</i>	
<b>Regular Articles</b>	
Smoking Behavior among Adolescents in Rural Schools in Malacca, Malaysia - A Case-Control Study	13
<i>Nor Afiah, M. Z., Rahmah M. A., Salmiah, M.S., Lye, M.S., Shamsul Azhar, S. and Fazilah, I.</i>	
Prevalence of Psychological Stress among Undergraduate Students Attending a Health Programme in a Malaysian University	29
<i>Phang, C. K., Sherina, M. S., Zubaidah, J. O., Noor Jan, K. O. N., Firdaus, M., Siti Irma, F. I. and Normala, I.</i>	
Analysing Elephant Habitat Parameters using GIS, Remote Sensing and Analytic Hierarchy Process in Peninsular Malaysia	37
<i>Suhaida Aini, Alias Mohd Sood and Salman Saaban</i>	
Removal of Dissolved Organic Carbon from Peat Swamp Runoff Using Assorted Tropical Agriculture Biomass	51
<i>Sim, F. S., Mohd Irwan Lu, N. A. L., Lee, Z. E. T. and Mohamed, M.</i>	
Optimization of Drilling Parameters for Delamination Associated with Pre-drill in Chopped Strand Mat Glass Fibre Reinforced Polymeric Material	61
<i>T. Panneerselvam and S. Raghuraman</i>	
RFID-Enabled Web-Based Interface for a Chemical Storage Management System	73
<i>Rosiah Osman, Abd. Rahman Ramli, Wan Azizun Wan Adnan and Intan Helina Hasan</i>	
Modelling of Carbon Dioxide Absorption into Aqueous Ammonia Solution in a Wetted Wall Column	89
<i>Ujjal Kumar Ghosh, Chiu Choon Hong, Jobrun Nandong and Shufeng Shen</i>	



Pertanika Editorial Office, Journal Division  
Office of the Deputy Vice Chancellor (R&I),  
1st Floor, IDEA Tower II,  
UPM-MTDC Technology Centre  
Universiti Putra Malaysia  
43400 UPM Serdang  
Selangor Darul Ehsan  
Malaysia

<http://www.pertanika.upm.edu.my/>  
E-mail: [executive\\_editor.pertanika@upm.my](mailto:executive_editor.pertanika@upm.my)  
Tel: +603 8947 1622/1620

**PENERBIT**  
**UPM**  
UNIVERSITI PUTRA MALAYSIA  
**PRESS**

<http://penerbit.upm.edu.my>  
E-mail : [penerbit@putra.upm.edu.my](mailto:penerbit@putra.upm.edu.my)  
Tel : +603 8946 8855/8854  
Fax : +603 8941 6172

