<table>
<thead>
<tr>
<th>Technology Cluster: OIL AND GAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology Platform: Oilfield Gas Treatment and Utilization</td>
</tr>
<tr>
<td>Hydrogen Production by Catalytic Decomposition of Methane</td>
</tr>
<tr>
<td>Noor Asmawati Mohd Zabidi, Sharif Hussein Sharif Zein and Abdul Rahman Mohamed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technology Platform: System Optimization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overcoming the Shrink-And-Swell Effect in Water Level Control Strategy on Industrial Boiler Drum</td>
</tr>
<tr>
<td>Fawnizu Azmadi Hussin and Rees, N.W.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technology Cluster: INTELLIGENT SYSTEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology Platform: Application of IT Systems</td>
</tr>
<tr>
<td>An Ethnicity Recognition System using Imaging Techniques</td>
</tr>
<tr>
<td>P. A. Venkatasahalam, Ahmad Fadzil Mohd Hani, Kavitha Shaga Devan and Siti Musilhani Abd Ghani</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technology Platform: Application of IT Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed Based Region Growing Technique in Breast Cancer Detection and Embedded Expert System</td>
</tr>
<tr>
<td>P. A. Venkatasahalam, Ahmad Fadzil Mohd Hani, Umi Kalthum Ngah and Ali Yeon Md Shakaff</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technology Cluster: TRANSPORTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology Platform: Fuel Combustion</td>
</tr>
<tr>
<td>Combined Laser Doppler Anemometer and Phase Doppler Anemometer System for Thermofluids Research at Universiti Teknologi PETRONAS</td>
</tr>
<tr>
<td>Shaharin Anwar Sulaiman and Mohd Arief Mohd Nor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OTHER RESEARCH AREAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development of a Small Scale Solar Pond Technology Testbed for Education Purposes</td>
</tr>
<tr>
<td>Rahmati L. Shazli, M. Fazil M. Nor Adi and Fakhruddin M. Hashim</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nanotechnology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Analysis of Catalytically Grown Carbon Nanotubes (CNTs)</td>
</tr>
<tr>
<td>Norani Muti Mohamed, Tan Yee Cheh, Saravanan Munirandy and Kadir Masrom</td>
</tr>
</tbody>
</table>

| Design and Development of the Laboratory Scale Rapid Thermal Processing (RTP) System | 60 |
| Norani Muti Mohamed, Khatijah Yaacob and Kamarulazizi Ibrahim |
PLATF0RM
July-December 2003

Advisor:
Dr. Rosti Saruwono

UTP Publication Committee
Chairman:
Assoc. Prof. Ir. Dr. Ahmad Fadzil Mohamad Hani

Members:
Assoc. Prof. Ir. Dr. Ibrahim Kamaruddin
Assoc. Prof. Dr. Mohamed Ibrahim Abdul Mutaalib
Assoc. Prof. Dr. Mohd. Noh Karstii
Assoc. Prof. Dr. Fakhruddin Mohd. Hashim
Assoc. Prof. Dr. Madzlan Napiah
Dr. Helmi Mukhtar
Dr. Abas M. Said
Dr. Noor Asmawati M. Zabidi
Habibullah Abdul Wahab
Habibullah Haji Ihsan
Mohamed Zahir Abdul Khalid

Secretary:
Raja Yasmin Raja Yusof

University Editorial
Editor-in-Chief:
Mohamed Zahir Abdul Khalid

Chief Editor, PLATFORM:
Dr. Kamarul Ariffin Amminudin

Editor, UTP Quarterly:
Feroz Mohd. Ridzwan

Representative, IRC:
Rabiatul Ahya Mohd. Sharif

Secretary:
Raja Yasmin Raja Yusof

PLATFORM Editorial
Chief Editor:
Dr. Kamarul Ariffin Amminudin

Co-Editors:
Prof. Dr. V. R. Radhakrishnan
Assoc. Prof. Dr. Varun Jeoti Jagadish
Assoc. Prof. Dr. Norani Muti Mohamed
Dr. Nasir Shafiq
Dr. Abdul Rashid Abdul Aziz
Jafreezal Jaafar

Address:
Chief Editor, PLATFORM
Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan
Malaysia

http://www.utp.edu.my
kamarul@petronas.com.my

Copyright © 2004
Universiti Teknologi PETRONAS

ISSN 1511-6794

Contents

Technology Cluster: OIL AND GAS

Technology Platform: Oilfield Gas Treatment and Utilization
Hydrogen Production by Catalytic Decomposition of Methane
Noor Asmawati Mohd Zabidi, Sharif Hussein Sharif Zein and Abdul Rahman Mohamed

Technology Platform: System Optimization
Overcoming the Shrink-And-Swell Effect in Water Level Control Strategy on Industrial Boiler-Drum
Fawuniz Azmadi Hussin and Rees, N. W.

Technology Cluster: INTELLIGENT SYSTEMS

Technology Platform: Application of IT Systems
An Ethnicity Recognition System using Imaging Techniques
P. A. Venkatachalam, Ahmad Fadzil Mohd Hani, Kavitha Shaga Devan and Siti Muslihani Abd Ghanai

Seed Based Region Growing Technique in Breast Cancer Detection and Embedded Expert System
P. A. Venkatachalam, Umi Kalthum Ngah, Ahmad Fadzil Mohd Hani and Ali Yeon Md Shakkaff

Soft Sensors for the Cement Industry - Neural Network Models for Kiln and Grinding Mill
Vydianathapuram R. Radhakrishnan

The Architectural Design of Intelligent Tutoring System Using Adaptive Learning Approach for Primary Schools
Jafreezal Jaafar, Mohd Azmir A. Amir and Dayang Nur Fatimah A. I.

Technology Platform: Nanotechnology
Surface Analysis of Catalytically Grown Carbon Nanotubes (CNTs)
Norani Muti Mohamed, Tan Yee Chech, Saravanan Muniandy and Kadir Masrom

Design and Development of the Laboratory Scale Rapid Thermal Processing (RTP) System
Norani Muti Mohamed, Khatijah Yaacob and Kamarulazizi Ibrahim

Technology Cluster: TRANSPORTATION

Technology Platform: Fuel Combustion
Combined Laser Doppler Anemometer and Phase Doppler Anemometer System for Thermofluids Research at Universiti Teknologi PETRONAS
Shaharin Anwar Sulaiman and Mohd Arief Mohd Nor

OTHER RESEARCH AREAS
On Performance of Hybrid Element Based FEM Approach for Capacitance Extraction in Electronic Packaging
Robert Paragasam, K. N. Seetharamu, G. A. Quadir, Varun Jeoti and P. C. Sharma

Development of a Small Scale Solar Pond Technology Testbed for Education Purposes
Rahmat I. Shazi, M. Farizal M. Nor Azliz and Fakhruddin M. Hashim
ABSTRACT

The large reserves of natural gas could serve as a feedstock for the production of an alternative fuel. Hydrogen can play a decisive role in a future energy system when petroleum becomes scarce, expensive and unsuitable because of ecological reasons. Currently, hydrogen is being used in many industries. Hydrogen is mainly produced from natural gas by steam-reforming of methane which is an energy intensive process and requires further separation of hydrogen from synthesis gas. Hence, it is desirable to develop a simpler and less energy intensive method. The decomposition of methane over catalyst has recently been receiving attention as an alternative route to the production of hydrogen. It produces only H\textsubscript{2} and solid carbon, thereby eliminating the necessity for the separation of H\textsubscript{2} from CO\textsubscript{x}. For fuelling the fuel cells, it is easier to use such methane-hydrogen containing mixture than to use synthesis gas which inhibits platinum electrodes, due to the CO content. Also, methane is more easily separated from hydrogen than CO\textsubscript{x}. The carbon produced can be used as promising sorbents, catalyst supports, carbonaceous composite materials etc. Therefore, with this process, not only hydrogen is formed at low cost, but the carbon formed can also be a value added product. Furthermore, pure oxygen, which requires expensive cryogenic separation, is no longer required in this process. In this study, methane catalytic decomposition on various Ni-containing catalysts has been investigated as a method for the production of CO\textsubscript{x}-free hydrogen for use in fuel cells. While different types of filamentous carbon form on the various Ni-containing catalysts, attractive nanocarbon tubes were observed on the Ni/Mn based catalyst. This type of carbon, coupled with stable activity of the catalyst and without requiring any pre-treatment of the catalyst before reaction, makes this an interesting conceptual process for hydrogen production for fuel cell applications.

Keywords: methane, hydrogen production, steam-reforming, methane decomposition

1.0 INTRODUCTION

The very large reserves of natural gas could serve as a feedstock for the production of an alternative fuel in the 21\textsuperscript{st} century. With increasing interest in fuel cells, the use of hydrogen as an energy carrier is likely to increase. Hydrogen can play a decisive role in a future energy system when petroleum becomes scarce, expensive and unsuitable because of ecological reasons. Currently, hydrogen is being used in many industries from chemical refining to metallurgical, electronics, and space applications.
Most of the world's hydrogen production is currently derived from natural gas, via steam-reforming of methane (SRM). Problems in using this process for hydrogen production are: the process is bulky, energy intensive and also produces hydrogen mixed with carbon oxides. Thus, the gas needs further treatment to separate hydrogen from the other gases. Hence, it is desirable to develop a simpler and less energy intensive method, which can reduce the capital cost compared to the conventional one. Thus, any principal improvement or new concept in hydrogen production from natural gas, which appears to be very important, is to avoid CO₂ formation (Muradov, 1998).

The decomposition of methane over catalyst has recently been receiving attention as an alternative route to the production of hydrogen from natural gas. Steinburg and Cheng (1989) made a comprehensive techno-economical analysis of existing hydrogen production technologies, and proposed with convincing data that decomposition of methane (DM), without assuming to employ a catalyst, and with assuming to burn the carbon as the energy source of the reaction heat, is the most economical route for hydrogen production. Muradov (1998) reported that DM is a technologically simple one-step process without energy and material intensive gas separation stages, while SRM is a multi-step and complex process. It produces only H₂ and solid carbon, thereby eliminating the necessity for the separation of H₂ from CO₂ product. For fuelling the low temperature fuel cells, it is easier to use such methane-hydrogen containing mixture than to use synthesis gas which inhibits platinum electrodes, due to the CO content. Poirier and Sapundshiev (1997) mentioned that hydrogen containing 40 – 50% of methane is usable in some kinds of fuel cells in a cyclic mode. Also, methane is more easily separated from hydrogen than CO₂ produced from steam-reforming of methane (Parmon et al., 1998). Takenaka et al., (2001) reported that the hydrogen produced through the methane decomposition can be supplied directly to the fuel cells without any CO-removal process due to no CO contained in the hydrogen formed by this process. The carbon produced from this process, which is also called filamentous carbon, has some advanced properties to be used as promising sorbents, catalyst supports, carbonaceous composite materials and in new areas. Currently, the total world production of carbon black is close to 6 million tons per year, with prices varying in the range of hundreds to thousands of dollars per ton, depending on the carbon quality. The potential uses of the carbon depend on their quality and structures; therefore, another goal of the process is to monitor the characteristics of the carbon. Thus, with this process, not only hydrogen is formed at low cost, but the carbon formed during this process can also be a value added product.

Decomposition of methane (DM) is a well-known process. It has long been used for the production of carbon black with hydrogen being used as a supplemental gaseous fuel. However, the process requires elevated temperatures. Attempts have been made to use catalysts to reduce the maximum temperature of the DM. However, it has never been utilized commercially nor studied extensively. Recently, DM over catalysts has been receiving attention as an alternative route to the production of hydrogen at lower temperatures (Zhang and Amiridis, 1998; Avdeeva et al., 1999; Ermakova et al., 1999 & 2000; Aiello et al., 2000; Monnerat et al., 2001). However, most yields of hydrogen is low due to thermodynamic limitation for the production of hydrogen at temperatures below 700 °C. At higher temperatures, the catalyst deactivates very fast due to an encapsulating type of carbon depositing on the catalyst and a decrease in the number of carbon nanotubes. For example, Ermakova et al., (2000) reported the decomposition of methane to produce hydrogen and filamentous carbon using very high concentrations (up to 90 wt %) of Ni catalysts – methane conversion was 8% at 500 °C, 15% at 550 °C, and complete deactivation at 600 °C. Thus, for this process to be put into practice, catalysts with high activity and high structural selectivity for the carbon morphology become necessary. In this study, methane catalytic decomposition on various Ni-containing catalysts has been investigated as a method for producing high H₂ yields and carbon nanotubes.
2.0 EXPERIMENTAL WORK

The catalysts used in this study were Ni/M-based methane dissociation catalysts (M= Mn, Fe, Co, and Cu). These are nickel catalysts promoted with transition metal. The catalyst was produced in a pellet form, which was then crushed and sieved before use. From N\textsubscript{2} adsorption at 77K, a BET surface area of 8.16 m\textsuperscript{2}/g\textsubscript{cat}, 8.79 m\textsuperscript{2}/g\textsubscript{cat}, 7.13 m\textsuperscript{2}/g\textsubscript{cat} and 4.79 m\textsuperscript{2}/g\textsubscript{cat} were obtained for the Ni/Mn, Ni/Fe, Ni/Co and Ni/Cu respectively.

The activity tests for the catalysts in the decomposition of methane were carried out at atmospheric pressure in a conventional fixed bed gas-flow system using the single-zone furnace (Carbolite VST 12) without end insulation as shown in Figure 1. A thermocouple, type K, was inserted to the middle part of the reactor to monitor temperature changes inside the reactor. Highly pure methane (Malaysian Oxygen Sdn. Bhd., 99.999%) diluted with argon (Sitt Tatt Industrial Gases Sdn. Bhd., 99.999%) was used as reactants. The flow of CH\textsubscript{4} and Ar were regulated using mass flow controllers (Brooks 5850E for argon and MKS for methane). Outlet gas flow was monitored by a gas flow meter (Alexander Wright DM3 B). Product gases were analysed using an on-line gas chromatograph (GC) (Hewlett-Packard Series 6890). A Propaq N column (1/8” diameter, 6 feet long) was used to separate carbon dioxide, ethane, ethylene and propylene and Molecular Sieve 5A column (1/8” diameter, 6 feet long) for separating hydrogen, oxygen, carbon monoxide and methane. Argon was used as a carrier gas. The thermal conductivity detector (TCD) and flame ionisation detector (FID) were installed in-series and the product gases passed first through the TCD and then FID. The GC was calibrated using a standard gas mixture supplied by BOC Gases, UK. Spent catalysts, covered with carbon were analysed using transmission electron microscope (TEM) (Philips TEM CM12) equipped with 80 kV for extracting electrons. TEM was conducted at the X-ray microanalysis laboratory, School of Biological Science, USM. In preparation for TEM experiments, a few particles of each sample were dispersed in distilled water. A drop of it was deposited on a standard electron microscope copper grid coated with a coating material.

![Figure 1: Experimental Rig for Methane Decomposition Study](image-url)
The conversion of methane and the yield of hydrogen are defined as follows:

\[
\text{Conversion (\%)} = \frac{\text{Mole of methane reacted}}{\text{Mole of methane input}} \times 100 \tag{1}
\]

\[
\text{Yield (\%)} = \frac{\text{Mole of hydrogen produced}}{\text{Mole of methane input} \times 2} \times 100 \tag{2}
\]

\[\text{CH}_4 \rightarrow \text{C} + 2\text{H}_2\]

### 3.0 RESULTS

Figure 2 shows the results of the decomposition of methane without any catalyst in the temperature range of 400 – 900 °C. These results reveal that the decomposition of methane without any catalyst in the temperature range of 400 – 900 °C was negligible as the conversion was significantly low. Thus, the reactor used in this study is a suitable reactor material for the study in searching for a suitable catalyst for the decomposition of methane.

<table>
<thead>
<tr>
<th>Catalyst</th>
<th>CH\textsubscript{4} Conv. (%)</th>
<th>H\textsubscript{2} Yield (%)</th>
<th>CH\textsubscript{4} Conv. (%)</th>
<th>H\textsubscript{2} Yield (%)</th>
<th>CH\textsubscript{4} Conv. (%)</th>
<th>H\textsubscript{2} Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 min.</td>
<td>60 min.</td>
<td>120 min.</td>
<td>5 min.</td>
<td>60 min.</td>
<td>120 min.</td>
</tr>
<tr>
<td>Ni/Mn</td>
<td>59</td>
<td>60</td>
<td>56</td>
<td>59</td>
<td>60</td>
<td>56</td>
</tr>
<tr>
<td>Ni/Fe</td>
<td>57</td>
<td>49</td>
<td>44</td>
<td>57</td>
<td>49</td>
<td>44</td>
</tr>
<tr>
<td>Ni/Co</td>
<td>66</td>
<td>59</td>
<td>-</td>
<td>66</td>
<td>59</td>
<td>-</td>
</tr>
<tr>
<td>Ni/Cu</td>
<td>61</td>
<td>67</td>
<td>46</td>
<td>61</td>
<td>67</td>
<td>46</td>
</tr>
</tbody>
</table>

Table 1 shows the effect of the transition metal for Ni/M-based catalysts (M= Mn, Fe, Co, and Cu) for the decomposition of methane to hydrogen and carbon at 60, 120, and 180 minutes on stream. At 60 minutes on stream, Ni/Fe gave the lowest methane conversion (50%). At 120 minutes on stream, Ni/Cu methane conversion decreased from 67% to 36% and from 50% to 44% for Ni/Cu and Ni/Fe respectively, while Ni/Mn almost maintained its activity. The data for Ni/Co catalyst was not taken at 120 minutes because of the pressure drop. Figure 3 shows the micrograph obtained with a TEM. Different transition metals gave different types of filamentous carbon. Long nanocarbon tubes were formed on Ni/Mn based catalyst – the catalyst particle is located at the tip of the carbon. For the Ni/Fe based catalyst, chain-like carbon tubes were formed – the catalyst particle is located at the centre of the carbon. Encapsulating type of carbon were formed on Ni/Co based catalyst. A mixed type of carbon which includes long nanocarbon tubes were observed on Ni/Cu based catalyst.

Since the Ni/Mn based catalyst gave better results for hydrogen production and long nanocarbon tubes, the experiments were carried out using the Ni/Mn based catalyst. Figure 4 shows the effects of temperature (550 - 900 °C) at GHSV of 3200 h\textsuperscript{-1}, 9600 h\textsuperscript{-1} and 1600 h\textsuperscript{-1} on the Ni/Mn based catalyst. At reaction temperatures of 900 °C and GHSV of 3200 h\textsuperscript{-1}, the conversion of methane and the yield of hydrogen was 96%. By increasing the WHSV from 3200 to 16000 h\textsuperscript{-1}, the yield of hydrogen decreased from 96% to 54%.
To facilitate the discussion, a short review of hydrogen production from decomposition of methane (DM) and steam-reforming of methane (SRM) processes, may be necessary, although many excellent reviews have been published recently (Steinburg and Cheng 1989; Muradov, 1998; Steinberg, 1999; Armor, 1999).

The process of SRM basically represents a catalytic conversion of methane (a major component of the hydrocarbon feedstock) and water (steam) to hydrogen and carbon oxides and consists of three main steps: (a) synthesis gas generation (eq. 3), (b) water-gas shift reaction (eq. 4), and (c) gas purification (CO₂ removal). The global reaction (eq. 5) is 4 moles of hydrogen are produced in the reaction with half of it coming from the methane and the other half from water. The energy requirements per mole of hydrogen produced for the overall process is 41.75 kJ/mol H₂ (Muradov, 1998).

\[
\begin{align*}
\text{CH}_4 (g) + \text{H}_2\text{O} (g) & \rightarrow \text{CO} (g) + 3\text{H}_2 (g) \quad (3) \\
\text{CO} (g) + \text{H}_2\text{O} (g) & \rightarrow \text{H}_2 (g) + \text{CO}_2 (g) \quad (4) \\
\text{CH}_4 (g) + 2\text{H}_2\text{O} (g) & \rightarrow \text{CO}_2 (g) + 4\text{H}_2 (g) \quad (5)
\end{align*}
\]

Decomposition of methane (DM) is another strategy for a CO₂-free production of hydrogen from natural gas. The energy requirement per mole of hydrogen produced is 37.8 kJ/mol H₂, which is somewhat less than that for the SRM process. The process is slightly endothermic so that less than 10% of the heat of methane combustion is needed to drive the process. DM was carried out batch-wise using firebrick contact at elevated temperatures (up to 1500 °C).

DM can be written as eq. 6:

\[
\text{CH}_4 (g) \rightarrow \text{C} + 2\text{H}_2 \quad (6)
\]

As can be seen from Figure 2, even at the temperature of 900 °C, the conversion was negligible as the conversion was significantly low. However, after using catalyst, the elevated temperature for the DM reduced. As shown in Table 1, Ni/M-based catalysts (M= Mn, Fe, Co, and Cu) were active at 725 °C especially Ni/Mn.
which maintained its activity even on 120 minutes on stream while at this temperature without using any catalyst the conversion was negligible. For the Ni/Co, at 120 minutes on stream, the pressure drop in the reactor suggested significant changes in the morphology of the bed and possibly blocking the flow of the reactor. It can be seen in Figure 3c that the morphology of the carbon formed on Ni/Co was an encapsulating type of carbon, which might hinder the flow of the reactants through the system. Eventually though, pressure drop was observed in the system due to the limitations imposed by the available free space in the reactor. However, for Ni/Mn, (Figure 3a) the carbon formed were long nanocarbon tubes, which allows the flow of the reactants through the system and maintained its activity. The carbon formed using the Ni/Cu catalyst (Figure 3d) was a mixed type carbon, which includes long nanocarbon tubes. Chain-like type carbon (Figure 3b) with the metal particle at the centre was observed using Ni/Fe as catalyst. The Ni/Mn based catalyst, which maintains its activity for an extended period of time without deactivation can be explained by its mode of carbon accumulation. From the TEM image, it can be seen that the growth of the carbon on the catalyst in which a catalyst particle is located at the tip of the carbon includes the following steps: carbon species formation on the front surface of the metal, diffusion through the metal, and precipitation from the metal at the rear surface for the formation of the filament body with an exposed metal particle at its tip. The rate determining step of this process is believed to be the diffusion of carbon through the metal particle. Therefore, it becomes apparent that the capability of this catalyst to accommodate carbon and maintain its activity for a prolonged time without deactivation is significantly higher. This mechanism may also provide an explanation for the observed fast catalyst deactivation due to active site blocking or pore-mouth blocking. Our results suggest a different mechanism of catalyst deactivation. If the catalyst deactivation were due to active site and pore-mouth blocking, then the nickel surface quickly becomes fully covered with carbon, leading to the interruption of the catalytic cycle as for the case of Ni/Co at 120 minutes on stream. Thus, based upon this viewpoint, it might be expected that the growth rate and the morphological structure of carbon would be mainly dependent on the metal used as a catalyst. Similar TEM image of a Co-alumina catalyst was obtained in which the catalyst particle is located at the tip of the filamentous carbon, indicating that the growth of the carbon from a metal particle in the methane decomposition reaction has been obtained (Avdeeva et al., 1999). However, the methane conversion is as low as 12%.

In Figure 4, the yield of hydrogen increased as the temperature increased. At temperatures below 700 °C, the yield of hydrogen was low. It was reported that in the decomposition of natural gas or other light hydrocarbons to carbon and hydrogen, thermodynamics limits hydrogen yield at temperatures below 700 °C (Parmon et al., 1998). By increasing the WHSV, the yield also decreased. This is due to less contact time of the reactants over the catalyst. At reaction temperatures of 900 °C and GHSV of 3200 h⁻¹, the conversion of methane and the yield of hydrogen was 96%.

5.0 CONCLUSION

Decomposition of methane (DM) is a technologically simple single-step process without energy and material intensive gas separation stages, while steam-reforming of methane (SRM) is a multi-step and complex process. DM process produces only H₂ and solid carbon, thereby eliminating the necessity for the separation of H₂ from the COₓ product. DM was carried out batch-wise using firebrick contact and at elevated temperatures (up to 1500 °C). Attempts have been made to use catalysts to reduce the maximum temperature of the DM. However, it has never been utilized commercially, nor studied extensively. Thus, if the decomposition of methane is to be utilized for the production of H₂ in a continuous process, catalysts with high activity is needed and an effective strategy must be developed for catalyst regeneration.

In this work, the catalytic cracking of methane to hydrogen and carbon over Ni-based catalysts has been
discussed on the basis of preliminary experimental results. It is possible to obtain a high concentration of hydrogen with a single pass reaction at moderate temperature. The growing rate and the morphological structure of carbon would be mainly dependent on the metal used as a catalyst. A stable production of hydrogen and carbon with a tubular morphology has been achieved by using Ni/Mn catalyst. The catalyst was stable even at high temperatures rather than complete deactivation reported in the literature. The hydrogen produced can be supplied directly to the fuel cells without any CO-removal process due to no CO contained in the hydrogen formed by this process. The structure of the carbon is also attractive.

5.0 ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support provided by the Ministry of Science, Technology and Environment of Malaysia under a long-term IRPA grant (Project No. 02-02-05-7003).

REFERENCES


Noor Asmawati Mohd Zabidi received her BSc in Chemistry from Nebraska Wesleyan University, Lincoln, USA in 1986. She carried out research in photocatalytic production of hydrogen at the University of Missouri-Kansas City, USA and received her PhD in 1995. She was a Lecturer at the School of Chemical Engineering, Universiti Sains Malaysia, Perak Branch Campus, from 1996-2000. She supervised Mr. Sharif Hussein Sharif Zein in the research project on catalytic decomposition of methane to hydrogen. Currently, Dr. Noor Asmawati is a Senior Lecturer at Universiti Teknologi PETRONAS.
OVERCOMING THE SHRINK-AND-SWELL EFFECT IN WATER LEVEL CONTROL STRATEGY ON INDUSTRIAL BOILER-DRUM

Fawnizu Azmadi Hussin¹ and Rees, N.W.²

¹Electrical & Electronics Engineering Department, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak Darul Ridzuan, Malaysia. fawnizu@petronas.com.my
²Electrical Engineering & Telecommunications, School of Faculty of Engineering, University of New South Wales, Australia.

ABSTRACT

Power generation has become an increasingly competitive arena. The cost of operating power plants comes mostly from the fuel bill, which runs in the billions of dollars annually. In order to minimise the fuel bill and maximise plant efficiency, a plant’s load-following capability must be optimised, i.e. to follow the demand of power closely. A great deal of attention has been given to the controller that regulates water level (and steam pressure) at the steam-generating unit – the boiler-drum. The control strategy is complicated by the non-linear and non-minimum phase characteristics of the boiler-drum. This paper illustrates our work in the optimisation of load-following scheme by applying a 3-element controller scheme to regulate the boiler-drum’s water level. The controller is then cascaded with another feedback loop that regulates steam pressure. The results from the control scheme have shown considerable improvement over a typical boiler-drum’s water level control strategy.

Keywords: boiler-drum, shrink-swell, load-following, level control

1.0 INTRODUCTION

The cost of running a 500 MW coal-fired unit can vary between USD$2,000 and USD$75,000 per day while the annual fuel bill is nearly USD$5 billion [5]. Waddington, et al. [5] showed that more than 99% of the cost in power plant operation comes from fuel – in this case, coal. The typical components of a power plant are furnace, boiler-drum, superheater and reheater, and turbine units. Figure 1 illustrates the boiler-drum with the downcomer and riser circulation tubes. The cylindrical drums are not heated. Rather, heat is supplied to the incoming water in the riser tubes by direct heat from the furnace gases. There are a large number of riser tubes in the drum-downcomer-riser circulating loop in order to maximise heat transfer. The downcomers are larger in size since no heat transfer takes place. Flow around the circulating loop can be either natural due to pressure difference or forced with pumps. In the design of the circuit, it is very important that sufficient circulation occurs at all times. The cost of plant operation is mainly on the fuel consumption. In order to optimise operation, power generation has to follow power demand very closely, i.e. load-following [4]. The complication in the load-following scheme is mainly caused by the shrink and swell phenomenon that occurs when drum pressure changes [2, 4]. The controller action tends to react negatively due to the misleading shrink and swell effect. The control scheme that is adopted has to counter the effect of the shrink and swell phenomenon.

This paper was presented at Sixteenth International Conference on Systems Engineering, 9-11 September 2003.
in order to optimise the cost of operating the power plant.

2.0 SHRINK AND SWELL PHENOMENON

Figure 1 shows the simplified diagram of the boiler-drum and downcomer-riser circulation loop. When power demand increases, steam flow rate is rapidly increased, causing the steam pressure to drop momentarily. This drop of pressure causes the air bubbles to increase in size and the water level to increase. The phenomenon is termed swell effect.

![Figure 1: Drum-Downcomer-Riser Circulation Loop](image)

The principle of mass balance, however, dictates that the increase of steam flow rate leaving the drum will cause reduction of the total mass inside the drum. Thus, by keeping the feedwater input constant, the mass of water inside the drum will eventually be decreased, causing the water level to drop. This is shown in the open-loop response in Figure 4. On the other hand, if steam demand is reduced, steam bubbles shrink initially and the water level will eventually increase due to the increasing mass of water and steam in the drum. The combined phenomenon is termed shrink and swell.

3.0 BOILER-DRUM DYNAMICS

Drum boiler model [1] is formed using the basic thermodynamics’ mass and energy balance equations. Below are the state equations of the boiler-drum dynamics. The four states are: drum pressure \( p \), total water volume \( V_{wt} \), steam quality at the riser outlet \( \alpha_{sd} \), and volume of steam under the liquid level in the drum \( V_{sd} \). These equations have been derived using mass and energy balances together. The resulting physical equations have then been manipulated into the following form.

\[
\begin{align*}
\frac{dV_{sd}}{dt} + e_{41} \frac{d\alpha_{sd}}{dt} + e_{44} \frac{dV_{sd}}{dt} &= \frac{\rho}{T_d}(V_{sd}^n - V_{sd}) + \frac{h_j - h_s}{h} q_j \\
\end{align*}
\]

where the coefficients \( e_{ij} \) are given by

\[
\begin{align*}
e_{11} &= \rho_s - \rho_i \\
e_{12} &= V_{sr} \frac{\partial \rho_s}{\partial p} + V_i \frac{\partial \rho_i}{\partial p} \\
e_{21} &= \rho_i h_s - \rho_s h_j \\
e_{22} &= V_i \left( h_j \frac{\partial \rho_i}{\partial p} + \rho_{s} \frac{\partial \rho_s}{\partial p} \right) + V_s \left( h_s \frac{\partial \rho_s}{\partial p} + \rho_i \frac{\partial \rho_i}{\partial p} \right) - V_i + m_i C_r \frac{\partial \alpha_r}{\partial p} \\
e_{32} &= \left( \rho_s \frac{\partial h_s}{\partial \alpha_s} + \alpha_s h_s \frac{\partial \rho_s}{\partial \alpha_s} \right) (1 - \alpha_s) V_i + \left( (1 - \alpha_s) h_i \frac{\partial \rho_i}{\partial p} + \rho_s \frac{\partial \rho_s}{\partial p} \right) \frac{\partial \sigma}{\partial p} \\
e_{33} &= ((1 - \alpha_s) \rho_s + \alpha_s \rho_i) h_i \frac{\partial \sigma}{\partial \alpha_s} \\
e_{41} &= \alpha_j \frac{\partial a_j}{\partial \sigma} \\
e_{42} &= V_{sr} \frac{\partial \rho_s}{\partial p} + \frac{1}{k} \left( \rho_i V_{sr} \frac{\partial h_i}{\partial p} + \rho_s V_{sd} \frac{\partial h_s}{\partial p} - V_{sd} \right) + m_s C_r \frac{\partial \alpha_r}{\partial p} \\
&+ \alpha_j (1 + \beta) V_i \left( \frac{\partial \rho_s}{\partial \alpha_s} + (1 - \alpha_s) \frac{\partial h_s}{\partial \alpha_s} + (\rho_s - \rho_i) \frac{\partial \sigma}{\partial \alpha_s} \right) \\
e_{43} &= \alpha_j (1 + \beta) (\rho_s - \rho_i) \frac{\partial \sigma}{\partial \alpha_s} \\
e_{44} &= \rho_r \\
\end{align*}
\]

The parameters notations are, e.g., \( \rho_m \) is specific density of metal.
4.0 MODELLING WITH SIMULINK

This model is implemented in Matlab in the form of an S function, in order to be used in Simulink to build the non-linear system in block diagrams. The working S function is given in [3]. The S-function is then masked to become a 4 input, 2-output MIMO system shown in Figure 2.

![Figure 2: Masked MIMO System of a Drum-Boiler Using S function](image)

The output equation for water level in Figure 2 is

\[ l = \frac{V_{\text{wd}} + V_{\text{sd}}}{A_d}, \]

where

- \( V_{\text{wd}} \) = Volume of water in drum
- \( V_{\text{sd}} \) = Volume of steam in drum
- \( A_d \) = Surface area of drum’s circular side

5.0 OPEN LOOP TESTS

Open loop tests are performed to verify the correct behaviour of the boiler-drum model. Sections 5.1 and 5.2 elaborate how the verification was conducted.

5.1 Mode of Operations

In order to work around the non-linear behaviour of the plant along its operating region (i.e. 0 - 100 percent load), it will be subdivided into three different regions – determined by three different load levels. The values shown in Table 1 are determined by the power plant engineers in such a way that they represent the most common operating modes of the boiler-drum. The PID-based control scheme will only work if we treat the non-linear system as being linear (locally) at each region.

<table>
<thead>
<tr>
<th>Table 1: Mode of Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Load</td>
</tr>
<tr>
<td>Pressure, ( p ) (Mpa)</td>
</tr>
<tr>
<td>Power Level (MW)</td>
</tr>
</tbody>
</table>

5.2 Open Loop Responses

To illustrate the dynamic behaviour of the model, we will simulate the responses-to-step changes in the inputs. The model was simulated using the following parameters, based on Oresund Power Station in Sweden: \( m_t = 300,000 \text{ kg} \); \( m_r = 160,000 \text{ kg} \); \( m_d = 20,000 \text{ kg} \); \( A_d = 20 \text{ m}^2 \); \( V_d = 40 \text{ m}^3 \); \( V_s = 37 \text{ m}^3 \); \( V_{dc} = 11 \text{ m}^3 \); \( V_{sdc} = 8 \text{ m}^3 \); \( C_p = 650 \); \( C_{fw} = 4.18 \); \( k_c = 25 \); \( b = 0.3 \). The steam
Figure 5 shows the comparison of responses to 10 kg/s steam flow rate change at different operating conditions. The swelling effect on the water level is largest at low load, as illustrated by the greatest overshoot. This is mainly caused by the greater variation of steam contribution at low load than at high load.

The non-minimum phase characteristics of the drum water level prove to be non-trivial. Any control scheme that we use to control the water level will be affected by the non-minimum phase characteristics. In addition, the varying sensitivity of the parameters at different operating condition will impose extra difficulty to the control design.

6. SINGLE ELEMENT CONTROL

Single element feedwater control uses only the drum level process variable as feedback. The measured drum level is compared to the drum level setpoint. When the difference deviates from zero (i.e. non-zero error), the feedwater control valve will be adjusted by the proportional-plus-integral (PI) controller to compensate for the error. The integral component of the controller regulates the drum level error to zero.
This control method ensures that the water level stays as close as possible to setpoint value.

This scheme performs satisfactorily under constant or small changes in load (steam flow) and saturation pressure in the drum. If the steam flow increases faster than the heat input, the drum pressure drops quickly and causes the saturation condition to change rapidly from one state to another [1]. This phenomenon is known as swell effect because of the swelling of steam bubbles underneath water surface. This would cause the water level to rise initially. On the contrary, a sudden decrease in steam flow would cause the steam bubbles to shrink and the water level to drop. If the transient is not too severe, the level will eventually return to the setpoint. In these circumstances, more complicated control is necessary.

7. THREE-ELEMENT CONTROL

Three-element control scheme (Figure 6) uses feedwater flow measurements and steam flow measurements as inputs to the controller in addition to water level feedback signals. This improved control scheme adds predictability by anticipating change in load by using steam flow as feedforward and feedwater flow rate as feedback regulation.

Figure 7 shows the comparison between single element control and three element control results on water level and steam pressure. The improvement shown by the improved control method is very significant. There is hardly any oscillation shown by the solid line, except during the shrink and swell (non-minimum phase) effect.

Figure 6: Three-Element Controller Structure. Heat Control Loop is Not Shown
Three-element control scheme is a good alternative to the simpler single element control structure. The performance shown by Figure 7 indicates how three-element controller is a much better alternative.

REFERENCES


Fawnizu Azjadi Husnin is currently a lecturer at Universiti Teknologi PETRONAS, Tronoh, Perak. He obtained his BSc in Electrical & Computer Engineering from the University of Minnesota, Twin Cities and Master in Engineering Science in Systems & Control from the University of New South Wales.

Figure 8 shows the feedwater and power input corresponding to the water level and steam pressure responses in Figure 7. The three-element controller input feedwater eliminates the initial reduction shown by the dotted line. This effect is due to the feedforward (prediction) steam flow signal, which increases feedwater flow even when water level is increasing. The controller knows that water level will eventually decrease. Therefore, it didn’t react to the misleading changes in water level. The oscillation in input feedwater right after the step input is due to the multi-cascaded structure of the controller feedback and feedforward loops.

8. CONCLUSION

The simple, pure feedback single-element PID controller performs satisfactorily to regulate water level error to zero when operating level stays constant. In today’s power industry, competition has driven power plant operators to maximise profit by optimising power generated-power demanded ratio. In order to follow the changing demand, power plant boiler has to change its steam production rapidly; therefore the load-following problem.
AN ETHNICITY RECOGNITION SYSTEM USING IMAGING TECHNIQUES

P. A. Venkatachalam¹, Ahmad Fadzil Mohd Hani, Kavitha Shaga Devan² and Siti Muslihani Abd Ghani
Electrical & Electronics Engineering Department, Universiti Teknologi PETRONAS,
Bandar Seri Iskandar, 31750 Tronoh, Perak Darul Ridzuan, Malaysia,
¹paruvachiammasai_venkatachala@petronas.com.my
²kavit212@yahoo.com

ABSTRACT

Ethnicity recognition is a new research topic proposed in this work. Effort has been made to try to solve this problem to a possible extent. A software implementation of an ethnicity recognition system based on inherent facial and few general features is introduced.

This system uses image processing and computer vision concepts to perform the identification. The system can, in general, identify any race. But the database created now will identify three major races living in Malaysia, typically, Malays, Chinese and Indians. The identification is based on an input in the form of digital face images. Feature extraction is performed in order to extract relevant information from the image.

The extracted features are classified according to a few inherent special characteristics phenomenon, namely skin color, lip color and shape, eyebrows and eye shapes. Statistical information based on color and shapes of various parts of the face extracted from the face images are classified according to the relevant facial features. Identification of ethnicity is performed by a similarity matching procedure between the information extracted from the images and the typical features of each ethnic group, which is already preprogrammed.

Key words: computer vision, image processing, feature extraction, similarity matching

1.0 INTRODUCTION

This work involves the development of a system that will be able to identify the ethnicity of a person based on a facial digital image. The ethnicity that has to be identified is that of a typical Indian, Malay and Chinese person living in Malaysia. This work encompasses a wide variety of techniques such as computer vision, image processing, feature extraction and recognition and as well as software development methods.

Face images consist of widely varied yet similar set of objects such as the eyes, mouth, nose, lips, eyebrows, etc. Even with the similar set of facial features, people of different ethnicity look somewhat different. However, people of the same ethnic group possess a set of facial characteristics that is indigenous to that ethnic group. Variations in features such as the eyes, nose and lips contribute to some of the subtle differences found between people of different ethnicity. Features such as the skin color, eye shape,
lip color and eyebrow color of people of various races provide sufficient discriminatory information for the identification.

A set of characteristics such as facial features and skin color is extracted to perform a multi-resolution analysis that yields successful identification capabilities. A wide variety of tools and techniques are developed and used to obtain the intended multi-resolution analysis. The input for this system will be the facial image of a person and the output will be the identification of the person’s ethnicity. The input image will be subjected to a series of image processing and analysis to identify the inherent features that pertain to a certain ethnicity and the features are classified accordingly.

The feature extraction is achieved by analyzing several facial characteristics of the input image applying some developed algorithms by which the ethnicity can be identified. Ideally, the system should be able to respond accurately to various facial variations such as head position, lighting levels, occlusions, aging, gender, etc.

A 100% successful recognition rate is unrealistic for the current research level. Hence, the work is aimed at only finding a feasible solution that is both workable and satisfies a minimum requirement.

2.0 OBJECTIVES OF THE WORK

i. To develop a system that will identify, in general, the ethnicity of a person based on a digital face image. The ethnicity that will be identified, in particular, is that of Malay, Chinese and Indian persons living in Malaysia.

ii. To apply image processing and computer vision concepts and techniques such as image acquisition, restoration, texture classification, feature extraction and ethnicity recognition [6].

iii. To develop a user-friendly ethnicity recognition system that will allow the user to easily perform the ethnicity recognition tasks. The user interface is made simple and require only a few manual adjustments from the user.

iv. To develop a software with a possible level of accuracy and reliability. Also, to provide a system which is robust and efficient.

3.0 HUMAN FACIAL PHYSIOLOGY AND COLOR PERCEPTION

Color is a property of enormous importance to human visual perception. Color perception depends on both the physics of the light and complex processing which integrates the properties of the stimulus with previous experience.

Face images consist of widely varied yet similar set of objects such as the eyes, mouth, nose, lips, eyebrow region, etc. Even with the similar set of facial features, the people of different ethnicity look different. However, people of the same ethnicity possess a set of facial characteristics that is indigenous to that ethnic group. Variations in features such as the eyes, nose and lips contribute to some of the subtle differences found between people of different ethnicity. Some of the readily apparent and discriminating features are skin color, nose shape, eye shape, facial texture, lip color, eye color, hair color, etc [1].

2.3 Feature Extractions and Analysis

The features of interest that can be extracted from an image include geometric properties of binary objects, histogram and color features. Sample histogram features for a typical Chinese, a Malay and an Indian are shown in Figure 1. One important aspect of feature analysis is to determine which of the features are important so that the specific application can be incorporated into the system. Features that can be extracted are color, texture and shape information as
well image statistical information [8]. The Table 1 shows the selected facial features of the three ethnic groups considered in this work.

3.0 SOFTWARE DEVELOPMENT

The ethnicity recognition system is developed as a series of software modules. The facial features taken into consideration are the facial skin color, lip color, eye shape and eyebrow region. Number of face images were processed for four selected features and the average range of pixel values measured are shown in Table 2.

The statistical color data of the face images are analyzed. This extraction of statistical data was applied to different regions of the face image.

This information is very valuable for this system. The core analysis of this system, is based on color. For the eye shape, a shape analysis is done. The height and width of each eye are determined. The ratio of eye width to its height is taken as a feature. It can be observed that this ratio for different ethnic groups varies. This is considered as the core feature for determining the eye shape. The system begins with the acquisition of an input face image from a digital camera under restricted resources. The face images must be taken under controlled compact environment such as constant lighting levels, background and head position. Once the suitable image is obtained, it will undergo preprocessing steps. The preprocessing steps are format transformation, image resizing, noise removal and brightness and contrast enhancements [5].

Figure 1: Histograms of the faces of a typical Malay, an Indian and a Chinese
**Figure 2:** Flow chart of Process Methodology for all facial features (Skin color, Lip region color, Eye shape, Eyebrow region color)

All the images used are in BMP format. The input image is read, processed and stored in an output location. The flowchart shown in Figure 2 gives various processing steps to be performed.
Table 1: Typical selected facial features of the three ethnic groups

<table>
<thead>
<tr>
<th>No.</th>
<th>Criteria</th>
<th>Chinese</th>
<th>Malay</th>
<th>Indian</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Skin Color</td>
<td>White/yellowish</td>
<td>Light olive brown</td>
<td>Light dark brown</td>
</tr>
<tr>
<td>2</td>
<td>Eye Shape</td>
<td>Small/narrow</td>
<td>Medium/big</td>
<td>Big/round</td>
</tr>
<tr>
<td>3</td>
<td>Eyelids</td>
<td>Not prominent</td>
<td>Prominent</td>
<td>Very prominent</td>
</tr>
<tr>
<td>4</td>
<td>Eye Color</td>
<td>Dark brown</td>
<td>Dark brown/black</td>
<td>Black</td>
</tr>
<tr>
<td>5</td>
<td>Eye Brow</td>
<td>Thin/sparse</td>
<td>Medium thick</td>
<td>Thick</td>
</tr>
<tr>
<td>6</td>
<td>Eye Lash</td>
<td>Short/straight</td>
<td>Long</td>
<td>Long/Curly</td>
</tr>
<tr>
<td>7</td>
<td>Eye Depth</td>
<td>Shallow/wide</td>
<td>Deep set</td>
<td>Deep set</td>
</tr>
<tr>
<td>8</td>
<td>Nose Shape</td>
<td>Wide/flat</td>
<td>High/wide</td>
<td>High, Sharp</td>
</tr>
<tr>
<td>9</td>
<td>Cheeks</td>
<td>Pinkish</td>
<td>Brownish</td>
<td>Brownish</td>
</tr>
<tr>
<td>10</td>
<td>Cheek Bones</td>
<td>Low</td>
<td>Low cheekbones</td>
<td>Low</td>
</tr>
<tr>
<td>11</td>
<td>Face Shape</td>
<td>Oval/long</td>
<td>Round/oval</td>
<td>Oval/long</td>
</tr>
<tr>
<td>12</td>
<td>Jaw line</td>
<td>Sharp jaw</td>
<td>Rounded</td>
<td>Sharp</td>
</tr>
<tr>
<td>13</td>
<td>Lip Thickness</td>
<td>Thin</td>
<td>Medium thick</td>
<td>Thin</td>
</tr>
<tr>
<td>14</td>
<td>Lip Color</td>
<td>Pink/coral</td>
<td>Pink/light brown</td>
<td>Reddish brown</td>
</tr>
<tr>
<td>15</td>
<td>Lip Shape</td>
<td>Wide set</td>
<td>Wide set</td>
<td>Wide set</td>
</tr>
<tr>
<td>16</td>
<td>Facial Hair</td>
<td>Not prominent</td>
<td>Slightly</td>
<td>Yes</td>
</tr>
<tr>
<td>17</td>
<td>Hair Color</td>
<td>Brown/black</td>
<td>Black</td>
<td>Black</td>
</tr>
<tr>
<td>18</td>
<td>Hair Texture</td>
<td>Smooth/straight</td>
<td>Straight/wavy</td>
<td>Wavy/curly</td>
</tr>
<tr>
<td>19</td>
<td>Skin Texture</td>
<td>Smooth/straight</td>
<td>Slightly rough</td>
<td>Slightly rough</td>
</tr>
<tr>
<td>20</td>
<td>Facial Structure</td>
<td>Soft structure</td>
<td>Medium soft</td>
<td>Hard</td>
</tr>
</tbody>
</table>

Table 2: Selected facial features and the average range of pixel values measured

<table>
<thead>
<tr>
<th>Ethnicity</th>
<th>Skin Color</th>
<th>Lip Region Color</th>
<th>Eye Shape (pixels)</th>
<th>Eyebrow Region Color</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Width</td>
<td>Height</td>
</tr>
<tr>
<td>Indian</td>
<td>70 – 100</td>
<td>42 – 63</td>
<td>27.4</td>
<td>20.3</td>
</tr>
<tr>
<td>Malay</td>
<td>80 – 130</td>
<td>45 – 63</td>
<td>25.2</td>
<td>19.5</td>
</tr>
<tr>
<td>Chinese</td>
<td>90 – 150</td>
<td>47 – 70</td>
<td>24.3</td>
<td>18.1</td>
</tr>
</tbody>
</table>

5.0 RESULTS AND DISCUSSION

The ethnicity recognition system was tested using a set of sample images. A set of 30 sample images have been used for testing purposes. It is seen that all the images used have a standard size, lighting level, frontal face pose and neutral facial expression. Four software modules; namely,

i) Skin color module,
ii) Lip color module,
iii) Eyebrow region module, and
iv) Eye shape module
have been developed and tested extensively to determine the systems’ accuracy and efficiency.

From the results, it is found that the skin color module is able to give good results with an efficiency of 63%. The eyebrow region module is also able to show a 62% efficiency. But the eye shape software module gives an efficiency of 53% and the lip-color module shows an efficiency of 50% only.

There are many factors that caused the output to a reduced efficiency. The factors are the difficulties in providing uniform lighting for every region of the face, lack of high precision image acquisition equipments, high resolution processors, monitors and output devices.

Thus, some images appear to be brighter while some look darker. The inconsistency in lighting may have caused some discrepancies in the results.

When the model is using cosmetics, the skin color, lip color as well as eyebrow color change. Thus, the system will not be able to give accurate identification.

Generally, incorrect identifications might also be caused due to the facial expressions of the models at the instant of capturing the images. As a sample, the table 3 shows the output given by the eyebrow region module.

### Table 3: Results of identification using eyebrow region module

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Image tested</th>
<th>Eyebrow Intensity</th>
<th>Identified ethnicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Malay</td>
<td>28</td>
<td>Malay</td>
</tr>
<tr>
<td>2</td>
<td>Malay</td>
<td>21</td>
<td>Indian</td>
</tr>
<tr>
<td>3</td>
<td>Malay</td>
<td>28</td>
<td>Malay</td>
</tr>
<tr>
<td>4</td>
<td>Malay</td>
<td>21</td>
<td>Malay</td>
</tr>
<tr>
<td>5</td>
<td>Malay</td>
<td>27</td>
<td>Malay</td>
</tr>
<tr>
<td>6</td>
<td>Malay</td>
<td>14</td>
<td>NO</td>
</tr>
<tr>
<td>7</td>
<td>Malay</td>
<td>23</td>
<td>Malay</td>
</tr>
<tr>
<td>8</td>
<td>Malay</td>
<td>21</td>
<td>Malay</td>
</tr>
<tr>
<td>9</td>
<td>Malay</td>
<td>20</td>
<td>Indian</td>
</tr>
<tr>
<td>10</td>
<td>Malay</td>
<td>21</td>
<td>Malay</td>
</tr>
<tr>
<td>11</td>
<td>Indian</td>
<td>40</td>
<td>NO</td>
</tr>
<tr>
<td>12</td>
<td>Indian</td>
<td>27</td>
<td>Indian</td>
</tr>
<tr>
<td>13</td>
<td>Indian</td>
<td>52</td>
<td>Chinese</td>
</tr>
<tr>
<td>14</td>
<td>Indian</td>
<td>23</td>
<td>Indian</td>
</tr>
<tr>
<td>15</td>
<td>Indian</td>
<td>27</td>
<td>Malay</td>
</tr>
<tr>
<td>16</td>
<td>Indian</td>
<td>16</td>
<td>Indian</td>
</tr>
<tr>
<td>17</td>
<td>Indian</td>
<td>20</td>
<td>Indian</td>
</tr>
<tr>
<td>18</td>
<td>Indian</td>
<td>29</td>
<td>Chinese</td>
</tr>
<tr>
<td>19</td>
<td>Indian</td>
<td>25</td>
<td>Indian</td>
</tr>
<tr>
<td>20</td>
<td>Indian</td>
<td>54</td>
<td>NO</td>
</tr>
<tr>
<td>21</td>
<td>Chinese</td>
<td>46</td>
<td>Chinese</td>
</tr>
<tr>
<td>22</td>
<td>Chinese</td>
<td>56</td>
<td>Chinese</td>
</tr>
<tr>
<td>23</td>
<td>Chinese</td>
<td>70</td>
<td>Chinese</td>
</tr>
<tr>
<td>24</td>
<td>Chinese</td>
<td>91</td>
<td>NO</td>
</tr>
<tr>
<td>25</td>
<td>Chinese</td>
<td>82</td>
<td>NO</td>
</tr>
<tr>
<td>26</td>
<td>Chinese</td>
<td>43</td>
<td>Chinese</td>
</tr>
<tr>
<td>27</td>
<td>Chinese</td>
<td>50</td>
<td>Chinese</td>
</tr>
<tr>
<td>28</td>
<td>Chinese</td>
<td>44</td>
<td>Chinese</td>
</tr>
<tr>
<td>29</td>
<td>Chinese</td>
<td>63</td>
<td>NO</td>
</tr>
<tr>
<td>30</td>
<td>Chinese</td>
<td>41</td>
<td>Chinese</td>
</tr>
</tbody>
</table>

### 7.0 CONCLUSION

An ethnicity recognition system has been successfully developed, under restricted facilities and environment, that would be able to identify, in general, the ethnicity of a Malays, Chinese and Indians living in Malaysia. This recognition system combines image processing and computer vision concepts for identification. This system employs feature extraction technique to obtain information on a few salient facial features. The research group is continuing the work and will be able to get better results using proper equipments and environmental conditions.
REFERENCES


P.A. Venkatachalam received his Bachelors Degree in Electrical and Electronic Engineering with First Class Honours. He read for his Masters in MTech (Control System Engineering) from the Indian Institute of Technology, Kharagpur and his PhD (Computer Engineering and Science Software Engineering) from the Indian Institute of Technology, Kanpur. He started his career as an Electrical Engineer (1957-61) and later, served in the Indian Government as a lecturer (1961-66) and Assistant Professor (1966-76). He held the position of Full Professor at the Asian Institute of Technology, Bangkok (2 years) and at Anna University, Madras, India (10 years) where he was also the Head of its Department of Electronics, Communication & Computer Science & Engineering. From 1988-2000, he served as Professor at Universiti Sains Malaysia (1988-2000). Currently, he is a Professor at the Electrical & Electronic Engineering Programme, Universiti Teknologi PETRONAS. His areas of research are in Software Engineering, Computer Networks, Image Processing, Medical Imaging and IT.

Ahmad Fadzil M.H. graduated in 1983 from the University of Essex, UK with an Honours BSc degree in Electronic Engineering. He completed his MSc in Telematics in 1984 and PhD in Image Processing in 1991 at the same university.

He has been a Lecturer in Signal Processing and Researcher in Image Processing at Universiti Sains Malaysia (USM) since 1984. Between 1988-91, he served at University of Essex, UK initially as a Senior Research Officer in Image Processing and subsequently as a Lecturer. On his return to Malaysia, he was made Dean of the School of Electrical & Electronic Engineering at USM from 1992-96. In 1997, he became the founding Dean of the Engineering Faculty at the newly established Universiti Teknologi PETRONAS. He became the Director of Academic Studies at the university in 1999. Currently, he is the Director of Postgraduate Studies, a position he assumed in 2003.

Dr. Ahmad Fadzil is a Fellow and a Council Member of the Institution of Engineers, Malaysia. He is a registered Professional Engineer with the Board of Engineers, Malaysia. He is also a Member of the IEEE, USA. His research interests include image compression and image processing applications in telemedicine and artificial intelligence.
ABSTRACT

Mammography has been shown to be effective in screening women to detect occult breast cancers and to reduce mortality by as much as 25% in women and few men. Mammograms can often detect a breast lump before it can be felt. A mammogram can also show small deposits of calcium in the breast. Such calcium deposits called microcalcifications may be an early sign of breast disease that may be benign or malignant. In order for mass screening to be cost effective, there is a need to achieve high accuracy and speed. However, it is difficult for radiologists to interpret large volumes of mammograms. Digital image processing techniques for the enhancement of mammograms to improve the detectability of diagnostic features have been developed in this work, amongst which, is the use of seed based region growing method. In addition, an expert system has been developed to diagnose breast diseases that hopefully can be carried out by general practitioners in hospitals and clinics where an expert radiologist is not available. The system has been tested on about 20 cases and found to give satisfactory diagnosis.

Keywords: breast cancer, microcalcifications, region growing, expert system

INTRODUCTION

Breast cancer is one of the leading causes of death in women. The disease also affects a small percentage of men. It is estimated that 15 to 20 percent of women are inflicted with the disease.

Recent studies have indicated that prognosis dramatically increases if the breast lesion can be detected earlier i.e. when it is found at a size less than 1 centimeter. This size is too small for the lesion to be palpable. The only way a lesion of this small size can be detected is through mammography.

A study conducted has found a 45% reduction in breast cancer mortality for women who received mammographic screening every 18 months. Mass mammographic screening of women can help detect breast cancer at the earliest stage possible but this means a large volume of mammograms need to be interpreted by radiologists. In such film-based mammography [3,4], a particular film image cannot be reprocessed to get a better image. If need be, the patient will be subjected to another exposure of x-rays. This is not really recommended. It is here that image processing techniques can be adopted to make the unsatisfactory images to be more useful. To assist in mass screening, computer-aided schemes have been investigated for the detection of the suspicious areas in digitized mammograms. In particular, an attempt has been made to identify microcalcifications which may be prominent symptoms of early breast cancers.
Mammographic images may be digitally processed to improve their quality. Features that may be missed by the naked eye can be enhanced and made more evident to identify significant signs. These can then be quantified to analyse large volumes of mammograms and identify those containing significant or suspicious features. The seed based region growing technique is one of the many digital techniques that have been developed to analyze digitized mammographic images.

THE SEED BASED REGION GROWING

Microcalcifications are considered to be important signs of breast cancer. The automated classification of microcalcifications have been investigated to identify the properties of benign and malignant individual and/or clustered calcifications. In this paper a seeded region based segmentation technique is proposed to highlight the shape of clusters of microcalcifications [1,2]. In this process, an initial set of small areas are usually merged according to similarity constraints. An arbitrary seed pixel is chosen and compared with neighbouring pixels that are similar, increasing the size of the region. During region growing every pixel in the image is chosen successively as the seed. The region growing is confined to the selected window of suspected area centered on the selected seed. Next, the seed pixel’s gray level is compared with the statistics (e.g. the mean, variance etc.) of its neighbourhood pixels. If some growing conditions are fulfilled from the comparison, the seed pixel will grow towards its neighbors. The process continues recursively until the region cannot grow anymore or all the pixels have been considered. When the growth of one region stops we simply choose another seed pixel which does not yet belong to any region and start again. This whole process is continued until all pixels belong to some region. The chosen seed is surrounded by a P x P neighbourhood pixels and is at the centre of all its neighbours. This is shown in Figure 1 for P = 7. There are three possible ways for a seed pixel to grow, as shown in Figures 2, 3 and 4 respectively using four connectivity and eight connectivity methods.

Starting with the number of seeds, these have been grouped into n sets: A1, A2, …, An. Sometimes individual sets could consist of single points. At each step of the algorithm, we add one pixel to some of the sets Ai, i=1,…,n.

Consider now the state of sets Ai after m steps. Let T be the set of unallocated pixels which border at least one of the regions, what means that T is the set of all pixels which are on the borders of the, up to now, formed regions. Here N(x) is the set of immediate neighbours of the pixel x. In this case, the 8-connectivity is considered [5].

Once the growing process is terminated two regions are obtained. One is the seed-grown region and the other is the surrounding region. The intensities of the two regions are compared. Based on the clusters of calcifications on the grown region it may be inferred...
whether the particular case is highly suspicious of malignancy or otherwise. This method has been applied on the mammograms obtained from a local hospital. The sample results obtained on the mammogram of patient X have been presented in Figure 5.

![Figure 5a: Original breast image](image)

![Figure 5b: ROI marked on the original image](image)

**THE EXPERT SYSTEM**

An expert system is a computer-based system that uses knowledge, facts and reasoning techniques to solve problems that normally require the abilities of human experts. An expert system’s knowledge is obtained from expert sources such as specialists, texts, journals and other sources deemed valuable and coded in a form suitable for the system to use in its inference or reasoning processes. Architecture of an expert system is shown in Figure 6. The expert system contains specific rule-base for the differentiation of breast diseases. It can be utilized both to train physicians in mammography and to promote a more consistent mammographic interpretation[4].

![Figure 6: The expert system architecture](image)
“MAMMEX”, the expert system developed in this work can achieve results that are consistent with those generated by the primary domain expert. In other words, each time MAMMEX is consulted, it is expected to provide the same advise as an expert radiologist on mammograms.

The system provides the range of certainty values which can be assigned to each rule in the knowledge base. To make results easy to interpret, a certainty (probability) system provides groupings between 1 and 10 with 10 as a base. The certainty values are based on six classes (very unlikely, unlikely, uncertain, certain, definite, most definite) indicating varying degrees of successes that could be expected when consultation takes place.

**SYSTEM DESCRIPTIONS AND OPERATION**

MAMMEX is available on a PC. During execution, questions relevant to mammographic features will be put on the screen. This is how the program obtains data needed to make a decision. The questions asked have multiple-choice answers. A list of answers are provided for of which the user can make a selection. A user is supposed to answer all the questions that are asked. The system will continue to supply questions until a conclusion is reached. Based on the answers provided, a set of outputs that include one or more diagnoses will be displayed with relevant certainty values. The questions that MAMMEX ask will be on the mammographic signs such as signs of asymmetry, presence of mass and calcifications, skin, nipple, trabecular and auxiliary nodal abnormalities. A flowchart of the procedures for assessing a mammogram is given in Figure 7. Altogether, MAMMEX covers seven levels of benign/malignancy and 33 diseases. These choices can be further expanded. Thirty-three premises form the basis from which rules can be developed and are used to describe the diseases. Because the effectiveness of the expert system depends upon the choice of premise, premises are chosen from standard medical text books and interview sessions carried out with practicing radiologists and experts. The certainty classes we used in the system are as follows: very unlikely - 0,1; unlikely - 2,3; uncertain - 4,5; certain - 6,7; definite - 8,9 and most definite 10 (Table 1). Classification of the breast

<table>
<thead>
<tr>
<th>Certainty class</th>
<th>Certainty Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very unlikely</td>
<td>0,1</td>
</tr>
<tr>
<td>Unlikely</td>
<td>2,3</td>
</tr>
<tr>
<td>Uncertain</td>
<td>4,5</td>
</tr>
<tr>
<td>Certain</td>
<td>6,7</td>
</tr>
<tr>
<td>Definite</td>
<td>8,9</td>
</tr>
<tr>
<td>Most definite</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 1: Certainty classes

Figure 7: The MAMMEX flow diagram
Technology Cluster: INTELLIGENT SYSTEMS

AN IMAGE EMBEDDED EXPERT SYSTEM (IMMEX)

An attempt has been made in this work to develop an image-aided expert system called IMMEX whereby the user can interact with the expert system which contains an expert knowledge base on breast diseases together with the different levels of processed images of relevant mammograms to accentuate possible certainties. The user can also carry out the necessary image processing functions available in the integrated image processing modules and these manipulations will further enable the user to respond to the enquiries by the system. This is shown in Figure 8.

Table 2: Classification of Breast diseases

<table>
<thead>
<tr>
<th>Adenosis</th>
<th>Calcified cyst</th>
<th>Calcified fat necrosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcified involuting fibroadenoma</td>
<td>Comedocarcinoma</td>
<td>Contusion</td>
</tr>
<tr>
<td>Cyst</td>
<td>Ductal carcinoma</td>
<td>Fat necrosis</td>
</tr>
<tr>
<td>Fibroadenolipoma</td>
<td>Fibroadenoma</td>
<td>Fibrosis</td>
</tr>
<tr>
<td>Galactocele</td>
<td>Giant fibroadenoma</td>
<td>Gynaecomastia</td>
</tr>
<tr>
<td>Hematoma</td>
<td>Hyperplasia</td>
<td>Inflammatory carcinoma</td>
</tr>
<tr>
<td>Intramammary lymph node</td>
<td>Lipoma</td>
<td>Liposarcoma</td>
</tr>
<tr>
<td>Medullary carcinoma</td>
<td>Metastatic breast cancer</td>
<td>Mucoid carcinoma</td>
</tr>
<tr>
<td>Oil cyst</td>
<td>Paget’s disease</td>
<td>Papillary carcinoma</td>
</tr>
<tr>
<td>Papilloma</td>
<td>Papillomatosis</td>
<td>Scirrhous carcinoma</td>
</tr>
<tr>
<td>Sclerosing adenosis</td>
<td>Secretory disease</td>
<td>Tubular carcinoma</td>
</tr>
</tbody>
</table>

Figure 8: The features of IMMEX
CONCLUSION

Breast cancer is a leading cause of death among women and its incidence is rising. Mammography has proved to be the primary radiological procedure for early detection of breast cancer. Between 60 percent and 70 percent of non-palpable breast carcinomas demonstrate microcalcifications on mammograms. Therefore, clustered micro-calcifications on mammograms are an important indicator of breast carcinoma. Mammographic screening of women at earlier stages can reduce breast cancer mortality, but requires a large volume of mammograms that need the interpretation by radiologists. Therefore computer-aided analysis has been developed to identify features that have characteristics associated with the disease easily and to determine whether the features detected represent malignancy. A number of digital image processing techniques for the enhancement of mammograms to improve the detectability of diagnostic features have been developed. The seed based region growing technique that was developed has been presented in this paper.

In addition to that, an expert system developed to diagnose breast diseases has also been explained. The expert system can be easily used by the doctors in hospitals where there is no expert radiologist available.

REFERENCE


P.A. Venkatachalam received his Bachelor's Degree in Electrical and Electronic Engineering with First Class Honours. He read for his Masters in MTech (Control System Engineering) from the Indian Institute of Technology, Kharagpur and his PhD (Computer Engineering and Science Software Engineering) from the Indian Institute of Technology, Kanpur. He started his career as an Electrical Engineer (1957-61) and later, served in the Indian Government as a lecturer (1961-66) and Assistant Professor (1966-76). He held the position of Full Professor at the Asian Institute of Technology, Bangkok (2 years) and at Anna University, Madras, India (10 years) where he was also the Head of its Department of Electronics, Communication & Computer Science & Engineering. From 1988-2000, he served as Professor at Universiti Sains Malaysia (1988-2000). Currently, he is a Professor at the Electrical & Electronic Engineering Programme, Universiti Teknologi PETRONAS. His areas of research are in Software Engineering, Computer Networks, Image Processing, Medical Imaging and IT.

Ahmad Fadzil M.H. graduated in 1983 from the University of Essex, UK with an Honours BSc degree in Electronic Engineering. He completed his MSc in Telematics in 1984 and PhD in Image Processing in 1991 at the same university.

He has been a Lecturer in Signal Processing and Researcher in Image Processing at Universiti Sains Malaysia (USM) since 1984. Between 1988-91, he served at University of Essex, UK initially as a Senior Research Officer in Image Processing and subsequently as a Lecturer. On his return to Malaysia, he was made Dean of the School of Electrical & Electronic Engineering at USM from 1992-96. In 1997, he became the founding Dean of the Engineering Faculty at the newly established Universiti Teknologi PETRONAS. He became the Director of Academic Studies at the university in 1999. Currently, he is the Director of Postgraduate Studies, a position he assumed in 2003.

Dr. Ahmad Fadzil is a Fellow and a Council Member of the Institution of Engineers, Malaysia. He is a registered Professional Engineer with the Board of Engineers, Malaysia. He is also a Member of the IEEE, USA. His research interests include image compression and image processing applications in telemedicine and artificial intelligence.
ABSTRACT

The cement kiln and clinker grinding mills are two of the critical operations in cement manufacture. The quality parameters of the cement depend on the type and extent of mineral transformations occurring in the kiln as well as the particle size distribution achieved in the closed circuit grinding. Control of cement kilns has inherent difficulties because the quality parameters are not amenable for online measurement. Though online analyzers are available for the cement particle size analysis, the instruments are expensive and prone to operational difficulties. An attractive solution to this problem is the use of soft sensors based on neural networks. In soft sensors, the quality variables are related to process measurements by a N-N model and estimated online.

INTRODUCTION

Manufacture of cement is one of the important tonnage industries contributing highly to activities of large economic value like housing and infrastructure development. Stringent quality specifications have to be maintained in the manufacture of cement for the safety of the structures. Currently the process for the manufacture of cement is the dry process method with pre-calciner technology. In this method, the major raw material, limestone, is blended with other materials like clay and iron ore to make the feed. The feed specifications are controlled within very narrow ranges. Traditionally, cement makers specify the feed quality by control ratios known as Lime Saturation Factor (LSF), Silica Modulus (SM), Iron Modulus (IM) and Residue (RES). These control ratios have a profound effect on the quality of the cement. The blended feed passes through a series of cyclones where the feed comes into contact with the hot gases from the kiln and is heated to about 900 °C. The calcined feed then enters the kiln. The kiln is a long, horizontal, tubular furnace typically 4 meters in diameter and 60 meters long. It is rotated about its axis at a speed of about 3-rpm. Fuel (pulverized coal, fuel oil, natural gas) is fired from the exit end of the calciner with the required amount of preheated air. The solids come into contact with counter-current hot combustion gases. Solid-solid and solid-liquid reactions takes place and the material forms into hard round granules about 5 cm diameter known as clinkers. This process is known as clinkerisation. The hot clinkers are used to preheat the incoming air and are cooled. The cooled clinkers are ground in closed circuit ball mills to close specifications (surface area 320 m²/kg) to make cement. The civil engineering specifications for cement are expressed in terms of its strength. Specifications like 24 hour strength, workability, 28th day strength and color are used to specify the cement quality. These civil engineering specifications are intimately connected with four mineral constituents of cement, Allite (tricalcium silicate, C₃S), Belite (dicalcium silicate, C₂S), Aluminate (tricalcium aluminate, C₃Al) and Ferrite (tetracalcium alumino ferrite, C₄AF). C₃S is responsible...
for early strength while C$_3$S is responsible for late strength. C$_3$Al is related to plasticity and workability and C$_4$AF determines the color. Relationships relating the mineral concentrations with the civil engineering quality parameters have been presented by Bogue, 1929 [1] and Hormain and Regourd, 1980 [2].

**VARIABLES AFFECTING CLINKER MINERALISATION**

The concentration of the mineral constituents in the clinker is affected primarily by two groups of variables, 1. Feed quality variables and 2. Operating variables in the pre-heater and kiln (Table 1).

The feed is made up of a blend of limestone, clay and iron ore to give specific composition to the cement and required burning characteristics in the kiln. Traditionally, cement makers have characterized the blend specifications by certain ratios. The Lime Saturation Factor (LSF) defines the actual content of CaO in the clinker with the maximum that can exist if all calcium present was in the form of tricalcium aluminate. Silica modulus is the ratio of the amount of silica to the sum of the oxides of aluminum and iron present in the feed. The Iron Modulus (IM) is defined as the ratio of alumina to iron oxide present in the feed. A high value of LSF increases the allite content and decreases the belite content of the clinker. This will make the raw mix more difficult to burn as well as increasing the grindability of the clinker. A low SM indicates good burnability and favorable solid-liquid reactions for clinker formation. Similarly, a high allite content and a low belite content gives a clinker which is easy to grind. Thus online monitoring of the clinker mineralization can lead to better burning conditions and thus lead to better cement quality.

The important process variables related to the clinker formation are the burning temperatures, flow rate of feed, air-flow rate and the residence time of the material in the kiln. The burning temperature is represented in the model by the feed temperature and the air temperature. The temperature of the solid feed cannot be directly measured. However it is close to the temperature of the air leaving the first cyclone in the pre-calciner chain. The feed rate and air flow rate are directly measured in the system. The residence time of the material in the kiln is well represented by the kiln rpm. Thus, the 12 variables shown in Table 1 were selected for inclusion in the N-N model as having a large influence in the mineralization in the kiln. The output variables of interest are the four clinker minerals, tricalcium silicate, dicalcium silicate, tricalcium aluminate and tricalcium alumino ferrite. These variables can be directly related with the quality of the cement produced.

### Table 1: Variables Affecting Clinker Mineralization

<table>
<thead>
<tr>
<th>Type of Variable</th>
<th>Name of the Variable</th>
<th>Unit</th>
<th>Range of Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material quality</td>
<td>Lime Saturation Factor, LSF</td>
<td>%</td>
<td>95.0-98.0</td>
</tr>
<tr>
<td>Raw material quality</td>
<td>Silica Modulus (SM)</td>
<td>%</td>
<td>2.0-2.7</td>
</tr>
<tr>
<td>Raw material quality</td>
<td>Iron Modulus (IM)</td>
<td>%</td>
<td>1.1-1.4</td>
</tr>
<tr>
<td>Raw material quality</td>
<td>Residue (RES)</td>
<td>%</td>
<td>8-12.5</td>
</tr>
<tr>
<td>Operating variable</td>
<td>Suction pressure</td>
<td>m bar</td>
<td>89-99</td>
</tr>
<tr>
<td>Operating variable</td>
<td>Feed inlet temperature</td>
<td>°C</td>
<td>865-976</td>
</tr>
<tr>
<td>Operating variable</td>
<td>Feed rate</td>
<td>tph</td>
<td>200-218</td>
</tr>
<tr>
<td>Operating variable</td>
<td>Kiln rpm</td>
<td>rpm</td>
<td>2.28-3.02</td>
</tr>
<tr>
<td>Operating variable</td>
<td>Secondary air temperature</td>
<td>°C</td>
<td>913-1125</td>
</tr>
<tr>
<td>Operating variable</td>
<td>Secondary air flow to chamber 1</td>
<td>m³/min</td>
<td>816-932</td>
</tr>
<tr>
<td>Operating variable</td>
<td>Secondary air flow to chamber 2</td>
<td>m³/min</td>
<td>809-931</td>
</tr>
<tr>
<td>Operating variable</td>
<td>Secondary air flow to chamber 3</td>
<td>m³/min</td>
<td>1034-1248</td>
</tr>
</tbody>
</table>
There have been several applications of neural networks for the modeling of process equipment. Ramachandran and Rhinehart, 1995 [3] used a neural network to model a distillation column. The N-N model was further used by them to design a GMC controller for the column. Hunt and Sbarbaro, 1995 [4] used an N-N to model the non-linear pH process. The only reported application of N-N for kiln modeling is the work of Ribeiro and Corriea, 1995 [5]. Radhakrishnan, 2000 [6] used a neural network to model the silicon, and sulfur concentrations in the hot-metal produced by a blast furnace.

NEURAL NETWORKS

Neural networks can be thought of as a non-linear mapping between a set of inputs and a set of outputs. The inputs and outputs are connected through a series of nodes arranged in several layers (Figure 1). Because of this complex interconnectivity between the nodes the N-N models are able to reproduce non-linear relations with excellent accuracy. The inputs $x$ are connected to the input layer. The outputs $y$ are taken from the output layer. There are no limitations on the number of inputs and outputs in the model. Between the input layer and the output layer there exists one or more hidden layers. Each hidden layer contains several nodes. The transformation or mapping takes place in the hidden layers. All the nodes in one layer are connected with all the nodes in the next layer. The connection strength of node $i$ with node $j$ is given by weight $w_{ij}$. The weight can take values between 0 and 1. A connection strength of 0 implies no connection while 1 implies the full output goes to node $j$. At any node $j$ all the inputs are summed to give the total activation. The output of the node is calculated as a non-linear function of the total activation. A common non-linear function used for the transformation is the sigmoid function. The mathematical operations at any node can be expressed by the equations,

$$Z_j = \sum_{i=1}^{n} x_i w_{ij} - b_j$$  \hspace{1cm} (1)

$$Y_j = \frac{1}{1 + e^{-z_j}}$$  \hspace{1cm} (2)

NOMENCLATURE

- $b$ – bias
- $w$ – weight
- $i, j$ – node number
- $x$ – input
- $y$ – output
- $z$ – activation

**Figure 1:** Feed Forward Neural Network
There are no hard and fast rules about the choice of the number of the nodes and number of hidden layers to be used in an application. Usually some trial and error is required to determine the best combination to minimize the prediction error.

Before a neural network can be used for predicting the output, it has to be trained. During the training phase, the best values of the weights $w_{ij}$ are determined by an optimization procedure. In the present work, a standard method of optimization known as the Generalized Delta Rule as presented by Quantrile and Liu, 1991 [7] was used for training. In the GDR algorithm, we start with an initial assumed set of weights. For all the data sets in the training set, we determine the calculated outputs using the N-N and compare it with the actual output. The error between the two is used to change the weights such that the summation of the squared errors are minimized. A suitable optimization technique is used for this purpose. In the present study, the Newton-Raphson method was used for the gradient search.

### DATA ACQUISITION AND PRETREATMENT

Data for training of the neural network was obtained from an operating cement kiln of capacity 3150 ton/day. The data was collected over a period of 2 months so that the entire horizon of operating conditions are reflected in the data. This is necessary for the trained N-N to accurately predict the output corresponding to any set of inputs. If the input data does not cover the complete data horizon then the N-N trained with such data will not be able to predict the output accurately when presented with data outside its training horizon. The operational data were obtained from the DCS logs of the plant. The corresponding raw material qualities were obtained from the laboratory logs. The clinker mineral constitution with respect to the four output minerals were obtained by spectroscopic examination. The total number of data sets used for training were 528. Hence the complete data set consists of a matrix of 12 input columns, 4 output columns and 528 rows of data. An additional 54 sets of data were collected after a lapse of 8 months to test the long term stability of the network predictions. The different statistical tests and data pretreatment performed to enhance the quality of the network are discussed briefly.

1. **Correlation Analysis:** Correlation coefficient were determined between input-output pairs, between pairs of inputs and between pairs of outputs. The correlation coefficient between pairs of inputs were found to be negligible showing that the input variables selected are independent. Similarly the correlation between outputs were also negligible attesting to their independence. The correlation between input-output pairs were high showing the strong dependency of the outputs on the inputs.

2. **Normality Test:** The data were tested for normal distribution by the method of normal scores as given by Devore and Peck, 1993 [8]. Most of the data failed the test showing the presence of skew. If the data were normally distributed the training would be simpler.

3. **Normalization:** The 12 input variables and the 4 output variables listed in Table 1 vary widely in their magnitude. If the raw data is used for training the N-N, data which are large in magnitude will influence the optimization disproportionately compared to the data which are small in magnitude. Such a network will give poor performance. Hence it is necessary to scale all the data to the same range of 0-1. A linear normalization was used for this purpose.

4. **Data Segmentation:** Neural Network training is performed in three stages, training, validation and testing. In the training stage, the data is trained with part of the data set. After the weights have converged during the training phase, the trained net is retrained using the data in the validation set. This prevents the over training of the N-N. Over training is the phenomenon where a network adapts itself to the special features of a data set to minimize the error. Consequently, when another
data set is presented to it, it fails to predict with high accuracy. Retraining with a validation set breaks the over training in the weights. After the convergence of validation phase, the N-N is presented with a fresh set of test data and error is determined. This tells how good the prediction accuracy of the trained network is.

TRAINING, VALIDATION AND TESTING OF THE NETWORK

The first task in N-N modeling is the choice of an appropriate network architecture. In general, the more the number of neurons and hidden layers, the more the accuracy. However with too many neurons the possibility of over training will increase. In the present work only a single hidden layer was used. N-N with 12 nodes, 20 nodes and 30 nodes were tested. The network architecture is represented in Figure 2. The training pattern shown in Figure 3 for tricalcium silicate (C₃S) is typical of all the others. The training was carried for 100,000 iterations. The best results were obtained with 20 nodes with a minimum 0.5% error. Increasing the number of nodes to 30 did not substantially reduce the error. Hence, the network containing 20 nodes in a single hidden layer was used for the modeling. The two-stage training-validation procedure was followed to prevent over training. The trained network was used for testing, using the data set earmarked for the purpose.

MODEL TESTING AND VALIDATION

To validate the neural network model, the predicted values were compared with the actual measured values from the kiln. A comparison of the predicted values with their actual values are shown in Figure 4. The model was able to predict the output variables with an accuracy of the order of 3% which is adequate for control purposes.

Figure 2: 12x12x4 Neural Network Architecture used for Kiln Model

Figure 3: Convergence of error during training and validation phases

The second important equipment in cement manufacture is the clinker grinding mill. This equipment is a ball mill working in closed circuit using a centrifugal air classifier system. The objective of the model was to predict the cumulative particle size analysis of the ground cement produced by the grinding mill. The major variables affecting the particle size analysis of the product (Table 2) were chosen considering the mechanism of the mill as well as the available instrumentation in the plant. The variables consisted of two groups of variables: 1. The properties of the material fed to the mill, and 2. The mill operating parameters. The first group of variables include the
average particle size of the clinker, the percentage of gypsum in the fresh feed, tonnage of fresh feed, Hardgrove grindability index of the clinker, the tonnage and average particle size of the recycle material. The important operating conditions affecting the mill performance includes the power input to the mill, material residence time in the mill and the conditions of the ball charge in the mill. Since the latter two variables were not available for direct measurement, two other variables were used in their place.

The noise produced by the mill (measured by a Folophone) is an important variable giving the overall effect of ball charge and holdup. Similarly, the temperature rise of the material is a measure of residence time and impact energy delivered to the material. These two variables were, hence, included in the model. The complete cumulative distribution curve was the desired output. For obtaining the cumulative curve size, analysis at several particle sizes are required. The particle sizes chosen were > 124 m, 90-124 m, 75-89 m, 63-74 m, 33-62 m and < 33 m.

A total of 520 data sets were collected and statistically processed before being used for network training. A neural network with one hidden layer and 25 neurons were used for modeling the system. The number of input layer neurons were 9 and the number of output layer neurons were 6 to give the 6 particle size ranges in the cumulative graph. A typical analysis predicted by the NN model is shown in Figure 5 together with the actual value of the size analysis obtained using a Malvern particle size analyzer. The neural network is able to generate the cumulative particle size analysis with extremely high accuracy. The standard deviation between the predicted and actual values is less than 5%.

Table 2: Variables affecting Ball Mill Grinding

<table>
<thead>
<tr>
<th>Name of variable</th>
<th>Range of values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed, tons/hour</td>
<td>50-150</td>
</tr>
<tr>
<td>Gypsum in feed, %</td>
<td>2.4-6.9</td>
</tr>
<tr>
<td>Return material, tons/hour</td>
<td>4.5-66.9</td>
</tr>
<tr>
<td>Folaphone reading, %</td>
<td>69-98</td>
</tr>
<tr>
<td>Temperature in, ºC</td>
<td>76-82</td>
</tr>
<tr>
<td>Temperature out, ºC</td>
<td>78-118</td>
</tr>
<tr>
<td>Power, kW</td>
<td>1000-2968</td>
</tr>
<tr>
<td>Hardgrove Grindability Index</td>
<td>150-161</td>
</tr>
<tr>
<td>Clinker average size, mm</td>
<td>16-21</td>
</tr>
</tbody>
</table>
It is proposed to use the neural network based models of the cement kiln and cement grinding mill for on line predictive control. The control system for the kiln will be based on an expert system model incorporating the NN predictive scheme together with a expert knowledge base on kiln operation. For the grinding mill a normal IMC controller is proposed using the NN mill model. The studies on the development of the control systems are currently under progress.

CONCLUSIONS

Neural network models have been proposed for two important equipment in cement making, the cement kiln and the cement grinding mill. By including relevant process measurements in the model and careful statistical treatment of the training data, the models developed have been found to perform very satisfactorily.

REFERENCES


V. R. Radhakrishnan obtained his BSc (Physics) from Madras University and BTech (Hons.), M Tech and PhD degrees in Chemical Engineering from the Indian Institute of Technology. He did his Post Doctoral Research from the University of Karlsruhe. He served the IIT as a Professor in Chemical Engineering and took voluntary retirement in 1995. His areas of interest includes Advanced Process Control, Process Modeling and Separation Processes. He has published 48 papers in refereed journals and over 150 papers in national and international conferences. He is the author of a widely used book entitled ‘Instrumentation and Control for the Chemical, Mineral and Metallurgical Processes’. He was a German Academic Exchange Fellow and a Fulbright Scholar. He was awarded the Corp of Engineers Gold Medal for Excellence in Research by the Institution of Engineers. He is with the Universiti Teknologi PETRONAS since 2001 as Professor in Chemical Engineering.
ABSTRACT

This paper presents the development of an Intelligent Tutoring System (ITS). The website can be used as an alternative learning method for e-learning. The aim of the research project is to design and develop an ITS prototype that integrates adaptive learning approach. The target users are year six students and the science subject has been selected as the course content. The development work combines four research elements in the ITS architecture which are knowledge-based design, student model design, instructional design and some addition of learning theory as the input. By introducing ITS to the primary school students, it is an extra exposure to other types of learning method as an extension to what has been used for education in Malaysia.

Keywords: intelligent tutoring system, adaptive learning, hypermedia system, e-learning

1.0 INTRODUCTION

Institutions nowadays, both public and private, offers e-learning courses for self-motivated individuals through independent study programs. An analysis of the situation may find that the determining factor for the success of e-learning is the students themselves. Students should be highly motivated so that they will gain as much knowledge from the presented materials.

E-learning websites, however, provide only a passive and static hypertext with no individual adaptation capability. In order to have non-static websites as well as interactive educational environment, it is necessary to extend the website framework so that it is capable of guiding the students to take into account their comprehension ability and area of interest [7]. An ITS is proposed and developed in this project to provide the capability of automatic student adaptation.

1.1 Problem Statement

Highly structured e-learning systems do not support the different learning styles and learning rates of students [8]. Good educational material should take into account a student’s background so that the instruction can be tailored to their specific capabilities and past history.

Ordinary e-learning systems lack features to motivate the students because they do not feel the sense of
ownership of the course material. Learners should have a possession of the learning goals as well as the learning materials [9]. The learning material is crucial since on-line materials are untouchable and intangible unlike textbooks.

1.2 Aims and Objectives

This research project aims to design and develop an e-learning system that incorporates the adaptive learning concept and approach. The project objectives are to include design the architecture of an interactive and intelligent e-learning website and to increase student motivation and sense of ownership when using e-learning facilities.

2.0 LITERATURE REVIEW

Analyzing the task-based adaptive learner guidance on the TANGOW web [3] shows that adaptive learning systems instantiate a relatively recent area of research. It integrates two distinct technologies in computer-assisted instruction, which are Intelligent Tutoring Systems and Hypermedia Systems. According to Eklund and Zeilliger (1996), the effect of the integration contributes more directive tutor-centered style of traditional AI based systems and the flexibility of student centered browsing approach of a hypermedia system.

The adaptive learning architecture consists of four different layers. The top layer is an Adaptive Learning Layer, where the learning process between students and the system takes place. The components of this layer are the instructional event and learning support unit. The second is an Adaptive Instructing Layer. This layer contains a set of logical protocols that responds automatically to the different learning strategies. It has three functions: to construct and to maintain the students cognitive model, to manage and to present the lesson content dynamically, and to integrate the instructional event. The last two layers are the Supporting Layer and the Administration Layer. These layers are important to guarantee that the objectives of adaptive learning strategies are achieved.

The conventional architecture of an intelligent tutoring system consists of four modules [12]:

- **Expert module** – The teacher’s knowledge are in the domain. This knowledge base has to contain all the relevant information about the domain of knowledge.

- **Tutor module** – This model contains the didactic knowledge of a human teacher. This component is an intelligent tutoring system that has to provide fundamental strategies to teach the content of the lesson.

- **Student module** – The student module is the teacher’s knowledge about the student’s knowledge state and his typical method of working. This component stores the information about the extent to which the student masters the domain and about his working characteristics (learner-type of the student or his preferences).

- **Communication module** – An intelligent tutoring system is required to present its knowledge in a comprehensible way. The use of a graphical presentation, especially animated, can provide illustration, perhaps even better than in conventional instruction.

During the past years, various artificial intelligent formalisms have been developed for knowledge representation that can be incorporate into the Intelligent Tutoring System [6]. Four ways to represent knowledge within knowledge-based are IF-THEN rules, IF-THEN rules with uncertainty measures, Semantic Network Representations, and Frame Based Representation [10].

The idea of having a Hypermedia system as a part of the adaptive system is to allow the user to have different goals and knowledge [4]. Students may have interest in a different piece of information and may use different links for navigation. Such adaptive navigation techniques comprehend direct guidance, sorting, hiding and annotation of links and map adaptation.
The techniques of link hiding and annotation are proved to be efficient for learning applications [1]. Link hiding is currently the most frequently used technique for adaptive navigation support. The idea is to restrict the navigation space by hiding links that do not lead to "relevant" pages, i.e., not related to the user's current goal or not ready to be seen [2]. Adaptive annotation is the augmentation of links with some form of comments, which can tell the user more about the current state of the nodes behind the annotated links [1]. The annotations can be either textual or visual and can be used with all possible forms of links, like for instance, indexes or contextual links.

3.0 DESIGN

The ITS has been designed using a guideline proposed by Bra (1999). The guideline stated that in applying adaptive concept in developing educational website, the following elements need to be considered:

(i) proper method must be used to retrieve user information;
(ii) provide short prerequisite information;
(iii) the website developed must permit more than one way of lesson presentation;
(iv) the link must be structured so it will guide the user during the navigation;
(v) provide guidelines for the novice user; and
(vi) use hyperlinks to provide details for the advance user as an alternative to adapt their need.

The architecture of ITS is shown in Figure 1. Three basic models have been used:
(i) Knowledge Based Model;
(ii) Student Model; and
(iii) Instructional Model.

Knowledge Based Model incorporates artificial intelligence techniques so that the Instructional Model can adapt to the learner's needs and styles. It is also used to embed an expert knowledge in the structure of the content and apply an appropriate instructional design model.

Student model represents two major kinds of information: student personal data and their current state of domain knowledge [11]. The student data are used to identify a student's learning style, where this is the data about the students that need to be learned before e-learning materials are presented.

The Instructional Model contains fundamental strategies to teach the courses, for instance, the way of presenting and choosing proper examples or the

![Figure 1: Architectural Design of ITS](image-url)
appropriate timing of help. The model selects the instruction sequences, teaching styles and learning scenario (e.g. guided free play, learn-by-doing, discovery learning and mixed-initiative dialogue).

The adaptive engine provides the facilities for reconciling the Student, Knowledge Based and Instructional models to produce individualized content. It is important that this is achieved in a fashion which is independent of the content or the specific properties of the learner. The Adaptive Engine interprets the three models to represent different sets of learning environments to the user.

The Administration sub module is where the instructor registers the user to the ITS. The student’s user ID and password is created here. This sub-module can only be accessed by the instructor.

3.1 Knowledge Based Model Design

The Knowledge Based Model serves two purposes. On one hand, it may be part of an expert system that assists the student in solving problems, and on the other hand, it is the basis for building the model of cognitive structure of a student [12]. In this prototype, knowledge-based will be represented using Semantic Network Representation (SNR) and it is supported with IF-THEN rules. The information taken from semantic networks is being stored in a database. The basic components of a semantic network representation are nodes and arcs. The node represents the object of the knowledge-base while the arc represents the relationships between nodes. Examples of predefined arcs are: IS_IN, INSTANCE_OF, IS, IS_CIRCULATE. Figure 2(a) illustrates an example of a knowledge-base which is represented using SNR.

The representation of knowledge-base using SNR is to solve problems caused by students of different perceptions. For example, a student’s perception of the shape between the Sun and the other Stars in the solar system differs from each other. The prototype will use the knowledge-base to provide them with the right answer by using SNR and IF-THEN rules as in Figure 2(b).

3.2 Student Model Design

The adaptation to student performance is very crucial. It will determine whether the student performs well or not after using the ITS. Students’ understanding of the material presented will be tested using multiple-choice questions. The result from the test will be the input for ITS to analyze to which level a student should be categorized. The process starts after a student completes the test or examination questions. Upon the first login, all students are treated as beginners. The

**Figure 2:** Knowledge-base: (a) Represented using SNR (b) Problem Solution

**Question:** Which one above figures represent the shape of Star in our solar system?

**Solution:**

Knowledge-based: Sun instance_of Star(z)
Alpha Phyx instance_of Star (x)
All Star is Spear

Using if-then rules: Goal: What is the shape of Alpha Phyx
if (x) then (y)
Therefore Alpha Phyx is sfera
system assumes that the students do not have a full understanding of their knowledge in the subject being taught. Based on their scores, students are stereotyped according to the following categories: expert (>80%), intermediate (40%-80%) and novice (<40%).

3.3 Instructional Model Design

Theoretical questions are widely used in the system because it comprises two benefits. First, is to develop a question and answer database, and the second, is to investigate the automatic generation of questions from subject knowledge-base [12].

Instruction design that is implemented in the system will generate strategies to acquire a student’s attention by ensuring that the material is easy to understand. The strategy varies. It can be a combination of many strategies or only one strategy to stimulate a student’s understanding. Figure 4 shows a tutoring strategy that is based on the sub-goal specified in an ALS process. Each of the sub-goals will determine whether the goal can be achieved or not. By taking into account, the knowledge-based information and the student’s status, the predefined instruction can be located for a learning strategy.

4.0 IMPLEMENTATION CONSIDERATION

Figure 5(a) shows the Course Page. The level of a student’s category will be to determine the type and format of the course page. Based on the student’s test performance, the ITS will use different techniques to display the course material. For instance, in a beginner category, the system will use simple words and some examples (prompt pages) about the topics that have been discussed to make it more understandable. Within the course page, there are link segments that provide some links to other sites in the Internet that are related to a particular topic. While in the Science Corner, some examples or implementation of a real application about a particular topic is illustrated.
Figure 5(b) shows the test/exam page. ITS will automatically select several questions to be answered by the student. The format of questions is multiple-choice. A student’s level will determine the type of question that will be displayed. For example, in a beginner page, ITS will select questions with diagrams and questions without diagrams with the ratio of 3:1. The difficulty of questions will be increased according to the student’s level.

An Explanation Page is shown in Figure 6. After the student has answered all questions, the system would display all the questions which the student had answered wrongly. Comments and hints like the key points that a student needs to be aware of before answering the question was given as feedback. To assist complex explanations, diagrams are used.

Bots is an intelligent agent for special purpose knowledge-based system that accomplish specific tasks for users. The idea of having interaction with a Bot Page is to introduce ITS to the student with the use of subjective answers. The implementation of this segment is limited to simple and direct answers. The complete application has to use the structural and keyword representation. In this segment, the system will have a question that must be solved by student. Students will be guided to solve the question until the right answer appears.

5.0 EVALUATION

ITS evaluation involved 30 students which were divided into three groups (Group A, B, C). Each of the groups were using 3 different types of learning methods. Group A used ITS, group B used the conventional style and group C used a multimedia courseware. The evaluation is done for one week in the Science class. The selected students were separated according to their respective group. Group A was placed in networked computer laboratories, Group C in the multimedia laboratories and Group B remained in the class. Before the session end, the students took a simple test and the results were recorded. After the 7th day, the results were collected and tabulated as in Figure 7. From the graph, the results for students who used ITS was better than the conventional and multimedia courseware, although on the first day, the Group A result was the lowest. However from time to time, Group A’s results kept improving. This was because on the first day, students in Group A were not familiar with the ITS learning style compared to the other groups.
6.0 CONCLUSION

In conclusion, having adaptive and intelligent characteristics, ITS can be a successful teacher in the future. Implemented through WWW together with e-learning methods, ITS is sufficient to achieve the basis for a learning system where it must be distributable, adaptive and intelligent. The idea of implementing ITS to reduce human interception between student and real teacher, provides one teacher exclusively for one student and supports an e-learning concept that can be realized by ITS.

REFERENCES


Jafreezal Jaafar graduated with a Degree in Computer Science from Universiti Teknologi Malaysia in 1998. He obtained his Master of Applied Science in Information Technology from RMIT University, Australia in 2002. He worked as a System Engineer before joining Universiti Teknologi PETRONAS (UTP) as Trainee Lecturer in 1999. Currently, he is a lecturer in the IT/IS Program at UTP. His main research areas are Software Design, Virtual Environment and Human-Computer Interaction.

Dayang Nur Fatimah A. I. graduated with a Degree in Information Technology from UNIMAS in 1998. She obtained her Master in Multimedia Computing from Monash University, Australia in 2002. Currently, she is a lecturer in the Faculty of Information Technology at UNIMAS. Her main research areas are multimedia and e-learning.

Mohd Azmir A. Aziz graduated with a BTech in Information Technology from UTP. Currently, he works as a System Engineer at Hei-Tech Padu Sdn. Bhd.
This paper presents our recent success in synthesising carbon nanotubes in powder form. The method adopted involved thermal chemical vapour deposition (CVD) using catalysts such as nickel (Ni), cobalt (Co) and iron (Fe). Measurements on the diameter of carbon nanotubes (CNTs) have been conducted using surface analysis software on the image derived from scanning electron microscopy (SEM). It is observed that the average diameter of CNTs follows the order of Fe > Co > Ni. This outcome is attributed to the effect of the particle size of the catalyst, which is in the same order before the synthesis. The morphologies of CNTs are almost the same regardless of the catalyst used. However, on closer examination, CNTs grown from Fe exhibit a fairly straight structure as compared to the ones grown from Ni and Co where curled and even some helical nanotubes have been identified. Results obtained imply that the structure and size of CNTs can be determined by the selection of the catalyst.

**Keywords:** nanotechnology, carbon nanotubes, catalyst, nanoparticles, deposition

---

**INTRODUCTION**

The work here focused on synthesising carbon nanotubes, which are considered to be the most promising materials and anticipated to create an enormous impact on future nanotechnology. Their unique structural and electronic properties [Yacobson et al., 1997, Dekker et al., 1999] have generated huge interest for use in a wide range of potential nanodevices [Tans et al., 1998, Martel et al., 1998, Soh et al., 1999].

Since the discovery of carbon nanotubes in 1991, various methods of production such as laser vaporization [Thess et al., 1996], pyrolysis [Sen et al., 1997, Terrones et al., 1997], plasma-enhanced [Ren et al., Ma et al., 1999], arc discharge [Bethune et al., 1993], and chemical vapor deposition (CVD) [Li et al., 1996, Fan et al., 1999] have been investigated. Recently, the CVD method has drawn a lot of attention because of its versatile advantages namely variety in products and hydrocarbon sources, adequacy for synthesis of high quality materials, controllability of microscopic structures, simplicity of apparatus and mass production.

The objective of this research work is to develop the right procedures for growing nanotubes by thermal CVD. The effect of Fe, Co, and Ni catalysts on CNTs was also investigated. CNTs were grown on three different catalyst particles under the same conditions. It is predicted that the particle size of the catalyst is one of the factors determining the diameter of the CNTs produced. Despite tremendous progress on the fundamental work on the growth and structure of catalytically grown nanotubes, not much have been
reported on the actual effect of catalysts on the structure and size of nanotubes produced.

**EXPERIMENTAL PROCEDURES**

The first procedure in the synthesis of CNTs using thermal CVD involved preparing three different catalytic metal particles, iron, nickel and cobalt in nano size. A new method of preparing nano size catalytic particles to grow powder form CNTs has been developed. The catalytic metal powder was first weighed and then etched in diluted hydrofluoric acid (HF). The next step of rinsing with deionized water will remove HF solution from the residue. Once completely removed, the residue was left to dry in the oven. The residue was then mixed thoroughly in ethanol by supersonic dispersion and several drops were spread on the wafer before drying out in the oven. This technique of using ethanol droplets will ensure an even spread of catalytic particles on the substrate wafer and to prevent agglomeration from occurring. Finally, the wafer was loaded on a quartz boat and inserted into a CVD reaction tube, ready for growing CNTs.

Initially, Argon (Ar) gas was allowed to flow at the flow rate of 200 sccm into the reactor to prevent oxidation of the catalytic particles while increasing the temperature. When the reaction temperature reached 950 °C, the flow of Ar gas was stopped and replaced by ammonia (NH₃) gas at the flow rate of 200 sccm for 5 hours. This pretreatment with NH₃ gas prior to the synthesis process is to reduce the catalyst particles to nanometer sized particles. After the formation of nanosized catalyst particles, CNTs were grown on these etched catalytic particles in the methane (CH₄) atmosphere flowed in at 40 sccm for an hour at 950 °C. When the growth of CNTs was completed and temperature was cooled down to 150 °C, the quartz boat was retrieved from the reaction tube and left to cool to room temperature. The powder sample of CNTs produced was washed by diluted hydrochloric acid (HCl) solution in order to dissolve catalytic particles. The remaining sample of CNTs was washed and cleaned with deionised water and then dried in the oven. Surface analysis on CNT’s grown on Fe, Co, and Ni catalyst particles was conducted using a scanning electron microscopy (SEM). SEM sample preparation involved coating the sample on conductive carbon tape with metallic film.

**RESULTS AND DISCUSSION**

Figure 1 depicts SEM image of CNT’s on Fe particles. From SEM micrographs, clear images of the tubes are chosen and their diameters are determined using surface analysis software of Carl Zeiss AxioVision 3.1. The value obtained ranges from 31 nm to 38 nm.

<table>
<thead>
<tr>
<th>Catalyst Type</th>
<th>Diameter distribution (nm)</th>
<th>Average diameter (nm)</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>31-38</td>
<td>35</td>
<td>Fairly straight with some curled nanotubes</td>
</tr>
<tr>
<td>Co</td>
<td>23-26</td>
<td>25</td>
<td>Curled nanotubes with some helical ones</td>
</tr>
<tr>
<td>Ni</td>
<td>19-24</td>
<td>21</td>
<td>A lot of curled nanotubes</td>
</tr>
</tbody>
</table>

Figure 2 describes the image of CNTs on an grown Co particles. The values of diameter obtained are in the range of 23 nm to 26 nm. With CNTs grown on Ni particles, the values are slightly smaller, about 19 nm to 24 nm (see figure 3). These results are summarised in Table 1.

The results indicated that CNTs grown on Fe catalyst have larger diameters compared to the ones on Co and Ni. Similar order in the size of CNTs grown catalytically on the same catalyst particles has been reported by Lee et al., 2002. This can be explained by the size effect of catalyst particles on the CNT growth. It is believed that the size of catalyst particles is in the order of Fe > Co > Ni before CNT growth. Lee has also reported the
highest growth rate with Ni particles because being the smallest particles, the rate of adsorption of carbon at the growth sites is faster, resulting in a faster growth rate.

It appears that the morphologies of CNTs on all catalyst particles are almost the same. However, closer inspection of the images showed a distinction between CNTs on different catalyst particles. Nanotubes grown on Fe particles seem to have fairly straight structure whereas a lot of curled ones can be observed on CNT images grown on Ni. Some helical tubes can even be identified amongst the curled ones grown on Co (see Figure 4). Similarly shaped nanotubes have been reported by Bernaerts et al., 1995.

Detailed model on curled and helical nanotubes is given by Amelinckx et al., 1994. The growth of these nanotubes is discussed in terms of a locus of active sites around the periphery of the catalytic particle, and growth velocity vectors. In the simplest case, the locus sites is circular and the extrusion velocity is constant, producing a straight tube propagating at a constant rate as can be seen in some of the tubes grown on Fe catalyst particles. In reality, the locus of active sites may not be circular, which introduces some complexity in the shape of the tubes. It has been shown that a catalytic activity, which varies around the ellipse, will produce helical growths.

CONCLUSION

In this work, the right procedures have been developed to grow carbon nanotubes catalytically in powder form.
using thermal CVD. The effect of using different catalyst particles on the size and shape of CNTs has also been investigated. It was found that the particle size of the catalyst which is in the order of Fe > Co > Ni produced CNTs with diameters in the same order. The size effect of catalyst particle is concluded to be the main factor determining the diameter of CNTs grown. Structurally, CNTs grown on Fe are fairly straight whereas CNTs grown on Ni and Co reveals some curled and even helical shaped tubes.

ACKNOWLEDGEMENTS

The financial support of Universiti Teknologi PETRONAS is gratefully acknowledged. The authors would also like to express their gratitude to AMREC for the use of SEM and Encik Rosli Mohd for the technical support.

REFERENCES


ABSTRACT

A key requirement in achieving successful submicron fabrication processes is the control of the thermal budget. This has created a considerable interest in transient methods of thermal processing which minimize the negative influence of high-temperature processes on semiconductor crystals. In brief, transient heating derived from rapid thermal processing can promise a lot of advantages. The emergence of this important processing technique has led to a rapid growth of research activities in this area involving all types of processes. The objective of this research is to design and develop a laboratory scale furnace system. Experiments conducted through deposition and doping processes on silicon wafers using the constructed system have revealed the superiority and advantages of the system over the conventional ones, in particular, the shorter time scales (measured in seconds), the reasonably low temperatures and the sheet resistivities produced. This type of system would open a vast scope of research at the laboratories without the huge investment on the commercial rapid thermal system.

INTRODUCTION

The current trend of miniaturization of integrated circuit (IC) elements in the development of microelectronics demands for successful fabrication processes of submicron structures. One of the most effective methods of controlling phase-structure, properties, and electrophysical parameters of materials and ICs is thermal processing. Conventionally, this process takes a longer duration, ranging from tens of minutes to several hours. However, with rapid thermal processing, shorter time scales, normally in seconds can be achieved.

This transient heating offers a number of advantages including the opportunity to modify material properties of the semiconductor in the solid phase combined with minimal negative effects at high temperature. Negative effects include diffusion redistribution of dopants, generation of defects, and generation of carrier traps in the oxide and at the semiconductor-oxide interface. Over the past 15 years, there has been a rapid growth of research activity for all types of processes, ranging from annealing of ion implant damage (Correra, 1980), dopant diffusion (Davies, 1986), gettering (Sparks, 1986), oxidation (D’Heurle, 1983), nitridation, and chemical vapour deposition of a range of materials (Hsieh, 1991).

Traditionally, rapid thermal processing (RTP) is used for defect annealing, recrystallization, and activation of doped implanted layers. The study here focuses on RTP operating in the heat balance regime with incoherent light and short heating times (Sedgwick, 1983). Thermal processing regime of heat balance occurs when the pulse duration is long enough to have uniform temperature distribution in the wafer. Using halogen lamp as the radiation source, this type of
A thermal processing regime can be produced and has been widely applied because of its simple technical implementation. The reduced temperature gradient of this rapid process can cause a reduction in the elastic stresses and consequent defect generation in the wafers.

Solid-state processes initiated in semiconductors by RTP are mainly of thermal origin and hence there are many similarities with conventional furnace annealing. However, the much shorter processing times, rapid heating and cooling produce distinct features. The non-equilibrium fast transient processes occurring can introduce structural changes during the initial moment of the thermal processing (Borenstein, 1986; Adekoya, 1987).

**EXPERIMENTAL DETAILS**

The constructed RTP system is divided into several main parts, namely the heating source, reaction furnace, lamp holder, and reflector and temperature control system. Halogen tungsten lamp is chosen because the incoherent radiation produced can provide a uniform temperature profile to the wafer (Borinsenko, 1984). Here, 12 lamps of 1000 W are used as the heating source. They emit ~ 55% of the radiation produced in the wavelength range of 0.4 – 4.0 mm.

Quartz tube was used as a reaction furnace because of its capability in withstanding high temperatures, between 1700-1800 °C and resistant to thermal shock and also 80% reflectivity in the wavelength range of 0.27 – 2.0 µm. The lamp holder consists of two pieces of circular plates made of 5 mm thick stainless steel. The circular plate of diameter 21.5 cm, has a hole at the centre to house the quartz tube of diameter 8.4 cm. Halogen tungsten lamps will be connected to the sockets attached to the circular plate. Both plates are connected with each other with a stainless steel rod. A stainless steel cylinder of 21.5 cm diameter and 3 mm thick is used as the reflector. The outermost layer of the system is the concrete cylinder of thickness 2.0 cm, which acts as the insulator. The lamps are controlled by the automated system control, solid-state relay and thermocouple.

Here, a comparative study was made between conventional and rapid thermal processing for doping process. Rapid thermal processing would use the constructed system shown in Figure 1, while the conventional processing required a conventional furnace (Naberthem, West Germany). In the conventional system, the copper tube coils surrounding the quartz reaction tube act as the heating source. The temperature is maintained by the control power provided by a copper tube coil.

![Figure 1: Configuration of RTP system](image)

Heat transfer in RTP systems involves the radiation mechanism between the tungsten filament and substrate where the latter has a much lower temperature. In this way, the sample will be heated directly through radiation causing the temperature of the wafer to rise up rapidly. Unlike RTP, the heat transfer mechanism in the conventional furnace involve transferring of heat from copper coil to the mullite tube which acts as a heat reservoir to heat the sample. This method takes a longer time to reach a high temperature.

Differences between the conventional and RTP furnace does not limit the rate of heating and cooling only, but also the mechanism involved in the thermal reaction. With a conventional system, the radiation source emit infrared and long wavelength radiation spectrum whereas RTP system ranges from short infrared wavelength to ultraviolet wavelength.
A thin film of spin-on diffusion source was deposited onto clean silicon wafer (p-type with orientation <111>) using spinning technique. Spin-on dopant source of phosphorus with concentration of $2 \times 10^{21}$ cm$^{-3}$ was used. Heat treatment processes involved are the pre-deposition and drive-in. Temperature for these diffusion processes is the same, at 800-900 °C. But the processing times vary from 30 to 240 s for pre-deposition of RTP and 5 to 20 minutes for pre-deposition of conventional processing. In the drive-in process, the processing time for RTP is 15 to 90 s whilst the conventional technique requires 10 to 40 minutes.

Wafer that had been deposited with dopant will be subjected to the pre-deposition process. The purpose of this heat treatment is to inject dopant atoms into the surface of the wafer. This will be followed by drive-in process, intended to distribute dopant atoms into the wafer. Sheet resistivity can then be measured by using the four-point-probe unit.

RESULTS & DISCUSSION

Phosphorus from the traditional group-V dopants, is the fastest diffuser in silicon. This property determines its unique behaviour during RTP. Figure 2 shows the sheet resistivity ($R_s$) of phosphorus-doped silicon after a certain period of heating using incoherent light rapid thermal processing and conventional furnace at 850 °C and 900 °C. Note that $R_s$ obtained in rapid thermal processing of range 40 to 60 Ω/sq requires only between 20 to 90 s whereas in the conventional processing, $R_s$ of 100 to 150 Ω/sq needs about 10 to 40 minutes.

With slightly higher temperature of 900 °C, $R_s$ of 43.5 Ω/sq. can be obtained in 15 s for RTP as compared to the conventional method where 30 minutes would be required to achieve $R_s$ of 46.1 Ω/sq. For both processing temperatures, lower values of $R_s$ can be observed with RTP compared to the conventional processing. This implies that the diffusion enhancement of phosphorus in silicon can be achieved in a very much-reduced processing time, within seconds.

Figure 2: Sheet resistivity of phosphorus-implanted silicon layers as a function of processing time for RTP and conventional processing at 850 °C and 900 °C

Figure 3: Sheet resistivity of phosphorus-doped silicon after RTP and conventional processing at different temperatures

Figure 3 displays sheet resistivity induced by RTP and conventional technique for phosphorus doping concentration of $2 \times 10^{21}$ atoms/cm$^3$ at different processing temperatures. Sheet resistivity of RTP was found to be within the values reported by Nielsen (1983) who used different doping doses. Higher values of the conventionally induced sheet resistivity were recorded here. It should be noted that in conventional processing, significant decrease of sheet resistivity from 800 to 900 °C could be observed. This is believed to be associated with phosphorus depth redistribution. However, similar to Nielsen’s observation, there is no obvious redistribution in the doped layer of RTP at impurity concentration of $2 \times 10^{21}$ atoms/cm$^3$. On the other hand, enhanced phosphorus redistribution can be observed with doping concentration of greater than $1 \times 10^{16}$ atoms/cm$^3$. It is concluded that the
observed differences could not be attributed to different concentration point defects, which are released during thermal processing. It seems that the occurrence of enhanced diffusion at concentrations beyond a certain critical value correlates with the steady-state phosphorus solubility in silicon. This leads to a suggestion that the cause of diffusion enhancement is by non-equilibrium point defects created by dissociation of supersaturated phosphorus solution.

CONCLUSION

Clearly, the lower values of RTP-induced Rs implies the enhanced diffusion of phosphorus taking place in the layer that is already recrystallized with the participation of mostly interstitial non-equilibrium point defects generated during RTP. Rapid heating of phosphorus-doped silicon crystals for time within seconds at a temperature of 900 °C results in an enhanced diffusion of the impurity without any noticeable redistribution.

Results obtained from the experiment using the constructed RTP system have shown that this technique is capable of reducing thermal budget of fabrication processes by drastically reducing the processing time. Here, a comparative study on RTP and conventional processing has revealed the advantage of rapid processing as a result of the distinct features based on the non-equilibrium conditions created in RTP. Thus, by constructing the laboratory scale RTP system, many more distinct features produced by this much shorter processing times, rapid heating and cooling technique can be explored and investigated without huge investments in the commercial RTP system.

ACKNOWLEDGEMENT

The authors wish to express their gratitude to Universiti Sains Malaysia (USM Internal Research Grant) and Universiti Teknologi PETRONAS for the financial support.

REFERENCES


Norani M. Mohamed graduated from the University of Essex with an Honours BSc degree in Physics in 1983. She then continued her MSc in Lasers & Their Application in 1984 at the same university. Later in 1992, she completed her PhD in Physics, specifically in the area of Ultrathin Langmuir-Blodgett Films.

She began her career as a lecturer at the School of Physics, USM in 1984, teaching courses such as Modern Physics and Lasers. In 1986, she moved to the School of Materials & Mineral Resources Engineering at the new engineering branch campus of USM in Ipoh. Here, she taught courses such as engineering materials, semiconductor physics, semiconductor technology, semiconductor & opto-electronic devices. During her tenure, she was appointed the Deputy Dean for the distance learning program, and then as the Program Chairman for Postgraduate Studies and finally as the Program Chairman of Advanced Materials. She joined Universiti Teknologi PETRONAS (UTP) in May 2001 and is currently the associate professor at the Electrical & Electronic Engineering program. Her research interests include thin film technology and semiconductor processing (both hardware and software). She is now actively involved in developing nanotechnology research at UTP.
COMBINED LASER DOPPLER ANEMOMETER AND PHASE DOPPLER ANEMOMETER SYSTEM FOR THERMOFLUIDS RESEARCH AT UNIVERSITI TEKNOLOGI PETRONAS

Shaharin Anwar Sulaiman and Mohd Arief Mohd Nor
Department of Mechanical Engineering, Universiti Teknologi PETRONAS,
Bandar Seri Iskandar, 31750 Tronoh, Perak Darul Ridzuan, Malaysia.

ABSTRACT

The thermofluids group laboratory of Universiti Teknologi PETRONAS (UTP) owns and operates a few high-end equipment in support of research and educational activities. The latest addition to the laboratory facility is the combined three-dimensional Laser Doppler Anemometer (LDA) and Phase Doppler Anemometer (PDA) systems. The PDA system is capable of measuring diameter and concentration of spray droplets, while the LDA systems can measure droplet velocity for both temporal and spatial averages. The acquired system, which is supplied by Dantec Dynamics, is a non-intrusive measurement method with the ability to measure spray droplet velocities in three components. Thus, the system is the first of its kind used in Malaysia. With this high-end and state-of-the-art facility, UTP is ready to contribute towards technology development in various thermofluids research in Malaysia, namely, in internal combustion, fluid dynamics, spray painting and chemical processes. This paper outlines the current research activities involving the use of 3-D LDA-PDA system, its functions, testing capabilities, and general characteristics, as well as an overview of the system.

Keywords: sprays, particle sizing, velocimetry, LDA, PDA

INTRODUCTION

The thermofluids research programs at UTP involves several areas of research where the studies of fluid and spray flow behavior are complicated, thus, this requires special measurement equipment. The research areas include the Internal Combustion Testing, Sprays Studies and Wind Tunnel Testing. In these research areas, the measurement of fluid flow velocity is crucial and in some areas there is a need to study the spray droplet size and concentration. Therefore, it has been identified that a 3-D Combined Phase Doppler Anemometer (PDA) and Laser Doppler Anemometer (LDA) System is one of important equipment for the research in thermofluids at UTP. The LDA system is a laser-based equipment capable of measuring fluid velocity as well as the velocity of a flowing droplet or particle. The PDA system, which uses almost the same principles of operation as the LDA system, measures the droplet or particle size and concentration. The combination of these systems is referred to as the LDA-PDA system, which is able to measure velocity or droplet size, or both at the same time.

In an internal combustion system, droplet size and flow characteristics of the injected fuel can be varied through the design of the injector nozzle for better efficiency and reduced exhaust emission. In the past, the spray investigations were generally made using a rapid cinematography technique [1]. However, the use
of the LDA-PDA system enables quantification of the droplet properties to be more accurate and achieved in a very quick time. With three-dimensional LDA capabilities, the measurement could be carried out for all the three velocity components, thus enabling the detail study of turbulence in a combustion chamber. The PDA part of the system is very useful for the study of fuel evaporation behavior, as it could measure particle size, volume concentration and number concentration. The rate of fuel evaporation is crucial as it determines the rate of fuel burning. Large droplets, for instance, is more difficult to burn and could also produce unburned hydrocarbon. Hence the LDA-PDA system capabilities could be extended to study the rate of atomization when using an injection system.

In wind tunnel testing, before the emergence of laser-based equipment like the LDA system, velocity measurements in wind tunnels were carried out using the Pitot-static tube or hot-wire anemometer. Nevertheless, there are many disadvantages in using these types of measuring system since these equipment are of intrusive type, which means their sensors have to be placed in the flow field. The result of placing the sensors in the flow field is the disturbance to the flow, which will alter the flow properties. In addition, these devices require penetrations to be made through the walls of the wind tunnel test section. The number of penetration holes for this purpose is limited in order to assure that the test section of the wind tunnel is always airtight. As a result, the number of point measurements that can be made using these devices is limited. The Pitot-static tube is inferior as it can only measure the total velocity, instead of components of velocity. Another disadvantage of the Pitot-static tube and hot-wire anemometer is that both of them are unable to detect reverse or backward flow [2], which is crucial in the study of flow behavior in wind tunnels. As for the hot-wire anemometer, the thin wire at its sensor is very delicate and it can break after a period of operation time in the wind tunnel, although it is capable of measuring up to three components of velocity. These weaknesses can be overcome by using the LDA-PDA system, which is a non-intrusive type measuring device, where no sensor or instrument penetration is required in the flow field, except for laser beams. Therefore, measurements can be made almost anywhere in the test section of the wind tunnel. However, only the LDA part of the system is normally required because wind tunnel testing is usually meant for the study of confined-flow behavior or for aerodynamic testing. Similarly, measurements can also be made for water tunnel testing.

Since commissioned at UTP in October 2002 the LDA-PDA system, which was supplied by Dantec Dynamics, has been operational to serve various research needs in the thermofluids area. This paper provides an overview of the LDA-PDA system including its testing capabilities and general characteristics.

PRINCIPLE OF OPERATION

Measurements using LDA-PDA system require the intersection of two collimated laser beams, which produces a fringe pattern or also known as the measuring volume, as shown in Figure 1. The measuring volume is actually an interference pattern consisting of light and dark fringes. Measurement occurs when a spherical droplet or particle passes through the fringe pattern. For LDA measurement of velocity, when a particle traverses the fringes, it is alternately illuminated by high and low light intensities. As a result, the scattered laser light
The frequency is shifted, with respect to the incident beam. The particle velocity, $U$ is proportional to the frequency shift, $f_D$:

$$U = f_D \cdot \Delta f$$

(1)

for which the fringe spacing, $\Delta f$ is,

$$\Delta f = \frac{\lambda}{2 \sin \theta}$$

(2)

where $\lambda$ is the wavelength of the incident light beam, and $\theta$ is the half angle of the intersecting laser beams.

The basic configuration of the beams for the LDA-PDA measurements is illustrated in Figure 2. To produce the laser beam, a laser source is required. The LDA-PDA system at UTP uses a 5-watt Argon-ion laser. The transmitting optics, which comprises of lenses and aligning mechanism, prepares the laser by splitting the source beam into two identical beams. Through the transmitting probe, the two beams are crossed and focused to produce the measurement volume earlier shown in Figure 1. The scattered light, which is frequency-shifted, is collected by the receiver probe and sent to the photodetector, which is a transducer that converts the receiving light power into a current pulse signal [3]. The signal processor converts the signal into an output voltage that is proportional to the particle velocity. For three velocity component measurements, three measuring volumes must be prepared therefore the number of transmitter and receiver detector must also be tripled.

For PDA measurement, the operation is almost similar to the one for LDA measurement. However in PDA the phase shift between the transmitting and receiving signals is used to measure the particle or droplet diameter, since they are linearly related when the receiver probe is positioned such that one light scattering mode dominates. Figure 3 shows the useful relationship between the droplet diameter and signal phase-shift, which enables the measurement of droplet diameter.

![Figure 2: Basic configuration of LDA-PDA system](image)

![Figure 3: Phase difference relation with droplet size [3]](image)
Because of the similarity in operation, both LDA and PDA measurements can be combined and performed simultaneously, thus allowing useful study of diameter-velocity relation in various research. The LDA-PDA system installed in UTP is an integrated type for simultaneous measurements of diameter and velocities. In Figure 4, which shows the system owned by UTP, only three probes can be seen. The first probe comprises of two transmitters, which are built-in together for the light beams that measure the first and second velocity component. The second probe produces another measuring volume for the measurement of the third velocity component. The third probe is the receiving probe, which has all the receiving optics and photodetectors built-in together for velocities and size measurement. These signals are then sent to processor for conversion into understandable information that can be monitored in the computer software, which is supplied together with the systems. The software called BSA Flow is used to display results and to configure hardware settings for measurement control that suits the user's requirement. The post-processing results include histograms, time-series plots, size-velocity correlation, etc. For particle size measurement, the presentation can be made using user defined size classes, for example, Sauter-Mean-Diameter (SMD).

A traversing system made of aluminum frames, which is also installed together with the LDA-PDA system, provides a mechanism for the mapping of properties of a given spray or particle flow, namely particle concentration or mass flux. With the availability of the traversing system, the transmitting and receiving probes can be mounted on the same frame to allow them to be shifted together. This means that the fringe pattern or measuring volume can be displaced anywhere in the x, y and z directions, thus allowing measurements to be made anywhere in a given space volume. The displacement increment can be as low as 6.25 micron. The operation of the traversing unit may be controlled automatically or manually from the computer, thus making the measurement job very smooth and reliable.

**SYSTEM CAPABILITIES AND ADVANTAGES**

Measurements using LDA-PDA system is a statistical measurement control technique. It has been agreed that single or double measurement is no longer conclusive for measurement of particle diameter [4] as well as its velocity. Therefore statistical techniques can be used to evaluate precision and accuracy, which keeps the data measurement under statistical control. In this sense, large amounts of droplet population is
collected at each measurement point in a short amount of time. The LDA-PDA system is also an online measurement that allows a user to immediately monitor and evaluate the measurement data, thus minimizing the experiment time. The system is able to measure particle diameter of between 0.5 micron to several millimeters, and handle velocity measurement at a rate of up to 1440 meters per second. In measuring velocity, the LDA-PDA system is also capable of detecting reversing flow, which is one of the outstanding features of the system. Another important advantage of the LDA-PDA system is the very high spatial and temporal resolution it offers, which makes an experiment more reliable and flexible. The high accuracy of the LDA-PDA system depends on a few basic parameters determined by the optical configuration and the principle of signal processing. The important parameters include the particle transmit time, number of optical interference fringes within the measuring volume and the processor bandwidth [5]. With good alignment, the accuracy of the LDA system can be very high with the tolerance of as low as one percent, while for the PDA the tolerance can reach around three percent [6].

Among the important applications of the LDA-PDA system for UTP thermofluids research are in the study of internal combustion (IC) engine and in wind tunnel testing. These are particularly due to the non-intrusive characteristic of the LDA-PDA measurements, which means no device or sensors are required to be in the flow region. The use of LDA measurement in internal combustion studies has probably started as early as in 1979 [7]; and probably in 1988 [8] for LDA-PDA. Previously velocity measurements were carried out using hot-wire anemometer, for instance in the work by Horvatin and Hussmann [9], where a few disadvantages were observed. In internal combustion chambers, LDA-PDA measurements have been made possible with the use of single cylinder optical access engine, as done in many previous and current works [10, 11, 12]. The engine is integrated with transparent sections made of quartz that allows penetration of laser beam, thus enabling the LDA and PDA measurements of the fuel spray. The 3-D LDA and PDA system at UTP can be connected with an engine system using an encoder to synchronize the measurement with the crank angle of the engine piston. Therefore the data acquisition can be set within a required portion of the engine cycle. With this feature the result can be presented in a more meaningful manner, for example by having velocity or droplet size versus crank-angle distribution profile.

In wind tunnel testing only the LDA part of the system is required because normally the subject of study is only air, or water in the case of water tunnel. However, because a spherical particle or droplet must cross the fringe pattern or the measuring volume, artificial seeding is introduced in the flow to enable fluid velocity measurement. The seeding particle velocity usually can represent the fluid velocity. Usually non-toxic smoke is used in wind tunnel testing, however the choice of suitable seeding particle depends specifically on the type of application [13]. Table 1 shows the list of some seeding particles and their

<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>Material</th>
<th>Mean Diameter, (µm)</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSP</td>
<td>Polyamide Particles</td>
<td>Polyamide 12</td>
<td>5, 20, 50</td>
<td>Water flow</td>
</tr>
<tr>
<td>HGS</td>
<td>Hollow Glass Spheres</td>
<td>Borosilicate glass</td>
<td>10</td>
<td>Liquid flow</td>
</tr>
<tr>
<td>S-HGS</td>
<td>Silver Coated HGS</td>
<td>Borosilicate glass</td>
<td>10</td>
<td>Liquid flow, with increased reflectivity</td>
</tr>
<tr>
<td>FPP</td>
<td>Fluorescent Polymer</td>
<td>Melamine resin based</td>
<td>10, 30, 75</td>
<td>Applications with high background light level</td>
</tr>
</tbody>
</table>

Table 1: Seeding particles used in LDA-PDA applications [13]
applications. LDA system has been used extensively for wind tunnel testing although hot-wire anemometer and Pitot-static tube are still in use in some relatively simpler measurements. Some of the examples of research that use LDA for wind tunnel testing can be found in the references [14, 15]. Among the distinguished capabilities that LDA could perform are three dimensional boundary layer, separation and wakes measurements. If only velocity is to be measured, the PDA receiver probe can be deactivated so that the backscatter mode may be used for better data acquisition rate and simplicity.

The use of the acquired LDA-PDA system is not limited only to Automotive IC engines and Wind Tunnel Testing. There are various other applications where this measurement system could contribute to research works, among others include spray forming, spray painting, agriculture sprays, gas turbine fuel injection and pharmaceutical sprays, where in each of these areas there are always opportunity for improvement in terms of efficiency and cost through the optimization of sprays.

**CURRENT RESEARCH ACTIVITIES**

An experiment was conducted using water sprays produced using an air gun at UTP laboratory to demonstrate the application of LDA-PDA system. The purpose of this experiment was to experiment the measurement capability of the LDA-PDA system while studying the spray and flow behavior by using an air gun. At the same time, this experiment also serves as a learning platform for all new users at UTP in understanding the basic functions and problems in the operation of the equipment, before venturing into more complicated studies. The experiment setup is shown in Figure 5. Water sprays were produced consistently using the air gun, which was connected to a 2-hp air compressor. Water was fed into the spray discharge nozzle, while air pressure was regulated at a constant pressure of 0.4 bar gauge. Two pairs of laser beams were transmitted from the transmitting probe while a receiver probe is installed at an angle of 30° from the main axis. This configuration was set for two velocity-components together with droplet diameter measurements.

30 sets of measurements at 2 mm increments were taken along the horizontal axis located at 100 mm below the nozzle outlet on the middle plane of the spray cone. This was done by shifting the measurement volume using the traversing unit control after each measurement. The measurements at each location were taken for 10 seconds or 5000 data counts, whichever came first. A sample data set for

![Figure 5: Experimental Setup](image-url)

- Water Source
- Air-gun
- LDA-PDA Transmitting Probe
- Receiver Probe
- Ar-ion laser
- Fiber Manipulator
- Regulator
- Air Compressor
- Signal Processor
- Size & Velocity Output
one location indicating the frequencies for the droplet size measurements is shown in Figure 6. The average values were also calculated for all the 30 locations. From these average data, the velocity profiles are plotted as shown in Figure 7. The experimental data presented in this paper was selected to demonstrate the applicability of the diagnostic techniques for the LDA-PDA system to study spray characteristics.

Further research activities using the experimental set-up are progressing. This includes, among others, the study of turbulence and fuel droplet behavior in internal combustion engine.

**CONCLUSION**

The UTP’s combined 3-dimensional Laser Doppler Anemometer (LDA) and Phase Doppler Anemometer (PDA) system is the first of its kind in Malaysia. The LDA-PDA system has the capability to measure fluid or spray flow properties. The LDA part can measure three velocity components of moving fluid, while the PDA is used to measure the size and concentration of flowing droplet or particle. The combination of LDA and PDA provides a very useful measurement tool for flow cases that are complicated to quantify, like in the combustion chamber of an automobile engine, which is the main purpose of its existence in UTP. The diagnostic techniques of the LDA-PDA system described here can be used to study combustion chamber geometry, flows at inlets and spray interactions to allow combustion systems to be selected and optimized. In the research of direct injection combustion, the LDA-PDA system has become the essential tool to obtain high quality data of the injector characteristics with different parameters of pressure, temperature and timing. In addition, the system has a wide range of application in other researches, which include wind tunnel testing, spray forming of metals, and fundamental spray studies. Besides high temporal and spatial resolution capability, measurements using the LDA-PDA system give high accuracy. With this advanced technology measurement facility, UTP will contribute towards technology development in thermofluids research in Malaysia.
ACKNOWLEDGEMENT

The authors wish to thank to Mohd Sani Selamat, Bahtiar Affendi Ishak and Bent Mortensen for their supports in the experiment works.

REFERENCES


Shaharin Anwar Sulaiman graduated with a BS in Mechanical Engineering from Iowa State University, USA in 1993. He earned his MSc in Thermal Power and Fluids Engineering from the University of Manchester Institute of Science and Technology (UMIST), UK in 2000. He worked as a Mechanical & Electrical (M&E) Project Engineer in YTL Construction for five years until 1999. He is also a certified Professional Engineer and a Corporate member of the Institution of Engineers Malaysia (IEM). Currently, he is pursuing his PhD studies at Leeds University, UK.

Mohd Arief Mohd Nor holds an MSc in Automotive System Engineering from Loughborough University, UK and graduated from Sheffield Hallam University, UK with BS in Mechanical Engineering. He started his career as a mechanical engineer in Perusahaan Otomobil Kedua Sdn Bhd (Perodua). His current position is a lecturer in the Mechanical Engineering Programme at Universiti Teknologi PETRONAS.
ON PERFORMANCE OF HYBRID ELEMENT-BASED FEM APPROACH FOR CAPACITANCE EXTRACTION IN ELECTRONIC PACKAGING

Robert Paragasam¹, K.N. Seetharamu², G.A. Quadir, Varun Jeoti and P.C. Sharma³

¹Advanced Engineering Design(M) Sdn Bhd, Suite G09, MSC Central Incubator, 63000 Cyber Jaya, Malaysia.
²Universiti Sains Malaysia, Engineering Campus, 14300Nibong Tebal, Seberang Perai Selatan, Penang, Malaysia.
³Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak Darul Ridzuan, Malaysia.

ABSTRACT

The investigations on computational efficiency of a hybrid approach for computing capacitance in wire interconnects in a packaging environment is proposed. The hybrid approach is found to be computationally more efficient than methods reported earlier. The results obtained by employing the proposed method are found to be in good agreement with the earlier results reported.

Keywords: Finite Element Method (FEM), electronic packaging, capacitance extraction

INTRODUCTION

It is critical to be able to predict the sources of pulse distortion, understand the nature and magnitude of cross talk, and control these effects through analytical and computer modeling techniques in the design of an electronic packaging [1]-[3]. One of the major elements to be modeled and computed in a packaging environment is the capacitance between conductors, and between conductors and ground. The modeling of interconnects in a typical package requires solution of Laplace's equation for fields near and far from the interconnects. Finite Element Method (FEM) is based on the solution of Laplace's equation throughout the region using a number of finite elements typically arranged as a mesh, to calculate the electrical field everywhere [1]-[2]. However, due to matrices of high order, the method requires large computational time and memory.

The concept of the infinite element [4] can be used to account for the unbounded computational domain that is consistent with the standard finite elements. Accordingly, standard finite elements are used to model the near field, while the infinite elements are used to model the far field in unbounded domain. An improved infinite elements element [5], to model the surrounding far field unbounded domain, has also been proposed in the literature. This method uses standard polynomial mapping functions to define the coordinate mapping through the computation of Jacobian matrix. For FEM formulation using logarithmic element [6], the logarithmic elements are used to model and simulate the transverse dimensions. The basic idea of the logarithmic element is to define a modified triangular finite element such the modified local stiffness matrix that is equal to the stiffness of the mesh. In the hybrid approach, the concept of logarithmic element and infinite element is combined together to obtain a new approach [6]. This paper presents results that the recently proposed hybrid approach [7] is computationally more efficient than the approaches reported earlier.
OTHER RESEARCH AREAS

SIMULATION RESULTS

A single stripline (Figure 1), with same parameters as in [8], is analyzed. The solver based on hybrid approach [7] yields the capacitance value of 4.2191 pF/m which is the value as obtained in [8]. In this particular case, only the linear triangular element subroutine is used so as to verify the functionality of the solver algorithm.

A single cylindrical conductor of Figure 2, as in [6], with radius $r = 0.5$ mm, in free space with height $h = 28.22$ mm above ground plane is also analyzed. The results obtained using linear triangular elements, the logarithmic and triangular elements, and infinite logarithmic and triangular elements subroutines—the hybrid approach are compared (Table 1) with the analytical value [9] of $(11.7707 \text{ pF/m})$ capacitance. The table illustrates that the hybrid approach requires smaller domain size, and therefore smaller elements and computational time as compared to the other two approaches. Also, the error in the computed value of the capacitance is less as compared to the value of the same obtained using the other two approaches.

CONCLUSION

The hybrid approach is computationally more efficient as compared to the approaches proposed earlier. The result obtained by using the solver based on hybrid approach is closer to the analytical value than those obtained by employing the other two approaches. The results for other circuit configurations are not included for want of space but would be presented at the conference.

ACKNOWLEDGEMENT

The encouragement and support from Universiti Teknologi PETRONAS, Universiti Sains Malaysia, and Advanced Engineering Design (M) Sdn. Bhd., Cyber Jaya, Malaysia is thankfully acknowledged.

![Figure 1: A single stripline (all dimensions in mm)](image1)

![Figure 2: Cylindrical conductor above](image2)

Table 1: Performance comparison among various element combinations

<table>
<thead>
<tr>
<th>Element Type</th>
<th>Linear Triangular</th>
<th>Logarithmic &amp; Triangular</th>
<th>Infinite, Logarithmic &amp; Triangular (Hybrid approach)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runs</td>
<td>8</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Domain Size (mm)</td>
<td>300</td>
<td>300</td>
<td>150</td>
</tr>
<tr>
<td>Elements Required</td>
<td>4640</td>
<td>2944</td>
<td>2100</td>
</tr>
<tr>
<td>Comp. Time (mins)</td>
<td>150</td>
<td>46.6</td>
<td>35.28</td>
</tr>
<tr>
<td>Error (%) with respect to the analytical value</td>
<td>2.46</td>
<td>2.74</td>
<td>1.98</td>
</tr>
</tbody>
</table>
REFERENCES


Robert Paragasam received the MSc and BEng degrees from Universiti Sains Malaysia in Mechanical Engineering. Currently, he is the Business Manager in Advance Engineering Designs, a cutting edge PCB design house located in Cyberjaya Malaysia. Mr. Paragasam has several years’ academic and industrial research experience in electronic packaging and Signal Integrity issues in boards and devices. His current interest includes high-speed board designs and related fabrication technologies.

K.N. Seetharamu graduated from Mysore University in Mechanical Engineering in 1960. He obtained his Masters Degree in Power Engineering in 1962 from the Indian Institute of Science, Bangalore, India. He obtained his doctoral degree in 1973 in the field of heat transfer from the Indian Institute of Technology, Madras, India. He joined the Indian Institute of Technology, Madras in 1968 as a lecturer and rose to the level of Professor in the year 1980. After taking voluntary retirement from IIT Madras in September 1998, he joined Universiti Sains Malaysia on invitation. He has more than 40 years of professional experience. He has published a book on “FEM Application Project in IIT,” published by John Wiley in 1996 along with the co-authors from UK. Prof. Seetharamu research interest includes heat transfer, fluid flow, stress analysis, energy systems, electronic packaging, and FEM applications to engineering problems.

G. A. Quadir graduated from Bhagalpur University, India, in Mechanical Engineering in 1966. He completed his Masters degree in Mechanical Engineering (Heat Power) from A.M.U., Aligarh, India. He obtained his PhD degree from I.I.Sc., Bangalore, India in the year 1979 in the field of turbo-machinery under the Quality Improvement Programme of the Government of India. Dr. Quadir has altogether 35 years of teaching and research experience at various universities in India, Algeria, Libya and Malaysia. Currently, he is working as an Associate Professor in the School of Mechanical Engineering, Universiti Sains Malaysia.

Varun Jeoti received his PhD degree from the Indian Institute of Technology, Delhi, India, in 1992. He worked on several sponsored R&D projects at IIT Delhi and IIT Madras during 1980 to 1989 developing Surface Acoustic Wave Pulse Compression filters, underwater optical receivers etc. He was a Visiting Faculty in the Electronics Department in Madras Institute of Technology for about 1 year during 1989 to 1990 and joined Delhi Institute of Technology for the next 5 years till 1995. He moved to the school of Electrical & Electronic Engineering of Universiti Sains Malaysia in 1995 and joined the Electrical & Electronic Engineering Programme of Universiti Teknologi PETRONAS in 2001. He was also briefly associated with Anna University – K.B. Chandrasekhar Center in 2001. His research interests are in Electronic Packaging, Wireless LAN and MAN technologies, ADSL/VDSL technology and related signal processing.

P. C. Sharma obtained his BE and ME degrees from University of Indore, India, in 1969 and 1972 respectively. He completed his PhD from Indian Institute of Technology, Kanpur, India in 1982. In 1972, he joined the Department of Electrical Engineering, SGS Institute of Technology and Science, Indore, India. In 1973, he became a lecture in this institute and rose to a level of professor in 1986. He was the Head of the Department of Electronics and Telecommunication Engineering from 1991-1996. In 1996, he became the Director of the same institute, which he served until the end of 1999. He was with Multimedia University Malaysia during 2000-2001. Presently, Prof. Sharma is with Electrical and Electronic Engineering Programme, Universiti Teknologi PETRONAS.
DEVELOPMENT OF A SMALL-SCALE SOLAR POND TECHNOLOGY TESTBED FOR EDUCATION PURPOSES

Rahmat I. Shazi, M. Farizal M. Nor Azli and Fakhruldin M. Hashim
Mechanical Engineering Programme, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750, Tronoh, Perak Darul Ridzuan, Malaysia.

ABSTRACT

One major limitation of current solar thermal systems is that they are totally dependent on insulated tanks to store the captured radiation. At night, they are usually ineffective due to heat loss from the storage system. Solar ponds show great promise in circumventing this weakness as it has the capability of storing and making available the energy 24 hours a day. The one currently in operation at Universiti Teknologi PETRONAS (UTP) is of the non-convecting type. It uses concentrated brine in the depths of the pond to capture solar rays. In this manner, thermal energy is contained in the pond, which can serve as the heat source for any appropriate power cycle or used for domestic or industrial heating purposes. To make the technology feasible for education purposes it is imperative that its cost is lowered. To this end, we made use of a commercial bathtub to simulate the body of water. This approach also greatly simplifies fabrication and maintenance. With this rudimentary setup, the highest temperature reached so far is 54 °C, achieved in a water depth of only 0.28 m. The next step is to increase the water depth, search for the most cost-effective side insulation and continue research into the appropriate energy extraction system to match the output and size of the solar pond. The main intent of this project is to educate students on this concept and develop it into an effective technology demonstrator. Awareness of the technology will be a step towards developing the human resources in renewable energy.

Keywords: non-convecting solar pond, low cost, solar energy, awareness education

INTRODUCTION

There is great potential for the development and utilization of solar energy in Malaysia due to its proximity to the Equator. The disperse nature of this technology allows it to be used in many remote areas, allowing rural folks to enjoy some level of modernization in the bid to improve the quality of life. Unfortunately, current ‘traditional’ solar energy gathering systems such as photovoltaic (PV) cells are still deemed too expensive for widespread use. Solar water heaters are also costly and cannot offer a comparable performance to electric ones.

A potentially cheaper and more effective solar energy solution especially in rural areas is the use of solar ponds. As the name suggests, solar ponds capture sunlight via a body of water. However, various methods can be used to allow the body of water to store this energy, in the form of heat round the clock. This factor makes it an attractive form of energy supply for out-of-town and processes that will benefit from a cheap form of energy, such as industrial heat applications.

This paper was presented at the International Symposium on Renewable Energy: Environment Protection and Energy Solution for Sustainable Development, Kuala Lumpur, 14-17 September 2003.
**FUNDAMENTALS OF SOLAR PONDS**

A solar pond is a body of water used to capture and store the sun's energy in the form of heat. This concept in itself lends to the ease with which solar ponds can be created. Currently, there are two types generally used worldwide. The convecting solar pond consists of merely water in a containment area with some basic measure to reduce convective heat losses, such as a covering. The non-convecting version uses a medium such as salt or a membrane to achieve heat loss reduction. The solar pond at UTP uses brine to set up a salinity gradient required to prevent the occurrence of convection currents in the water. This helps in improving the solar-gathering performance of the pond. With the proper insulation, the trapped heat will be available 24 hours a day.

The salt gradient solar pond has three operational layers of water that determines its behaviour [1] as shown on Figure 1. These are the Upper Convective Zone (UCZ), the Non-Convective Zone (NCZ) and the Lower Convective Zone (LCZ). The LCZ is made up of concentrated brine, a supersaturated solution of salt that absorbs the incident solar heat rays and stores the energy in the form of heat. Generally the LCZ will reach temperatures in the range of 45°C to 90°C Celsius in operational solar ponds, as found in El Paso in Texas [2] and the Bhuj solar pond in India [3]. Concentrated salt solution is denser than water, counter-acting the tendency of the hot solution to rise to the surface. The UCZ is a layer of fresh water that allows sunlight penetration into the lower zones. The NCZ is the piecemeal in this concept. This layer has a varying salt concentration, changing from salty to fresh as the depth decreases. This layer acts as a barrier to any convective currents trying to reach the upper surface of the pond, reducing the heat transfer rate.

Figure 2 shows the basic parametric behaviour in non-convecting solar ponds. Sukhatme [1] showed that if $T_1$ and $\rho_1$ are the temperature and density of the UCZ respectively and $T_2$ and $\rho_2$ are the temperature and density in the LCZ, then no effective convection will occur if the slope of the curve AB is positive. Based on the work by Green [5], the concentration of salt required for the solar pond to experience no convection is given by the equation

$$\frac{dC}{dx} > \frac{1}{T(V + D)} \left\{ \frac{d\rho}{dT} \frac{dT}{dx} \right\}$$

which in turn is derived from the concept that the lower layers must remain denser than the upper ones.

Surprisingly, there is very limited data published with respect to the dependence of the temperature on the incident sunlight intensity. Future work at UTP will attempt to establish a correlation.

**EXPERIMENTAL WORK**

In order to establish the operational behaviour of the solar pond, it was decided to start by creating a small-scale solar pond in UTP [6]. A commercially available bathtub of standard size is used to simulate the solar pond as opposed to digging a dedicated pond in the drive to keep the system cheap. This was felt to be the
best approach to a research area not really well understood in Malaysia. The problems associated with possible leakage of brine are reduced as well as the overall initial start-up cost. No side insulation was introduced at this point. Data will imply that the sidewall heat losses are very significant. Figure 3 shows the basic set-up.

The main experiment was initiated on the 1st of March 2003. A total of 16kg of salt was used in the solar pond that contained approximately 230 litres of water to a depth of about 0.28m. The resulting brine has a concentration of around 350 ppt at the bottom of the bathtub, obtained using a salinity probe. The temperature is obtained using a simple mercury-in-bulb thermometer instead of thermostats and data loggers to ensure repeatability at schools.

![Figure 3: Picture of the standard sized bathtub converted into a small-scale solar pond. Perspex sheet lifted off for clear view.](image)

**RESULTS AND DISCUSSION**

The work done showed that at the specified depth and concentration, it took about 10 days before the temperature in the LCZ reached a consistent temporal value. After that length of exposure to typical Malaysian sunlight, where the sunlight intensity has an average of 650 W/m² [7], the LCZ temperature almost always remain above 40 °C at around 1 p.m. The highest temperature ever achieved is 54 °C on 18th of March 2003 at 3 p.m, 18° greater than ambient. More importantly, the LCZ temperature is always at least 6 °C higher than the ambient temperature, least at around 7 a.m. This performance persisted for about one month. The latter is the only suggestion that the solar pond is storing energy throughout the night.

A typical temperature profile of the LCZ with respect to time is shown in Figure 4. Clearly the temperature profile shows that it is roughly proportional to the incident radiation that is expected to peak in the afternoon and drops significantly over time. This indicates that a lot of the captured energy is lost through the sidewalls and through the ground that is in contact with the bathtub. Figure 5 shows the temperature profile with respect to depth of the particular days at 3 p.m. This gives a better indication of the salinity-gradient in action, showing peak temperatures in the depth of the bathtub and temperatures levelling off near the surface.

The performance of the solar pond degraded after this time. The temperature gradient is no longer as pronounced, with the highest temperatures achieved only around 45 °C. Salinity measurements over this period as shown in Figure 6 confirmed that salt diffusion is taking place, reducing the concentration of brine in the LCZ. Although the changes are subtle, it is enough to affect the performance of the solar pond. This corresponds well with large-scale operational solar ponds that need to reclaim salt from the top UCZ layer from time to time.

![Figure 4: Plot of LCZ temperature vs. time for three selected days](image)
CONCLUSIONS

The work carried out shows this approach to solar pond technology to be a promising one for the dissemination of awareness of future engineers. However, the drop in temperature as the day progresses indicates that the solar pond is not storing energy effectively. Future work involves insulating the sides of the bathtub as well as preventing heat from going into the ground. Not only is it simple enough to carry out in secondary schools, its overall cost is low due to the use of easily obtainable equipment. Current work shows that the depth is inadequate to prevent the salinity gradient from losing its effectiveness over a long period of time. However, it is long enough for sufficient data to be collected, illustrating the concept. With modifications it will be able to further demonstrate possible applications of this technology. These include the extraction of heat via heat exchangers and supplying it for a reverse-Rankine power cycle or for preheating fluids for varying purposes such as drying or to drive an adsorption refrigeration cycle.

NOTATIONS

\[ C \] – Concentration
\[ x \] – Distance from surface
\[ \nu \] – Kinematic viscosity
\[ a \] – Thermal diffusivity
\[ D \] – Diffusivity of salt in water
\[ \rho \] – Density

ACKNOWLEDGEMENTS

The authors would like to thank UTP for the assistance and support given for this work.

REFERENCES


Rahmat I. Shazi is a lecturer in the Mechanical Engineering Programme at Universiti Teknologi PETRONAS, Perak. He received his Masters in mechanical engineering from the University of Illinois at Urbana-Champaign in May of 2003. His current research interest includes computational fluid dynamics, autoignition and combustion, remotely operated vehicles, solar energy and natural gas. He is the current advisor to the university’s engineering exhibition, representative for solar energy work and is active in the arts, especially theatre.
Fakhruldin M. Hashim is an Associate Professor and the Head of Mechanical Engineering Programme at Universiti Teknologi PETRONAS. He obtained his PhD from University of Leeds, UK in 1993. His current research work encompasses CAD/CAM, product design development, manufacturing automation and bioengineering. He is involved in many professional activities including the Robotics Round-Table (RRT) Working Committee, the Malaysian Industry Development Agency (MIDA) Working Committee on Machinery and as Secretary to the Robotics and Automation Association of Malaysia (RAAM). He has also served as consultant to the National Science & Technology Defence Centre and the Malaysia Centre for Robotics and Industrial Automation (MCRIA). He has two IRPA projects related to DFMA and Robotics. He is also an assessor for the Industrial Grant Scheme (IGS) proposal.
**NOTES FOR CONTRIBUTORS**

**Instructions to Authors**

Authors of articles that fit the aims, scopes and policies of this journal are invited to submit soft and hard copies to the editor. Paper should be written in English. Authors are encouraged to obtain assistance in the writing and editing of their papers prior to submission. For papers presented or published elsewhere, also include the details of the conference or seminar.

Manuscript should be prepared in accordance with the following:

1. The text should be preceded by a short abstract of 50-100 words and four or so keywords.

2. The manuscript must be typed on one side of the paper, double-spaced throughout with wide margins not exceeding 3,500 words although exceptions will be made.

3. Figures and tables have to be labelled and should be included in the text. Authors are advised to refer to recent issues of the journals to obtain the format for references.

4. Footnotes should be kept to a minimum and be as brief as possible; they must be numbered consecutively.

5. Special care should be given to the preparation of the drawings for the figures and diagrams. Except for a reduction in size, they will appear in the final printing in exactly the same form as submitted by the author.

6. Reference should be indicated by the authors’ last names and year of publications.

-Chief Editor, PLATFORM
Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan
MALAYSIA
| Technology Cluster: OIL AND GAS |
|-----------------------------|-----------------|
| Technology Platform: Oilfield Gas Treatment and Utilization |
| Hydrogen Production by Catalytic Decomposition of Methane |
| Noor Asmawati Mohd Zabidi, Sharif Hussein Sharif Zain and Abdul Rahman Mohamed |
| 3 |

| Technology Cluster: TECHNOLOGICAL INNOVATION AND STRATEGIC PLANNING |
|-----------------------------|-----------------|
| Technology Platform: System Optimization |
| Overcoming the Shrink-And-Swell Effect in Water Level Control Strategy on Industrial Boiler Drum |
| Fawnzmi Azmadzai Hussin and Rees, N.W. |
| 10 |

| Technology Cluster: INTELLIGENT SYSTEMS |
|-----------------------------|-----------------|
| Technology Platform: Application of IT Systems |
| An Ethnicity Recognition System using Imaging Techniques |
| P.A. Venkatachalam, Ahmad Fadzil Mohd Hanie, Kavitha Shaga Devan and Siti Mushinani Abi Ghani |
| 16 |

| Technology Cluster: TRANSPORTATION |
|-----------------------------|-----------------|
| Technology Platform: Fuel Combustion |
| Combined Laser Doppler Anemometer and Phase Doppler Anemometer System for Thermofluids Research at Universiti Teknologi PETRONAS |
| Shaharin Anwar Sulaiman and Mohd Arief Mohd Nor |
| 43 |

| Technology Cluster: OTHER RESEARCH AREAS |
|-----------------------------|-----------------|
| Development of a Small Scale Solar Pond Technology Testbed for Education Purposes |
| Rahmat I. Shazi, M. Fatizal M. Nor Aziz and Fakhruldin M. Hashim |
| 51 |

| Technology Cluster: NANOTECHNOLOGY |
|-----------------------------|-----------------|
| Surface Analysis of Catalytically Grown Carbon Nanotubes (CNTs) |
| Norani Muti Mohamed, Tan Yee Chee, Saravanam Muniandy and Kadir Masrom |
| 56 |

| Technology Cluster: OTHER RESEARCH AREAS |
|-----------------------------|-----------------|
| Design and Development of the Laboratory Scale Rapid Thermal Processing (RTP) System |
| Norani Muti Mohamed, Khatijah Yaacob and Kamarulazizi Ibrahim |
| 60 |