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Dear Readers,

In this volume, there are six research work related in engineering presented. The first work proposes T-shape electrode design for an open type electro-wetting on dielectric materials. Then, impacts of window frames on building for energy consumption is analyzed, following by investigation in effects of low NaOH concentration on compressive strength and products of high calcium geopolymer and on-road visualizations for suspension tuning of a race car. Finally, engineering technology of the two-dimensional simulation of temperature in paddy bulk storage with closed-loop oscillating heat pipes and an analysis of student learning outcomes in power electrical engineering courses: a case study are presented.

I hope that this MIJET volume will bring you some useful information and initiative ideas for the further research work and development in the field of engineering, which would eventually drive and sustain human well-being.

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T-Shape Electrode Design for an Open Type Electro-Wetting on Dielectric

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Abstract. This work proposes the electro-wetting on dielectric (EWOD) design for manipulating the movement of 5 microliter DI water droplets on a T-shaped electrode layer. The fabrication methods for open-type EWOD are mentioned in detail. With the attached voltage and frequency control equipment, the created EWOD device could precisely manipulate the droplet movement on top of the device as expected.

Keywords: Open Type EWOD, Electrode, Manipulation of Droplet, Electro-Wetting on Dielectrics

1. Introduction

An open typed electro-wetting on dielectric (EWOD) device can manipulate and control the movement of droplets as small as micro to nano liters by utilizing the induce electrical force between two parallel electrodes to disturb the wet contact angle of droplets; thus causing the droplet to morph and move in Fig 1. An open type EWOD device is composed of substrate layer, positive and negative electrode layers, dielectric and hydrophobic layer as shown in Fig. 2.

Because of the structure is not complicate and the ability to manipulate tiny droplets, an open typed electro-wetting on dielectric technique is widely used in many applications especially in biochemical engineering (i.e. in Lab on a chip PCR [1], enzyme assays [2] and proteomics [3] in mechanical micro-actuation [4] and on-chip cooling for electronics circuit pad [5]. The common EWOD fabrication is composed of three processes: the fabrication of electrode layers by light photolithography and sputtering technique, fabrication of dielectric layer by spin coating, and fabrication of hydrophobic layer by spin coating. In this work, silver due to its high electrical conductivity and cheap prices was used to replace the precious materials [6] such as gold [7] and platinum [8] to create the electrode layer. The paralleled positive and negative electrodes in Fig. 1 are the crucial component used to create the induced electrical force. Parylene [9] and Polydimethylsiloxane [10] are two materials with high dielectric constant and are commonly used to create the dielectric layer. The hydrophobic characteristics of EWOD surface are normally created by spin-coating of Teflon-AF [11], which can improve the wet contact angle of the droplet to be greater than 110 degrees.

In this work, the suitable electrode design for manipulate the liquid droplet with the volumetric size of 5 microliter was designed to have T-shaped pattern in order to demonstrate the capability of EWOD devices to move the droplet in 90 degree turn condition. The fabrication of such device is mentioned in details.
2. EWOD Fabrication

An open-type electro-wetting on dielectric device is composed of three layers: first is the silver electrode layers deposited on top of a glass substrate. Second is the dielectric layer and finally is the hydro-phobic layer. The fabrication steps could be done as follows.

2.1 Fabrication of electrode layers

2.1.1 Design of electrode layout on top of light protecting mask for photolithography

In this step, the size of electrodes and gap between each electrode must be appropriately designed to match the droplet size. Of course, the tiny electrodes cannot handle large droplets, while the oversize electrodes cannot create the appropriate connection of electrical field between two adjacent electrodes. Therefore, the size of each electrode depends directly on the size of wetted area of liquid droplet with spherical shape as in Fig. 3. The relation between the wetted area (the cut-sphere area) and the electrode area is shown in Eq. (1).

\[ V_{\text{cut sphere}} = \left( \frac{\pi}{3} \right) h^2 (3r - h) \]  

Figure 2 also shows the geometrical relation of the droplet wetted on top of a flat surface as follows,

\[ h = \frac{L_1}{\sin \theta_A} - \frac{L_2 \cos \theta_A}{\sin \theta_A} \]  

and

\[ r = \frac{L_3}{\sin \theta_A} \]  

Therefore,

\[ h^2 (3r - h) = \left[ \frac{L_1^2}{\sin^2 \theta_A} \left( 1 - 2 \cos \theta_A + \cos^2 \theta_A \right) \right] \frac{L_2}{\sin \theta_A} (2 + \cos \theta_A) \]

which can rewrite as

\[ h^2 (3r - h) = \frac{L_1^3}{\sin^3 \theta_A} (1 - \cos \theta_A)^2 (2 + \cos \theta_A) \]  

Substituting Eq. (4) into (1) leads to

\[ L_1 = \sin \theta_A \sqrt{\frac{3V}{\pi (1 - \cos \theta_A)^2 (2 + \cos \theta_A)}} \]  

By using Eq. (5) to design the electrode size for handle 5 micro-liter droplets with wetted contact angle of 110 degree, we have the wetted area radius of 1.16 mm or the wetted area of 4.22 square-millimeters, while leads to the electrode size of 2.05 mm as demonstrated in Fig. 4.

The suitable gap size between two adjacent electrodes can be selected from the relation in Fig. 5 [12]. In this work, the ratio between gap size and electrode size is kept at 5% and applied voltage should be use between 120-500 V to avoid the dielectric breakdown.

![Fig. 3: the geometrical relation of wetted area for spherical shape droplets](image1)

![Fig. 4: the selected electrode size](image2)

![Fig. 5: the relation between wetted contact angles and required applied voltage at various ratios of gap and electrode sizes](image3)
From the geometrical relation as mentioned, the light protecting mask for photolithography was created as shown in Fig. 6, given that the gap size is 50 micron and the electrode size is 1 mm.

Fig. 6: the designed light protecting mask for photolithography

2.1.2 Creating the electrode layout

In this work, a glass slide was used as the perfect substrate. The light sensitive AZ film (liquid photoresist) with 10 micron in thickness was coated on the glass slide by spin-coating at 1,250 rpm for 30 seconds. After spin-coating to create the AZ film, the designed light protecting mask was attached to on top of the film. The UV light was then applied on the mask aligner machine for 3 seconds. Then the AZ solvent was applied; thus leaving the electrode layout on top of the glass slide as shown in Fig. 7.

Fig. 7: the electrode layout on top of glass slide

2.1.3 Creating electrodes by sputtering

To deposit silver on top of glass slide, chromium was selected as bonded material between silver of 99.995% pureness and glass surface. The silver media was coated with chromium before sputtering on glass slide in order to prevent the oxide layer between silver and chromium. The duration for sputtering was set at 30 min to create the silver electrode with the thickness of 3 microns. After completing the sputtering process, the un-desired deposited silver was cleaned by acetone in ultrasonic bath. The complete electrode layer is presented in Fig. 8.

Fig. 8: the created silver electrode

2.2 Fabrication of dielectric layer

Polydimethylsiloxane (PDM) prepared by mixing silicon elastomer base with silicon elastomer curing agent with the ratio 10:1 was spin-coated on the electrode layer at 4,000 rpm for 30 seconds by spinner. Then the coated glass slide was baked on heat plate at 95˚c for 60 min. The 5-7 µm polydimethylsiloxane layer was left to be dielectric layer.

2.3 Fabrication of hydrophobic layer

Teflon AF was spin-coated at 1,000 rpm for 30 second to create hydrophobic layer with the thickness of 100 nm. To stabilize the layer, the coated glass slide was baked on a heat plate at 95˚c for 60 min and. The Teflon coated surface could provide the large wetting contact angle of droplet, thus increasing the hydrophobic property of the surface and reducing the surface tension of the droplet. After completing the fabrication of hydrophobic layer, the created EWOD device is ready for manipulating droplet movement.

3. Component of EWOD Controlling Devices and Testing Conditions

EWOD controlling devices are composed of three important devices connecting in series as in Fig. 9. Those three devices are

1. Function/Arbitrary Waveform Generator
2. Power Amplifier
3. Switching Transformer

The EWOD device was tested at the supplied frequency of 400 Hz and at the voltage of 250 V. (The testing conditions comply with a relation between Viscosity of droplet and minimum applied voltage required to manipulated droplet [13] as show in fig.10.) A size of DI water droplet was 5 µL.

Fig. 9: diagram of EWOD controlling devices
Fig. 10: the minimum applied voltage required to disperse diluted viscous liquids [13]

4. Test Results

The created T-shape open type EWOD device with silver electrodes as shown in Fig. 11 was under experimental test. During the test, a DI water droplet was applied and moved along the T shape configuration of EWOD device.

Fig. 11: water droplet movement on top of created EWOD device

5. Conclusion

Figure 11 shows the effectiveness of EWOD device to move 5 microliter DI water droplets along the electrode shape. The device could successfully move the droplet to the left and right direction of the T-shaped junction.

6. Acknowledgement

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7. References


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Impacts of Window Frames on Building Energy Consumption

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Abstract. In general, only properties of pure glass are used for windows in building energy calculation. However, past researches showed that properties of window frames could alter overall window system properties by 20-30%. Therefore, this study was set up to investigate the significance of window frames on building energy consumption. First, comparisons of properties obtained from the Window 6.3 software of various combinations of window systems were carried out. Six-mm-thick clear glass was treated as the base case. The combinations of window systems were generated from 3 glass types (6-mm clear glass, 6-mm green glass, 6-mm low-E coating glass), 2 frame materials (aluminum, PVC), and 2 frame configurations (fixed frames, sliding frames). After that, each window system was applied to a sample office building to simulate building energy consumption using the EnergyPlus software. The sample building had 4 floors with a total area of 1,295.91 m² and a window-to-wall ratio (WWR) of 37%. The results showed that properties were most different between the base case and the case of low-E glass with PVC sliding frames. Overall heat transfer coefficient (U), solar heat gain coefficient (SHGC), and visible transmittance (Tvis) were found to be different by 58%, 37%, and 26%, respectively. On the contrary, energy consumption between these two cases differed by only 0.67%. It implies that even with as high as 58% deviation, properties of window systems with frames added have insignificant impacts on energy consumption of the building. In turn, building energy calculation may be done by using only properties of glass with no frames for windows as conventionally done without causing significant errors.

Keywords:
window system, window frame, thermal property, building energy consumption

1. Introduction

Globally, buildings account for around 40% of total energy use [1-4]. In Thailand, 46% of total electrical energy is consumed by the building sector [5]. Half of it is used in air conditioning systems [6]. Since 20-40% of heat gains into a building are from window systems, properties of window systems and window-to-wall ratio (WWR) become important factors that affect building energy consumption [7]. For WWR, buildings that have less WWR would consume less energy due to less heat gains through windows [4, 8]. It was found that appropriate WWR for buildings in Thailand is approximately 40% [9]. For buildings without external shading devices, WWR should be about 30% [10].

For properties of window systems, the most important three parameters are 1) overall heat transfer coefficient (U) which is related to conduction and convection of window systems, 2) solar heat gain coefficient (SHGC) which is related to solar radiation through window systems, and 3) visible transmittance (Tvis) which characterizes the ability to transmit visible light through window systems important for daylighting application of buildings [1]. Designing window systems to have small U and SHGC values to mitigate incoming heat gains to reduce energy use in air conditioning systems and maintain adequate Tvis value to exploit free daylight and save energy in electrical lighting systems is a crucial concern for building designers. Sekhar and Lim even mentioned that improving window and envelope systems might be the only remaining option for energy saving in buildings associated with building structure [7]. Therefore, having standards for window system properties and knowing impacts of such properties on building energy consumption are necessary.

There is a set of international standards regarding properties and performance of window systems which can be grouped into calculation approach and testing approach [11-26]. In Thailand, there are only standards for categories and dimensions of window systems [27-30] while standards for window system performance are still in progress.

Regarding impacts of window system properties on building energy consumption which is the main point of this article, it is normal to use properties of pure glass without frames for windows in building energy calculation for the sake of convenience. However, past researches showed that properties of frames could alter the overall properties of
window systems by 20-30% [1, 31]. Hence, it was of interest to investigate impacts of properties of window frames on building energy consumption. A sample office building was used as a case study.

2. Methodology

The sample office building had 4 floors with a total area of 1,295.91 m² and a WWR of 37%. It was assumed that the building was located in Nakhon Pathom province, Thailand. Brief details of the building are shown in Table 1.

This research was divided into 2 parts. The first part was the analysis of properties of 15 combinations of window systems. The combinations were generated from 3 glass types (6-mm clear glass, 6-mm green glass, 6-mm low-E coating glass), 2 frame materials (aluminum, PVC), and 2 frame configurations (fixed frames, sliding frames) as summarized in Table 2. Relevant properties of glasses and frames are presented in Table 3. Frame configurations are illustrated in Fig. 1. Main properties of window systems comprising U, SHGC, and Tvis of each case were evaluated by using Window 6.3 software [32].

In the second part of this research, each of the 15 combinations of window systems was applied to the sample building and annual electrical energy consumption by air conditioning systems, lighting systems, and building equipment was simulated by using the EnergyPlus software to see the impacts of different window systems on building energy consumption [7, 33, 34]. An uncertainty of ±5% was applied to the property values corresponding to the uncertainty that might occur when using a hot box set to test for the properties of window systems [11].

3. Results and Discussions

3.1 Analysis of Properties of Window Systems

Fig. 2 illustrates comparisons of properties among 3 glass types which were input as windows without frames into the building simulation model. The case of using 6-mm clear glass without frame was treated as the base case. It can be seen that the U value of the green glass is very close to that of the clear glass. On the other hand, SHGC is lower by 26% and Tvis is lower by 13%. This is because the green glass is also clear glass but its tint diminishes the amount of sunlight coming through it so SHGC and Tvis are reduced.
For the low-E glass, U and SHGC are lower by as high as 53% and 20%, respectively, compared with the base case which agrees well with the literature [33]. The value of Tvis is found to be only 3% lower. The reason that U is decreased relatively much is that the low-E glass is coated by metal substances to prevent heat transfer through the glass and reflect solar radiation. In turn, SHGC and Tvis are reduced but not at the same degree as in the case of the green glass since the low-E glass is clearer corresponding to the findings by Ihm et al. [35].

Fig. 2 shows comparisons of properties of window systems using fixed frames made of 2 materials with the base case to see the effects of the frame material. It can be seen that the clear glass with fixed aluminum frames causes reduction in U, SHGC, and Tvis by 1%, 12%, and 16%, respectively. The small reduction in U is due to the fact that U of aluminum is slightly lower than that of the glass so that the overall U value of the window system is a little lower. The reduction in SHGC and Tvis is because the frames decrease the area of solar transmittance through the windows.

For the case of using clear glass with fixed PVC frames, the values of U, SHGC, and Tvis are reduced by 15%, 18%, and 20%, respectively. The reduction in U is due to that U of PVC is lower than that of the glass thus the overall U value of the window system is lower. The reduction in SHGC and Tvis is because the frames decrease the area of the glass portion of the windows. However, SHGC and Tvis in this case are lower than the previous case, especially Tvis that should be equal due to the same frame configuration, because the PVC frames have a little larger area. PVC is categorized as plastic or polymer which has lower strength than aluminum which is metal so the PVC frames need some reinforcement to increase the strength causing a larger area that blocks solar transmittance more than the aluminum frames.

Fig. 3 shows comparisons of properties of window systems using fixed and sliding frames with the base case to see the impacts of the frame pattern. In the case of PVC fixed frames, U, SHGC, and Tvis are decreased by 15%, 18%, and 20%, respectively. In the case of PVC sliding frames, U, SHGC, and Tvis are decreased by 17%, 22%, and 24%, respectively. The sliding frames cause lower values of window system properties compared with the fixed frames because of a larger frame area.

### 3.2 Impacts of Window System Properties on Building Energy Consumption

Annual energy consumption of the sample building when each case of window system combinations was applied is shown in Fig. 5. It can be seen that the energy consumption is less when properties of frames are taken into account. The energy consumption when using PVC frames is less compared with the cases of using aluminum frames. The lowest energy consumption occurs in the case of using low-E coating glass with PVC sliding frames.
When considering the two cases that have the most difference in properties, i.e., the base case of using clear glass without frames and the case of using low-E glass with PVC sliding frames, it was found that the energy consumption differs by only 0.67% even though U, SHGC, and Tvis are different by as much as 58%, 37%, and 26%, respectively. This suggests that applying properties of pure glass without frames for windows when calculating or simulating building energy consumption can be done as usual without causing any significant errors.

Nonetheless, only one sample building with only one WWR is considered in this work. Moreover, the results are not consistent with the work of Sekhar and Lim that mentioned that good window systems could help reduce heat gains into a building thus the size of air conditioning systems while utilizing daylighting and cutting down the number of electric lighting fixtures both of which would lead to a significant decrease in building energy use [7]. Further studies using more number of buildings, more building applications, and more values of WWR should be carried out.

4. Conclusion

This work was to study the impacts of window frames on building energy consumption. The analysis was carried out using 3 glass types, 2 frame materials, and 2 frame configurations applied to a sample office building. It was found that even though when the values of U, SHGC, and Tvis differ the most between the base case of using clear glass without frames for windows and the case of using low-E glass with PVC sliding frames (differ by 58%, 37%, and 26%, respectively), the annual energy consumption from the simulation is different by only 0.67%. Therefore, using properties of pure glass without frames for windows in the building energy consumption calculation or simulation as conventionally done would not cause significant errors in the results. Further studies using more number of buildings, more building applications, and more WWR values should be carried out to gain more solid evidences on the conclusion.

5. Acknowledgement

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6. References


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Effect of Low NaOH Concentration on Compressive Strength and Products of High Calcium Geopolymer

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Abstract. This research aims to study effect of low NaOH concentration on compressive strength and products of high calcium geopolymer. Fly ash was used to be starting material to synthesize geopolymer and mixed with 2 M sodium hydroxide (NaOH) concentrations. Silica fume was also used to be addition of silica in mixture to make different Si/Al ratios. Geopolymer pastes were determined compressive strength at the ages of 7, 14 and 28 days. The products of geopolymer pastes were characterized by Fourier transform infrared spectroscopy (FTIR) and salicylic acid with methanol (SAM solution) leaching test. The products of geopolymer were determined by the FTIR in different patterns before and after SAM solution leaching which is specific for calcium composite gel. It was found that low NaOH solution can produce the highest compressive strength of 15.91 MPa at the age of 28 days. The products of high calcium geopolymer were possible be calcium silicate hydrate (CSH gel), calcium aluminate silicate hydrate (CASH gel), geopolymer (NASH gel) and zeolite which were characterized by FTIR and SAM leaching tests.

Keywords: geopolymer, silica fume, FTIR, SAM leaching

1. Introduction

Geopolymer is an aluminosilicate material which can be synthesized by using aluminosilicate materials such as fly ash and metakaolin with alkali hydroxide solution such as sodium hydroxide (NaOH) or potassium hydroxide (KOH). In the geopolymerization reaction, aluminosilicate material is dissolved to form free of tetrahedrons of silica and alumina. To the develop reaction, water is gradually spitted out and tetrahedrons of silica and alumina is linked by sharing oxygen atom [1]. Generally, there are three classes of geopolymer structures, depending on the silica/alumina ratio: polysialate (Si-O-Al), polysialate-siloxo (Si-O-Si-O-Al) and polysialate-disiloxo (Si-O-Si-O-SiO-Al) which have Si:Al ratios of 1:1, 2:1 and 3:1, respectively [1]. The products of geopolymer are composed of both amorphous phases and crystalline phases. They are also contributed to the superior mechanical strength of geopolymers.

Fly ash is one of the most famous starting materials of geopolymer. There are two types of fly ash which are Class F and Class C fly ash as described by ASTM C618 [2]. Class F fly ash is more popular to be starting material for geopolymer than Class C fly ash because Class F fly ash has high silica and alumina content [3]. Nevertheless, fly ash in Thailand is classified in Class F fly ash with high calcium content. A few researchers reported that the calcium might be interfered reaction of geopolymer or formed other products in geopolymer [4]. Moreover, it is possible that high calcium in fly ash can be formed calcium hydroxide (Ca(OH)₂) and gave alkali solution (OH⁻) to geopolymer pastes. It might be resulted in geopolymer synthesis with decreasing concentration of NaOH in system. In addition, calcium might be formed other products such as calcium silicate hydrate, calcium aluminate hydrate and calcium geopolymer. Some researchers found that calcium in fly ash improves mechanical properties of geopolymer. It accelerates the hardening process and increases the strength [4]. In Thailand, some researchers have used fly ash with high calcium to synthesize geopolymer and obtained high strength [5-8].

NaOH solution is commonly used as an alkali activator in geopolymer production. Alkaline solution (NaOH and/or KOH) is an essential reactant in geopolymerisation. Many researchers found that NaOH concentration between 10 – 14 M produced geopolymer with high compressive strength [9-10]. Somna et al. [8] found that geopolymer mixed with 14 M NaOH presented the highest compressive strength as 23.0 MPa at 28 days. Although the use of a high concentration of sodium hydroxide gave high compressive strength, the mixture is costly due to the sodium hydroxide solution. In addition, high concentration of NaOH has high viscosity which affects workability of geopolymer [10]. The idea of this
research is to use low NaOH concentration to synthesize geopolymer and study the compressive strength test as well as study products of geopolymer.

Thus, the aim of this paper is to study effect of low NaOH concentration on compressive strength and products of high calcium geopolymer. Class F fly ash was synthesized with low NaOH solution. The products of geopolymer were characterized by FTIR and salicylic acid with methanol (SAM solution) leaching test. The compressive strength of geopolymer was also investigated. Utilization of fly ash which is a by-product from electric thermal power plant to synthesize geopolymer is beneficial in environmental management. The geopolymer product would be environmentally friendly cementitious material.

2. Experimental Program

2.1 Materials

Fly ash (FA) was obtained from Mae Moh, Lumpang province, Thailand. To improve the reaction, fly ash was sieved by 200 meshes to obtain particles with size smaller than 100 microns. Silica fume (SF) was purchased under the name of Elkem Company, Chonburi province, Thailand.

The particle size distributions of fly ash and silica fume are shown in Fig. 1 and the chemical compositions of fly ash and silica fume are shown in Table 1.

Table 1: Chemical compositions of fly ash and silica fume

<table>
<thead>
<tr>
<th>% by wt.</th>
<th>GFA</th>
<th>Silica Fume</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>39.47</td>
<td>98.51</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>29.46</td>
<td></td>
</tr>
<tr>
<td>CaO</td>
<td>13.82</td>
<td>0.54</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>9.85</td>
<td>0.06</td>
</tr>
<tr>
<td>SO₃</td>
<td>3.66</td>
<td></td>
</tr>
<tr>
<td>K₂O</td>
<td>1.95</td>
<td>0.79</td>
</tr>
<tr>
<td>Na₂O</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>LOI</td>
<td>1.8</td>
<td></td>
</tr>
</tbody>
</table>

2.2 Alkali hydroxide solution

Sodium hydroxide (NaOH) solution was used as alkali hydroxide solution. 2 M NaOH concentration was used all mixtures in this research.

2.3 Geopolymer synthesis

Geopolymer samples were prepared by mixing ground fly ash (GFA) with silica fume and 2 M NaOH solution. Silica fume was used to replace fly ash at 5, 10, 20 and 30% by weight. A NaOH solution to solid ratio of 0.55 was assigned to the mix. They were stirred for 5 minutes then, cast in cylindrical mold with 30 mm in diameter and 60 mm in height. The geopolymer pastes were demolded and kept at ambient temperature until the test age. The compressive strength of geopolymer was investigated at the ages of 7, 14 and 28 days. The pastes were ground and characterized by FTIR and SAM solution leaching test. Typical chemical ratios of activated geopolymer pastes are given in Table 2.

Table 2: Typical chemical ratios of activated geopolymer pastes

<table>
<thead>
<tr>
<th>Sample</th>
<th>FA</th>
<th>SF</th>
<th>Si:Al</th>
<th>Ca:Si</th>
<th>Na:Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>2SiO</td>
<td>100</td>
<td>0</td>
<td>1.54</td>
<td>0.53</td>
<td>0.20</td>
</tr>
<tr>
<td>2Si5</td>
<td>95</td>
<td>5</td>
<td>1.76</td>
<td>0.46</td>
<td>0.21</td>
</tr>
<tr>
<td>2Si10</td>
<td>90</td>
<td>10</td>
<td>2.00</td>
<td>0.41</td>
<td>0.22</td>
</tr>
<tr>
<td>2Si20</td>
<td>80</td>
<td>20</td>
<td>2.56</td>
<td>0.32</td>
<td>0.25</td>
</tr>
<tr>
<td>2Si30</td>
<td>70</td>
<td>30</td>
<td>3.29</td>
<td>0.25</td>
<td>0.28</td>
</tr>
</tbody>
</table>

2.4 FTIR technique

Fourier transform infrared spectroscopy was chosen to study the products of geopolymer. FTIR was obtained from PerkinElmer model Spectrum 100. The specimen was prepared by 0.001 mg of sample in 0.04 mg of KBr. Spectra analysis was performed in terms of the wavenumber range

2.5 Salicylic acid with methanol (SAM solution) leaching test

The SAM solution was first introduced by Takashima who used this technique to dissolve alite and belite in Portland cement. It was used to dissolve calcium bearing phase in geopolymer pastes. In this research, SAM leaching test was studied using the steps proposed by Somna and Bumrongjaroen [12]. 7 grams of salicylic acid and 40 ml of methanol were prepared to study products of geopolymer.

The geopolymer pastes were ground and stirred with SAM solution for 3 hours. After that, it was filtered and dried at 100°C. Part of insoluble residue of geopolymer after SAM leaching test was characterized by FTIR technique.

Steps to determine the products of geopolymer are as follows:

1. Fly ash was characterized by FTIR.
2. Geopolymer pastes were characterized by FTIR and subtracted with FTIR spectra of fly ash. The possible products found in resultant FTIR spectra are calcium silicate hydrate gel (CSH gel), calcium aluminate silicate hydrate gel (CASH gel), geopolymer gel (NASH gel) and zeolite.
3. Insoluble residue of geopolymer pastes after SAM solution leaching test was characterized by FTIR. They were subtracted with FTIR spectra of fly ash. The possible products found from FTIR spectra are NASH gel and zeolite.

4. FTIR spectra of CSH gel and CASH gel was obtained by subtracting FTIR spectra obtained from step 2 and step 3.

3. Results and Discussion

3.1 Properties of materials

Chemical compositions of fly ash and silica fume are shown in Table 1. For fly ash, the sum of SiO₂, Fe₂O₃, and Al₂O₃ was 78.78%. The CaO and loss on ignition (LOI) values were 13.85% and 1.8%, respectively. Fly ash was indicated to be Class F fly ash as prescribed by ASTM C 618 [2] with high calcium oxide content. For silica fume, the chemical composition of silica fume had high in SiO₂ content as 98.51%.

The particle size distributions of fly ash, ground fly ash and silica fume are shown in Fig. 1. The particle sizes of GFA were smaller than those of OFA. It is noted that the small particles can react better and faster than the large particles.

Fig. 1: Particle size distributions of fly ash, ground fly ash and silica fume

3.2 FTIR and SAM solution analysis

Fig. 2 shows FTIR spectra of geopolymer pastes after subtracting by FTIR spectra of fly ash. The remaining FTIR spectra after subtracting by FTIR of fly ash could be those of geopolymer products (CSH gel, CASH gel, NASH gel and zeolite).

FTIR spectra presented the two major peaks at 980 cm⁻¹ which is associated with Si-O in Q₂ units [13] and at 1120 cm⁻¹ which is associated with Si-O in Q₃ units [7]. There is the band characteristic of carbonate group around 1450 cm⁻¹ which was supposed to be CaCO₃. All bands at 1650 and 3460 cm⁻¹, respectively, related to O-H stretching and bending modes of molecular water.

Fig. 3 showed FTIR spectra of insoluble residue of geopolymer after SAM solution leaching test. The products of this part would be NASH gel and zeolite. Interestingly, peak at 980 cm⁻¹ disappeared. The major peaks of geopolymer shifted to higher wavenumber around 1100-1200 cm⁻¹ which were contributed to Si-O in Q₃ units, typical NASH gel or zeolite. Since salicylic acid is organic acid, many sharp peaks of salicylic were interfered in insoluble residue of geopolymer pastes after SAM leaching test.

Fig. 4: Subtraction FTIR spectra between FTIR spectra of geopolymer pastes after subtract by FTIR spectra of fly ash and FTIR spectra of insoluble residue of geopolymer after SAM solution leaching test

From this part, FTIR technique can used to determine the products of geopolymer with SAM solution leaching test. The products of geopolymer were possible be
CSH gel and CASH gel which were presented with wavenumber at 970 cm\(^{-1}\)[13]. In addition, NASH and zeolite were also observed at wave number around 1000 – 1100 cm\(^{-1}\). It was described that additional of silica in high calcium geopolyme can be formed CSH gels products. Some silica and alumina in fly ash can react with calcium to form CASH gel. Moreover, silica and alumina in fly ash can release out to form NASH gel and zeolite under low NaOH concentration.

### 3.3 Effect of low NaOH concentration on compressive strength

Fig. 5 showed the geopolymer compressive strength test results for different silica fume replacements and curing ages. It was found that silica fume replacement has an effect on the compressive strength of geopolymer pastes. Additional silica fume in system led to increase Si:Al ratio of geopolymer. The compressive of geopolymer increased with increasing the Si:Al ratio in mixture of geopolymer. The compressive strength slightly increased from 7 to 28 days. The compressive strength of geopolymer pastes with silica fume replacements of 5, 10, 20 and 30% at the age of 28 days were 10.28, 11.18, 12.02, 14.27 and 15.91 MPa, respectively. The maximum compressive strength was found to reach 15.91 MPa with 30% silica fume replacement. The compressive strength of 2Si30 was 10.08, 11.00 and 15.91 MPa at the ages of 7, 14 and 28 days, respectively. It was found that addition of SiO\(_2\) to geopolymer led to an increase in compressive strength.

Thus, low concentration NaOH solution mixed with fly ash and silica fume can give the highest compressive strength of 15.91 MPa at the age of 28 days with 30% silica fume replacement which had Si:Al ratio of 3.92. It can be mentioned that high calcium oxide contents in fly ash can react with silica fume to form calcium silicate hydrate. This product would be similar to product obtained from cement hydration reaction which can produce strength.

### 4. Conclusion

1. Geopolymer which synthesized by using low concentration NaOH solution, high calcium fly ash and silica fume can produce a high strength. The highest compressive of geopolymer was 15.91 MPa in 2Si30 at the age of 28 days.
2. The Si:Al ratio in mixture of geopolymer increased led to increase compressive strength of geopolymer.
3. The products of geopolymer which characterized by FTIR and SAM leaching were possible be CSH gel, CASH gel, NASH gel and zeolite.
4. High calcium geopolymer can be activated with low alkali hydroxide solution. The pastes provided strength which was closed to the strength obtained from cement hydration reaction.

### 5. Acknowledgement

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On-Road Visualizations for Suspension Tuning of a Race Car

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Abstract. The objectives of this study are to investigate and propose a new method of using visualization for measuring the dynamic behavior of a race car which corresponds to the tuning of the suspension system. All investigations were conducted on the race car called the “Student Formula CMU F-712”, which was strictly constructed following the 2012 Formula SAE Rules. The behavior of this race car according to variations of the rear tire’s pressures and rear cambers were visualized to evaluate the optimized suspension system’s setup values. These values were suited for drug and skid-pad events. The type of front and rear suspensions of the race car was unequal length A-arm double wishbone. The vibrating force was transferred through push rods and bell cranks to shock absorbers and springs. Digital still cameras were used to capture the car’s behavior and analyses performed from these pictures. It can be concluded that the on-road visualization is acceptable for measuring the dynamics of the race car corresponded to the tuning of the suspension system. The visualization methods used were the pitch angle of the car during launching and the outside rear camber and roll angle of the car during turning. Results obtained from the visualizations were compared with the results obtained from quantitative and qualitative tests to validate the analysis. It was found that very good agreement was archived.

Keywords: Visualization, Suspension tuning, Double wishbone, Camber, Roll angle

1. Introduction

The suspension system consists of mechanical parts whose primary function is to isolate the car’s structure from shock loading and vibration due to irregularity of the road surface. Moreover, it must do this without impairing the stability, steering, or general handling qualities of the vehicle. It can meet these requirements by the use of flexible elements, dampers, and mechanical linkages; such as, springs, stabilizer bars, shock absorbers, tires, wheels, wheel hubs, upright arms, linkages, joints, etc. [1]. The suspension system’s parts can be generally adjusted, such as the wheel alignment, kingpin inclination, spring stiffness, shock absorber damping rate, tire pressures, especially in race cars. These are for optimal vehicle stability during driving which directly affects speed. This directly affects the competition result and also the safety of the driver. There are a number of optimized designs on suspension systems; such as, (a) geometrical and shape analysis which is used for suspension system design [2-4], (b) dynamic analysis which is important for the dynamics and response of the suspension systems [5-7], and (c) strength analysis which is a useful tool for selecting suitable material and sizing of the suspension systems [2].

Although the suspension system has been very well designed and manufactured by the above mentioned methods, a consequent problem is how the suspension system can be tuned to suit with each different driving characteristic. Although the dynamic analysis can lead to a solution, a great number of outside factors can cause the analysis to become very complicated. Therefore, another method for tuning the suspension system, which is not so complex, is desired among the automotive community. Transducers are installed on each part of the suspension system [8] in order to measure the dynamic properties, such as, linear and angular accelerations, forces and torques. The designer takes these measured values to be a guideline for tuning the suspension system. The high cost of the instruments and the large amount of equipment are the major disadvantages to this method. Thus, this method cannot be reasonably used by small design units which rarely have high capital, such as the “CMU Auto Club” of the Faculty of Engineering, Chiang Mai University, where the Student Formula is designed, constructed and competes in the annual TSAE Student Formula Challenge [9] organized by the Society of Automotive Engineers Thailand.

The requirement for tuning the suspension system within a limited budget, a new measurement concept called ‘visualization’ in which physical behaviors are visualized and recorded is therefore proposed in this study. The objective is to investigate the possibility of using the visualization for measuring the dynamics of the race car which corresponds to the tuning on suspension system. Results obtained from this study will be useful for evaluating the car’s behavior and this usefulness will apply to all levels in the automotive development including industrial complexes, companies, universities, colleges and private or local garages.
2. Experimental Setup and Procedure

All investigations were conducted on the race car “Student Formula CMU F-712” which was strictly constructed following the 2012 Formula SAE Rules [10] as shown in Fig. 1. The front and rear suspensions were of the type unequal length A-arm double wishbone. The vibrating force was transferred through push rods and bell cranks to shock absorbers and springs (Fox, DHX RC 4.0). The camber and toe, shock absorber’s damping rate and tire pressure could be adjusted freely between the front and rear suspensions. The controlled parameters for the race car were as follows: front track of 1,225 mm, rear track of 1,225 mm, wheelbase of 1,650 mm, curb weight including a driver of 390 kg, static weight distribution between the front and rear of 44:56, aluminum alloy wheels (Lenso, Raiden, 13 x 7.5 inch), 599-cc 4-cylinder 4-stroke gasoline engine with manual transmission (Suzuki, GSX-R, Model year 2007), chain and sprocket transmission with a final ratio of 4.076:1, and 1.5-ways viscous limited slip differential (Subaru, Impreza 2.0L). The experiment was divided into 2 parts as (a) the visualization to investigate the car’s behavior according to rear tire’s pressures for a drag event and (b) the visualization to investigate the car’s behavior according to rear cambers for a skid-pad event. Details of each experiment are described as follows.

![Fig. 1: Student Formula CMU F-712](image)

2.1 Experiment on the effect of the rear tire pressures

For this section, the additional controlled parameters were as follows: the front tire pressure was 20 psi, the front and rear shock absorber’s damping rate were 75% and 50% of the maximum respectively, the front and rear cambers and toes were 0° and 0 mm respectively. The tire pressure and camber angle were measured by a mechanical bourdon pressure gauge and a handheld wheel-alignment tester (Banzai, MB-40E, ±0.5° accuracy), respectively. The investigation was conducted by varying the rear tire pressure from 4 to 20 psi in order to understand which value suits for the launching and accelerating in a drag event by considering the pitch angle of the race car which was recorded by a digital still camera (Nikon, D7000, 16.2 Mpixel). This was located at the start line of the drag strip as shown in Fig. 2. The experimental procedure began when the car’s nose reached the start line and the engine speed was locked at 8,000 rpm. The digital camera consequently took continuous pictures with a speed of 6 frames per second. The clutch was instantly released to launch the car and the car then was fully accelerated to the finish line and each gear was shifted up constantly at 8,000 rpm. The pitch angle of the car in this study was defined as an angle between (i) the connecting line from the lowest part of the nose of the car taken at just-before launching (0th second) to the one taken at just-after launching (1/6th second) and (ii) the horizontal plane as shown in Fig. 3. The elapsed time from the start to the finish line was simultaneously recorded. Also the well-trained driver was interviewed and his opinions were reported in an evaluation form and used as qualitative data in further analysis. The experimental procedure was repeated until all of the rear tire pressures were investigated. Finally, the pitch angles, elapsed times and the opinions of the driver obtained from all experiments were simultaneously analyzed for the effect of the rear tire pressures on the race car’s launching. The possibility of using the visualization for the race car’s dynamic performance was investigated.

![Fig. 2: Drag strip and camera’s location](image)

2.2 Experiment on the effect of the rear cambers

For this part, the following were the additional controlled parameters: front and rear tire pressures, shock absorber damping rates and toes of 18 psi, 75% of the
maximum and 0 mm respectively. The front camber was -2°. The investigation was conducted by varying the rear camber from 0° to -3° in order to understand the optimum stability in the skid-pad event by considering the outside rear camber and roll angles of the race car which was recorded by two digital still cameras (Nikon, D7000, 16.2 Mpixel) located beside the skid-pad track as shown in Fig. 4.

![Skid-pad track and camera location](modified from [10])

Fig. 4: Skid-pad track and camera location

The experimental procedure began when the car’s nose reached the start line and the engine speed was locked at 6,000 rpm and then launched. The car was driven in clockwise and counter-clockwise directions, two laps each and the engine speed was constantly controlled at 6,500 rpm in second gear until the car reached the finish line. The outside rear camber and roll angle which were measured from an angle between the rearmost frame and the horizontal plane, were captured as shown in Fig. 5 (a) and (b), respectively. Experimental procedure was repeatedly done until all variable parameters were investigated. Finally, outside rear cambers, roll angles, elapsed times and well-trained driver’s opinions reported in an evaluation form obtained from all experiments were simultaneously analyzed for the effect of the rear cambers on the race car’s stability. The possibility of using the visualization for the race car’s dynamic investigation was also evaluated.

3. Results and Discussions

3.1 Investigating the behavior from rear tire pressure visualization

It was found from the data that when rear tire’s pressure increased from 4 to 8, 12, 16, and 20 psi, the pitch angle of the car decreased from 7.59° to 7.23°, 4.97°, 4.40°, and 2.26°, respectively. Pictures of the 0th and 1/6th second after launching taken from each experiment are shown in Fig. 6 (a) to (e).

![Car’s behavior according to rear tire pressures](a) 4 psi, pitch angle = 7.59°

(b) 8 psi, pitch angle = 7.23°

(c) 12 psi, pitch angle = 4.97°

(d) 16 psi, pitch angle = 4.40°

(e) 20 psi, pitch angle = 2.26°

Fig. 6: Car’s behavior according to rear tire pressures
The pitch angle of the car is affected by the acceleration or deceleration exerting on the car. Note that only acceleration is focused on in this study. When the car’s velocity increases after a sum of longitudinal forces acting on the car is higher than zero, the inertia force will be exerted on the car. This causes a higher portion of car’s weight to be transferred to the rear. While the weight is transferring rearward, the rear suspension is bumping and the front one is rebounding. This causes a change in the pitch angle. In general, an increase in the pitch angle implies that the weight exerting on rear drive wheels has increased and friction between tires and road surface also increased. This causes a decrease in slippage of the tires and an increase in the acceleration during launching. In addition, since the shock absorber’s damping rate and spring stiffness were constantly controlled for all the experiments, the pitch angle will increase directly proportional to the transferring weight and the acceleration’s magnitude during launching. For this reason, it can be concluded that the rear tire’s pressure of 4 psi causes the best launching behavior of the Student Formula CMU F-712 since the maximum pitch angle of 7.59° is archived. This is a result from the most rearward weight transfer which subsequently causes the highest launching acceleration or the lowest slippage of the drive wheels.

This conclusion on the suitable rear tire’s pressure can be validated with quantitative results by comparing the elapsed time in the drag strip. It was found that when the rear tire’s pressure increased from 4 to 8, 12, 16, and 20 psi, the elapsed time increased from 3.54 to 3.57, 3.59, 3.72 and 3.84 seconds respectively. It can be seen that the rear tire’s pressure of 4 psi is the best value since it causes the lowest elapsed time. Moreover, the visualized and quantitative results agree well with qualitative data which is the driver’s feedback. It was reported when the rear tire’s pressure was 4 psi that, the rear suspension obviously bumped and the drive wheels instantly created good traction. Nevertheless, after the rear tire’s pressure increased, the rear suspension was found to be stiffer, and increased slippage of the drive wheels was sensed.

3.2 Investigating the behavior from rear camber visualization

It was found that when the rear camber decreased from 0° to -1.0°, -2.0°, and -3.0°, the outside rear camber during turning changed from +3.34° to +1.00°, +0.35°, and +0.35°, respectively, and roll angle changed from 1.77° to 0.88°, 0.31°, and 1.10°, respectively. Pictures taken from each experiment are shown in Fig. 7 (a) to (d).

Fig. 7: Car’s behavior according to rear cambers

This dynamic behavior results from the relationships between lateral weight transfer, body roll and camber change during turning. Camber angle equals the inclination of the wheel with respect to the vertical plane. It takes a positive value when the top of the wheel leans outward from the car centerline [11]. Generally, a tread area of the tire will fully contact with road surface when the camber is 0°. For a case of driving in a straight line, zero camber causes the best grip and stability.

Nevertheless while the car is turning, a centrifugal force is exerted on the center of gravity (CG) of the car in the lateral direction outside of the car. This causes the body to roll and the force will consequently transfer through upper A-arm and wheel located on the outside of the car. According to this force, the upper portion of the wheel is pushed outward and then the camber will change to be more positive. The tread area of the tire fully contacting with the road decreases and the grip will decrease compared to the former case. Thus, stability during turning decreases. For this reason, the cambers of race cars driven in curved tracks such as skid-pad or full course tracks, including general passenger cars are initially adjusted to have a negative value. Due to this setup, outside cambers will not change to positive while the cars are turning. The
visualization showed that when the rear camber decreased from 0° to -2.0°; while the race car was on the curve, the outside rear camber decreased from +3.34° to +0.03° (tread area of the tire almost fully contacted with the road surface). This change causes an increase in grip of the drive wheel and a decrease in oversteer. Thus, the slip angle of the tire will decrease [11, 12]. In general, if a slip angle decreases, the tire will create higher grip to resist more centrifugal force. The stability during turning will increase. In addition to the decrease in outside camber, wheel and upper A-arm will support the body to roll decreasingly. Evidence can be seen from the visualization that the roll angle decreased from 1.77° to 0.31°. After the rear camber decreased from -2.0° to -3.0°, a change in physical behavior was seen as described above. The outside wheel had a higher grip and lower slip angle. In general, if the slip angle decreases beyond a certain value, the oversteer will disappear. This causes the outside wheel to have excessive grip during turning. The contacting point between the tire and road surface will be equivalent to a rotating point. Simultaneously, the high magnitude of the lateral weight transfer causes the body to roll increasingly and the inside wheel will subsequently lift. It could be seen from the visualization that the roll angle suddenly increased from 0.31° to 1.10°. From this viewpoint, power transmission to a road during turning rapidly drops along with the stability. These behaviors are affected by the jacking force which increases as the roll center (RC) locates closer to the CG. For the Student Formula CMU F-712, the roll center was designed to be located near the CG since the roll moment and roll angle of the car during turning will decrease [12].

From the visualization, it can be concluded that the rear camber of -2.0° is the best value for the Student Formula CMU F-712 being in the skid-pad event since the tread area of the outside tire fully contacts with a road surface. The conclusion can be validated with quantitative result by comparing to the elapsed time in the skid-pad track. It was found that when rear camber decreased from 0° to -1.0°, -2.0°, and -3.0°, the elapsed time changed from 27.10 to 26.42, 26.00, and 26.50 second, respectively. It can be seen that when the rear camber is -2.0°, results in the lowest elapsed time. Moreover, the visualized and quantitative results very well agree with qualitative data from the driver’s feedback. It was reported when the rear camber was -2.0° that the car rarely had oversteer and the car could turn in the track with constant steering wheel angle. Nevertheless, after the rear camber increased, the oversteer was observed to increase, thus, the driver had to correct the direction of the car for the entire track.

3.3 Impacts and suggestions

The visualization for measuring the dynamic response of the race car corresponded to the tuning of the suspension system proposed in this study is expected to be a new interesting tool which can help engineers, mechanics, students and people interested in automotive engineering in the suspension system tuning and design. An advantage of this method is that, the instruments are inexpensive, testing procedure is not complex and the dynamic behavior of the car at a specified time can be directly investigated. However, it should be reminded that error in the visualization is always higher than error in the quantitative test. Therefore, a suitable method should be carefully chosen to match with the objective of each test.

4. Conclusion

The study entitled on-road visualization for suspension tuning of a race car has been conducted. Good agreements of results were obtained from the visualized, quantitative and qualitative experiments. It can be concluded that the on-road visualization can be used for measuring the dynamics of the race car corresponded to the tuning on the suspension system. The suitable visualization to investigate the car’s behavior according to the rear tire pressures for drag event is an analysis of the pitch angle of the car during launching. It is found that the higher pitch angle, the better launching. In this case, when the rear tire’s pressure was 4 psi, the maximum pitch angle of 7.59° was achieved which proved to be the best for launching. Moreover, the visualization to investigate car’s behavior according to the rear cambers for skid-pad event is an analysis on the outside rear camber and roll angle of the car during turning. It is found that when the outside rear camber approaches zero and the roll angle was the lowest, the car had the best stability during turning. For this case, the best result was obtained when the rear camber was -2.0°, since the outside rear camber mostly approached zero as of +0.03° and the roll angle was a minimum of 0.31°.

5. Acknowledgement

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Two-Dimensional Simulation of Temperature in Paddy Bulk Storage with Closed-Loop Oscillating Heat Pipes

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Abstract. The temperature distribution characteristic of 250 kg paddy was computational studied. The paddy was kept in the cylindrical bin with 0.7 m diameter and 1.0 m height and cooled by an array of closed-loop oscillating heat pipes (CLOHPs). The moisture content of paddy was 14\% wet basis. CLOHPs were made of copper capillary tubes with 0.0014 m inside diameter and 0.0022 m outside diameter and filled with R134a at 50\% of the total internal tube volume. The evaporator and condenser lengths of CLOHP were 1.0 m and 0.5 m respectively. CLOHPs were arranged in a circular form within the bin. The evaporator section was buried in the storage bin and the condenser section was exposed to the ambient air in order to remove heat from the respiration of paddy. The temperature distribution inside paddy bulk was numerical analyzed as the two-dimensional transient heat transfer in cylindrical coordinates (r, z, t) and the temperature of paddy in circumferential direction was supposed to be uniform. The temperature distribution within paddy bulk with CLOHP was investigated through 60 h and compared to the temperature distribution of system without cooling unit. The temperature difference of paddy inside the storage bin with and without CLOHPs was found in the range of 0.99-2.55\%. The array of CLOHPs within paddy bin can remove the heat from grain during storage and reduce the bed temperature although there are a few temperature differences of paddy and ambient air. The thermal efficiency of simulated CLOHPs cooling system was about 45.2\%.

Keywords: Closed-loop oscillating heat pipe, paddy storage, temperature distribution

1. Introduction

The paddy is deteriorated during storage due to heat liberated from respiration process especially for the paddy after harvest in which the moisture content is high at 26.9\% wet basis. After the drying process, the moisture content of paddy is reduced and kept at 14\% wet basis which is the safety condition for a long storage time. The deficient paddy storage management induces important grain damage. Normally, the aeration with cool or ambient air is used to remove the heat from grain during storage and reduce the bed temperature. Because Thailand is in humid tropical climate and the rice cultivation is 2-3 times per year, the fan operating time is really long which follows by the high electricity expense per year. In order to decrease the operating cost of electricity consumption, the thermosyphon was applied as a cooling unit in paddy bulk storage [2]. The working fluid used was R22 at 100\% filling ratio of evaporator volume. Although the bed temperature of paddy with the high moisture content was clearly reduced, the construction of tested thermosyphon was specific and complicated in order to add the evaporator and condenser areas and its design theory was restricted. Therefore a closed-loop oscillating heat pipe (CLOHP) which was one type of heat transfer device with high thermal performance [3-5] was concentrated in this research. Since it is made of a long capillary tube that is severally bent between the evaporator and condenser sections to form the meandering turns, there are simplicities of construction and an increase in the heat transfer surface area of CLOHP. Because of these advantages, CLOHP was widely investigated in cooling the small electronic devices [9], enhancing the performance of turbo charge diesel engine [10] and an application in waste heat recovery. The understanding of temperature distribution in the stored paddy is able to predict the grain deterioration potential. A numerical simulation model viz., a two-dimensional finite difference model, was developed to predict temperature in a paddy storage bin during the non-aeration period [1] and
the aeration period [11] of the storage process. Recently the heat transfer model of paddy bulk with 26% wet basis was carried out in our previous research and it will be applied and developed for practical storage condition. In this research, a two-dimensional finite difference model was developed to investigate the temperature distribution in the 14% wet basis paddy storage bin with using CLOHPs as a cooling unit.

2. Mathematical Model and Computer Program

The temperature distribution inside paddy bulk was considered as the two-dimensional transient heat transfer in cylindrical coordinates \((r, z, t)\) and the temperature of paddy in circumferential direction was supposed to be uniform as shown in Fig. 1.

In order to simplify the model, it is necessary to suppose that the radiation heat exchange with surroundings is negligible. The ambient temperature is constant at 25°C. The thermal energy generation is uniform within medium. The paddy moisture content is constant at 14% wet basis. The CLOHPs arrangement is defined in a circular form within the paddy storage bin and the distance between the adjoined CLOHPs in radial direction is 0.08 m as shown in Fig. 2. The evaporator sections are buried in the storage bin. The condenser sections are exposed to the ambient air in order to remove the respiration heat. The designed parameters of the paddy storage bin with using CLOHPs as a cooling unit are summarized in Table 1.

The finite-difference equation for each nodal point in Fig. 1 was developed by applying energy balance to a control volume about the nodal region. That is

\[
\dot{E}_g + \dot{E}_{in} - \dot{E}_{out} = \dot{E}_{st}
\]

where \(\dot{E}_g\) is the rate of thermal energy generated in the control volume due to respiration process of paddy. \(\dot{E}_{in}\) is the rate at which thermal energy enter the control surface due to the heat conduction from adjoining nodes. \(\dot{E}_{out}\) is the rate of thermal energy removed from the control surface by CLOHPs. \(\dot{E}_{st}\) is the rate of change of internal thermal energy stored within the control volume of paddy.

Table 1: System specifications

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of paddy</td>
<td>250 kg</td>
</tr>
<tr>
<td>Height of bin</td>
<td>1.0 m</td>
</tr>
<tr>
<td>Diameter of bin</td>
<td>0.7 m</td>
</tr>
<tr>
<td>Inner diameter of CLOHP</td>
<td>0.0014 m</td>
</tr>
<tr>
<td>Outer diameter of CLOHP</td>
<td>0.0022 m</td>
</tr>
<tr>
<td>Evaporator length of CLOHP</td>
<td>1.0 m</td>
</tr>
<tr>
<td>Condenser length of CLOHP</td>
<td>0.5 m</td>
</tr>
<tr>
<td>Number of CLOHP turns</td>
<td>20</td>
</tr>
<tr>
<td>Working fluid of CLOHP</td>
<td>R134a</td>
</tr>
<tr>
<td>Filling ratio of working fluid</td>
<td>50%</td>
</tr>
<tr>
<td>Initial temperature of paddy</td>
<td>26.5°C</td>
</tr>
<tr>
<td>Paddy moisture content</td>
<td>14 % w.b.</td>
</tr>
<tr>
<td>Paddy storage time</td>
<td>60 h</td>
</tr>
<tr>
<td>(Ar)</td>
<td>0.0146 m</td>
</tr>
<tr>
<td>(\Delta z)</td>
<td>0.00416 m</td>
</tr>
</tbody>
</table>
The rate of thermal energy generated in the control volume due to respiration process of paddy was evaluated by using the expression as follow [7]:

$$\Delta T = \frac{15778(DML)}{c_p}$$

(2)

where $\Delta T$ is the temperature increment due to heat generation in the paddy. $c_p$ is the paddy specific heat and can be calculated as [8]:

$$c_p = 3.1 \times M_w + 1.2648$$

(3)

where $M_w$ is the paddy moisture content. $DML$ is the dry matter loss which indicates the amount of heat generated from respiration process. It is written as [7]:

$$DML = 1 - \exp(-Term)$$

(4)

where

$$Term = A \left( \frac{t}{1000} \right)^c \exp\left[D(1.8T - 28)\right]$$

(5)

$$A = 0.001889, \quad C = 0.7101, \quad D = 0.0274, \quad E = 31.63. \quad t \text{ is the paddy storage time, } T \text{ is the paddy temperature.}$$

The rate of change of internal thermal energy stored within the paddy control volume can be expressed as:

$$\dot{E}_i = \rho c_p \frac{dT}{dt} dV$$

(6)

where $\rho$ is the paddy density and can be calculated as [8]:

$$\rho = 171.02 \times M_w + 560.16$$

(7)

The rates of heat conduction between adjoining nodes in the radial direction ($q_r$) and axial direction ($q_z$) were evaluated from Fourier’s law,

$$q_r = -k_{eff} \frac{\partial T}{\partial r}$$

$$q_z = -k_{eff} \frac{\partial T}{\partial z}$$

(8)

where $k_{eff}$ is the effective thermal conductivity of paddy and can be calculated as [8]:

$$k_{eff} = 0.27 \times M_w + 0.0653$$

(9)

$A$ is the heat transfer area. $\partial T/\partial r$ and $\partial T/\partial z$ are the temperature gradients in $r$ and $z$ directions respectively.

The rate of thermal energy removed from the control surface by CLOHP was calculated from the non-dimensional empirical correlation given by Charoensawan et al., 2007 [6]:

$$Ku = 213 \times 10^{-5} Pr_t^{0.75} Ja^{0.38} Bo^{0.84}$$

(10)

$$Ka^{0.53} (k_c/k_a)^{0.11}$$

where $k_c/k_a$ is the ratio of the thermal conductivities of the coolant at the required temperature and the ambient air at 25°C. $Pr_t$ is Prandtl number of liquid. $Ka$ is Karman number. $Ja^*$ is modified Jacob number. $Bo$ is Bond number. $Ku$ is Kutateladze number that can be written as [6]:

$$Ku = \frac{q'}{h \rho_l \left( \frac{\sigma (\rho_v - \rho_l)}{\rho_l \rho_v} \right)^{0.11}}$$

(11)

where $h_l$ is the latent heat of vaporization of working fluid, $\rho_l$ and $\rho_v$ are the liquid and vapor densities of working fluid respectively, $g$ is the gravitational acceleration, $\sigma$ is the surface tension and $q''$ is the radial heat flux of CLOHP that can be calculated as [6]:

$$q'' = \frac{q}{2 \pi n D L \sigma}$$

where $q$ is the heat transfer rate of CLOHP and $n$ is the number of turns. All properties of working fluid used in these dimensionless parameters were evaluated at an operating temperature of CLOHP.

In order to obtain all nodal finite-different equations, the following initial and boundary conditions were considered:

$$\frac{\partial T}{\partial r} = 0 \quad \text{for } r = 0$$

(13)

$$T(r, z, 0) = T_0(r, z) \quad \text{for } t = 0$$

(14)

$$-k_r \frac{\partial T}{\partial r} = h_r (T - T_w) \quad \text{for } r = r_s$$

(15)

$$-k_z \frac{\partial T}{\partial z} = h_z (T - T_w) \quad \text{for } z = 1$$

(16)

$$-k_z \frac{\partial T}{\partial z} = h_z (T - T_b) \quad \text{for } z = 0$$

(17)

where $h_r$, $h_z$ and $h_l$ are the convective heat transfer coefficients on the bin wall, the grain top surface and the grain bottom surface respectively and can be obtained from the previous research [1]. $T_0$ is the initial paddy temperature. $T_a$ is the ambient air temperature. The computational steps for modeling the system are described in Fig. 3. The simulation model of stored paddy with and without CLOHPs was studied. The temperature distribution inside paddy bulk was analyzed along the storage time of 60 h for five representative temperature points shown in Fig. 4.
3. Results and Discussion

3.1 Paddy storage with and without CLOHPs

The dependency of average temperature of paddy stored in the bin on time is shown in Fig. 5. The paddy temperature increases from 28°C to 31.5°C in the storage time of 20 h and then it is nearly constant. This might be because the rate of heat generation in paddy is high until 20 h and after that it decrease. In addition, the simulation data obtained in this research is compared to the experimental data given by Dussadee et al. (2004) [2]. It is seen that the simulation data entirely agrees with the experiment result and the standard deviation is ±2.2%. Therefore the two-dimensional finite difference simulation model developed in this research can predict the temperature distribution in a paddy storage bin.

Fig. 6 shows the evolution of predicted paddy temperature for different points. The paddy temperatures with and without CLOHPs at point S1, S2, S3, S4 and S5 were indicated above in Fig. 4. The paddy temperature difference between with and without CLOHPs for point S1, S2, S3, S4 and S5 were calculated as 2.55%, 1.31%, 1.47%, 1.45% and 0.99% respectively.

3.2 Temperature distribution inside paddy bulk with and without CLOHPs

At the initial time, the paddy temperature stored in the bin is uniform at 26.5°C for with and without CLOHPs. The maximum temperature always occurs in the middle bed region of storage bin. The temperature decreases with an increase in the r-direction distance from centerline of storage bin as shown in Table 2.

For paddy bulk without CLOHPs, with the longer the storage time, the temperatures of all points within medium gradually decrease. The maximum temperature occurs in the middle region of bin and the value was about 26°C. The minimum value occurs at the bin wall and the top and bottom surfaces of paddy. The value is about 25.7°C at 60 h.

Table 2: Temperature distribution inside paddy bulk

![Fig. 3: Computational steps for modeling.](image)

![Fig. 4: Positions of temperature in paddy storage bin.](image)

![Fig. 5: Dependency of average temperature of paddy stored in the bin on time](image)
For paddy bulk with CLOHPs, with the longer the storage time, the temperatures of all points within medium steeply decrease. At 60 h the paddy temperature in the middle region of bin is reduced to about 25.3°C. The minimum temperature occurs at the bin wall and the top and bottom surfaces of paddy and the value is about 25°C at 60 h. After that the paddy had temperature equal to the ambient temperature. Therefore the array of CLOHPs within paddy bin can remove the heat from grain during storage and reduce the bed temperature although there are a few temperature differences of paddy and surrounding. It was found that the thermal efficiency of CLOHPs cooling system for 250 kg paddy was about 45.2%.

4. Conclusions

From all results, the conclusions are:

- The developed model can be used to predict the temperature inside 250 kg and 14% wet basis paddy bulk stored in the cylindrical bin with and without CLOHPs as a cooling unit.

- The temperature difference of paddy inside the storage bin with and without CLOHPs was found in the range of 0.99-2.55%.

- The minimum temperature occurs at 60 h with the average value of 25.4°C. The lowest value occurred at the bin wall and the top and bottom surfaces of paddy are as same as the ambient temperature.

- The array of CLOHPs within paddy bin can remove the heat from grain during storage and reduce the bed temperature although there are a few temperature differences of paddy and air. The thermal efficiency of CLOHPs cooling system for 250 kg paddy was about 45.2%.

- The developed model can be applied to predict the temperature distribution in cylindrical bin with and without CLOHPs for investigate the deterioration from respiration process of the other grains storage.

5. Acknowledgement

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6. References

Bibliography

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Analysis of Student Learning Outcomes in Power Electrical Engineering Courses: A Case Study

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Abstract. Teaching methods have been changed recently to focus on student learning. Various pedagogical methods have been introduced to motivate students to participate in classroom. However, the most important thing is student learning outcome. To ensure that new teaching methods are effective and students have accomplished learning goals, appropriate assessments are needed to reflect student learning outcomes. In power electrical engineering program for bachelor’s degree, Power System Analysis (PSA) course and Power Plant and Substation (PPS) course are two courses from eight specific engineering courses specified by council of engineering (COE). These two courses should be taken by senior students. At Dhurakij Pundit University, these courses were held at the last semester for the same group of students and taught by the same lecturer. The course contents and teaching materials were different, whereas teaching methods were similar but different in detail. There were significant differences in student scores. Average score from PPS course was 11.62% higher than that from PSA course. The objectives of this paper are to analyze the assessments and student learning outcomes from these two courses. Questionnaires and interviews were carried out. Finally, student feedbacks were analyzed and comparison results were concluded.

Keywords:
Assessments, learning outcomes, scores, comparison

1. Introduction

Teaching methods have been changed continuously [1]-[3]. Lecturers change their roles to be facilitators whereas student learning outcome is focused. There are many effective learning methods in electrical engineering such as problem-based learning [4], hierarchy of effective learning [5], etc. However, they are implemented with the same goal: to develop students in self learning. To ensure that the learning goals are accomplished, appropriate assessments are needed. They are used to measure learning outcomes and evaluate student knowledge [6]. In addition, facilitators have influenced on student behaviors and learning outcomes [7], [8].

In power electrical engineering program for bachelor’s degree, students must learn at least eight specific engineering courses specified by council of engineering (COE). Power System Analysis (PSA) course and Power Plant and Substation (PPS) course are both specific engineering courses. At Dhurakij Pundit University, senior students should learn these two courses in the last semester before they graduate. These courses were taught by the same lecturer in year 2015.

Experience from teaching PSA course more than ten years, the lecturer has learned that students should be evaluated in 3 parts: thinking process, calculation and consideration of feasible solution. Student should study each content carefully, do exercise and homework regularly and seek addition knowledge from other sources. Furthermore, students should analyze and solve problems by integrating their fundamental knowledge.

There are 6 important principles, which must be concreted as basic knowledge in PSA course, as following electrical power system, power directions, economic dispatch, power flow, power system faults and stability. They act as foundation of power system analysis. Therefore, students must understand these principles thoroughly. After that, students should learn how to apply them in various systems. They should study each content carefully, search for relevant knowledge from other sources, do exercises and learn to evaluate the feasible solution. Understand the principle correctly would enable students to utilize them to analyze any power system appropriately. To ensure that students understood correctly, students should perform self tests for each chapter. In addition, primary contents i.e. per unit system, vector, phasor sequence, circuit connection are important as fundamental knowledge which are needed to analyze and solve problems. If students were absent 1-2 classes without learning the missing content, they would not able to follow the subsequent contents.

In PPS course, key contents are electrical power plants, substations, equipment in substation, minimum clearance, substation grounding and lightning protection in substation. The calculation process should follow international standard such as the International Electrotechnical Commission (IEC), the Institute of Electrical and Electronics Engineers (IEEE). The contents
such as design of ground grid, clearance between equipment and lightning protection in substation, are straight forward following standard codes.

Many learning methods have been implemented in PSA course and PPS course in recent years. They include game-based learning, problem-based learning, project assignment, academic trip supporting assignment, etc. However, contents in PSA course are more difficult and more complex. These result in different examination scores.

The objectives of this paper are to compare student scores to analyze student outcomes and to find the appropriate learning methods for each course. It was performed as a small research project in a classroom [9]-[10].

2. Methodology

Four methods were used in this paper. First, raw data such as learning goals, assessment methods, student scores, were collected. Learning plan and goals were studied and compared. Learning goals must be specified before selecting assessment tool. Assessments were considered. Student scores were compared and analyzed. Second, questionnaires were distributed to students in PSA and PPS courses. Third, students were interviewed in a small group. Fourth, statistical tool such as t test [11] was used.

2.1 Learning goals

Learning goals were knowledge from PSA and PPS courses mentioned in Section I, and other skills i.e. problem solving, working as a team, communication, presentation, etc. Furthermore, students should develop their self-learning skill. Knowledge could be evaluated by examination whereas other skills could be evaluated via assignments and presentations.

2.2 Assessment methods

Learning outcomes were evaluated from their assignments, tests, exercises, presentations, examinations. To assess student learning outcomes, students were evaluated in three processes: i) project assignments to evaluate student self-learning, ii) participation and responsibility to evaluate skills in communication and team work iii) tests, midterm and final examinations to evaluate knowledge in each course.

Assessments for these two courses were quite similar. However, the questions in examinations for PSA course were more complex. Students should use 3-7 relevant processes, to solve problems. In addition, they must have fundamental knowledge such as circuit analysis theory, mathematics, complex number, phasor sequences etc. To solve problems, students needed to integrate knowledge from many areas. Whereas, questions in PPS course were quite straight forward i.e. to examine the design whether it complied standard codes and guidelines. Thus, examinations of PSA course were more difficult than those of PPS course.

2.3 Comparison student scores

Student scores from these two courses were collected, compared and analyzed. Mid-term and final examination scores were focused.

2.4 Questionnaires

There were 37 and 34 students for PSA course and PPS course respectively. Students were asked to answer questionnaires. Questionnaires were distributed to 25 students (13 students from 4 year program, 12 students from 3 year program). Note that the 3 year program is set for students who graduated from high vocational certificate level.

2.5 Student feedbacks

After final examination, four students were interviewed in a small group in the meeting room at electrical engineering department.

2.6 Statistical tool

The statistical tool for data analysis procedure such as t-test was used for hypothesis testing. It was used to test the difference of average scores from midterm and final examination, from PPS and PSA courses.

3. Results

Scores of 31 students who took both courses were compared. Student scores, evaluations and feedbacks were considered. Student scores and feedbacks from PSA and PPS courses were considered.

3.1 Student scores

Their scores are shown in Fig. 1-3 and Table 1. The scores from two courses for each student are compared. Most of students got higher scores from PPS course than those from PSA course.

In midterm examination, the scores were quite similar. There was no big difference, 10.50/20 for PSA course and 11.84/20 for PPS course. In PSA course, the key contents in first half course were power development plan in Thailand, economic dispatch and power flow. Economic dispatch was not too complicated. Teaching materials were power point files, seven short video clips, eight exercises and solutions. Power flow was quite difficult due to numerical calculation which was performed in several iterations until the solution converges to the final value.
Thus, students should learn this content via project assignment. In the first half term, contents and midterm examination in PSA were not too complex. Whereas, in PPS course, the contents were power plant, equipment in substation, substation type and switching order. They needed less calculation. However, students needed to understand the principle and logical control. Two students got zero scores in PSA course because they lacked problem solving skill and calculation skill and they could not raise process/methodology. In Table 1, the average midterm examination score in PPS course was 12.76% higher than that in PSA course. Note that the scores of student in 4 year program were higher than those of student in 3 year program.

In final examination, the scores of most students in PPS course were higher than those in PSA course except one student who was good at calculation. She liked to learn by reading from text books at home. Her skills for doing assignment, working as a team and presentation were less than her reading skill. Her learning from assignment was much less than learning by self-reading.

In Table 1, the average final examination score in PPS course (28.83/50) was 60% higher than that in PSA course (18.02/50). Note that the scores of students in 4 year program were still higher than those of students in 3 year program. The contents in PSA course in the second half term were power system fault, stability and protection which were much more complex. Whereas, learning contents in PPS course were solar power plant, minimum clearance, substation grounding and lightning protection in substation. The process of calculation was quite long but direct forward. Students learned them through many assignments. They took longer time in class in learning by doing. These developed the ability of problem solving to perform in steps and in sequences of calculation.

The total scores of most students in PPS course shown in Fig. 3 were higher than those in PSA course except one student who did not submit some assignments. There was one student who got the lowest mark in PSA course. He was absent class many times due to his private reasons. The continuously absent made him confuse. He could not follow the subsequent contents in class. He should have learned from teaching material and video clips, but he did not pay any attention. In Table 1, the total score in PPS course (60.96/100) was 11.62% higher than that in PSA course (54.61/100). Note that the scores of students in 4 year program were still higher than those of students in 3 year program.

![Fig. 1: Mid-term exam score comparison](image1)

![Fig. 2: Final exam score comparison](image2)

![Fig. 3: Total score comparison](image3)

<table>
<thead>
<tr>
<th>Course</th>
<th>Average Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mid-term examination</td>
</tr>
<tr>
<td>PSA</td>
<td>4 year program</td>
</tr>
<tr>
<td></td>
<td>3 year program</td>
</tr>
<tr>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>PPS</td>
<td>4 year program</td>
</tr>
<tr>
<td></td>
<td>3 year program</td>
</tr>
<tr>
<td></td>
<td>Total</td>
</tr>
</tbody>
</table>
For other learning outcomes, the evaluations of project assignments from two courses were compared and shown in Fig. 4. There were three project assignments in PPS course whereas there was only one in PSA course. In PPS course, some students could not find the actual data in practical use for some assignments. Some students did not submit assignments in time. However, students had developed skills in problem solving, working as a team, communication and presentation.

Fig. 4: Comparison of project assignment evaluations

3.2 Comparison student scores across years

Student scores from PSA and PPS courses were compared across consecutive years. Student scores from PSA course in 2013, 2014 and 2015 are shown in Fig. 5. The related average scores were 13.95, 18.02 and 38.67, respectively. Actually, they could not be compared directly. It was the same content, the same lecturer but different students. Student behaviors and learning skill were different. Students in 2015 learned together as a strong team. They had very close relationship and participated in many activities. However, lecturer has used lessons learned from year 2014 to improve her teaching method. In addition, video clips were put on YouTube, teaching material and assignments were put on Google Classroom. Whereas, student scores from PPS courses in 2013 and 2014 are shown in Fig. 6. The related scores were 17.44 and 28.83, respectively. PPS course was first taught in 2013. There were a few students who were in 3 year program. Thus, student scores from different year should not be compared directly. Student scores in 2015 were not taken to comparison since another lecturer was assigned to teach this course.

Fig. 5: Comparison of final examination scores from PSA course in 2013, 2014 and 2015.

Fig. 6: Comparison of final examination scores from PPS course in 2013 and 2014.

Table 2: Evaluation from student obtained by survey questionnaires. Rating scale is in interval 0-5, where 5 is the highest scale.

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>4 year Program</th>
<th>3 year Program</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Availability of text, teaching material, multimedia</td>
<td>4.54</td>
<td>4.00</td>
<td>4.17</td>
</tr>
<tr>
<td>2</td>
<td>Complexity of contents</td>
<td>4.39</td>
<td>3.12</td>
<td>4.58</td>
</tr>
<tr>
<td>3</td>
<td>Satisfying of learning method</td>
<td>4.58</td>
<td>3.92</td>
<td>4.42</td>
</tr>
<tr>
<td>4</td>
<td>Knowledge obtained</td>
<td>3.96</td>
<td>4.04</td>
<td>3.83</td>
</tr>
<tr>
<td>7</td>
<td>Difficulty of examinations</td>
<td>4.23</td>
<td>3.31</td>
<td>4.58</td>
</tr>
<tr>
<td>8</td>
<td>Clarity of examinations</td>
<td>3.92</td>
<td>4.23</td>
<td>3.5</td>
</tr>
<tr>
<td>9</td>
<td>Subject favourable</td>
<td>4.31</td>
<td>4.23</td>
<td>4.00</td>
</tr>
<tr>
<td>10</td>
<td>Subject benefit</td>
<td>4.31</td>
<td>4.31</td>
<td>4.00</td>
</tr>
<tr>
<td>11</td>
<td>Appropriation of Lecturer</td>
<td>4.62</td>
<td>4.69</td>
<td>4.58</td>
</tr>
</tbody>
</table>
3.3 Evaluations from student

The evaluations from survey questionnaires shown in Table 2, illustrated that the contents in PSA course were more difficult than those in PPS course (item 7). In PSA course, the contents were complex and difficult to understand, unclear questions in examinations (item 2 and 8).

Students from 3 year program liked learning by practice via project assignments (item 3, 5, 6 and 9). In other words, in PSA course, contents were more complex, examinations were more difficult, questions were unclear and there was only one assignment. In PPS course, contents were less complex, students could learn through project assignments. These resulted in less knowledge and benefit obtained from PSA course (item 4 and 10) though more teaching material, text book, video clips were provided in PSA courses (item 1). Students from 3 year program who had background in practice, enjoyed learning via project assignments whereas student from 4 year program preferred to learn in class, do some exercises and concentrate in calculation.

3.4 Student Feedbacks

Most of students had positive feedbacks. They could understand the contents in PPS course more clearly than those in PSA course. Student feedbacks were obtained through many questions as shown below.

3.4.1 The reason why students could get higher scores in PPS course:

- The contents in PSA course were more difficult than those in PPS course.
- The principle, equations in PPS course were direct forward and easy to understand.
- In PPS course, there were fewer contents.
- In PPS course, most of contents were based on design calculations with easier formulas.
- In PPS course, I have learned from doing and I could touch real-world tasks.
- PPS final examination was the last examination on the last day, I could prepare myself perfectly.
- I could understand contents in PPS course more clearly.
- I lacked calculation skill.
- I was absented in PSA course in some classes which I could not understand thoroughly by self learning.

- I have prepared myself for examination and selected contents relevant.

3.4.2 The reason why some students could get higher scores in PSA course:

- In PSA course, contents were easier than those in PPS course (only one feedback).
- I preferred PSA course since I had fun, more calculation, less memory needed.
- I was sick so that I could not prepare myself good enough and I missed one chapter in PPS course.

3.4.3 Learning methods that students liked:

- Assignments helped me in self-learning.
- Exercises in class.
- Games: bidding, matching equipment name.
- Quiz/test after learning.
- Brief lecture and assignments.
- I liked every learning method provided.
- Lecture from teacher and then doing case study under teacher coaching.
- Exercises after class to ensure my understanding.

3.4.4 Learning methods that students did not like:

- Lecture in whole class and memory needed.
- Lecture too much, calculation too fast.
- Presentation of my assignment without knowing the practical data.
- Teaching without paying attention for students.
- Too much lecture, practice or learning by doing would make us learn to think.
- Self learning and answer questions from the lecturer during presentation.

3.4.5 Other feedbacks:

- The complex process of calculation should be taught slowly.
- The complex contents should be emphasized.
- The clarity of contents should be improved.
- It should be emphasized for students to watch the video clips before class.
- There should be more tests.
- Specify the contents in final examination clearly.
- We should make a learning trip to get some experience before we do our assignment because it is needed for design.
- We should make a learning trip in real site or real power plant.
- There should be more learning activities.
- There were too many contents in PSA course.
- The examinations in PSA course were too difficult.
- There should be more exercises in PSA course.
- I wanted to learn so that I can picture it clearly in PSA course.
- Learning time in class was too short for contents in PSA course. It was too fast in learning class.
- Contents should be repeated and there should be more time for PPS class.
- Text book should be provided for PPS course.
- I liked these learning methods. I learned from my assignments and presentations. I learned mistakes from my presentations.
- I liked assignment for working in a team. We could learn from each other.
- I liked bidding game. It made me thinking and learning to think.
- More problems or exercises to make me understand the questions in PSA course.
- Too many assignments.
- Teaching too fast.

3.5 Comparison

The comparison was performed in course contents, clarity of examinations, learning methods, and teaching material, assignments.

The examination scores were divided into three parts: process of calculation or solving methodology, correctness of calculation and feasibility of solutions. The assessments were midterm and final examinations, tests and project assignments. They were compared between those assignments in PSA course and PPS course. Students have obtained higher scores, knowledge and benefit from PPS course in which students could learn via project assignments.

Statistical tool, t-test was used for hypothesis testing. Student scores, midterm and final examination, from PPS and PSA courses, were used as input data. The results showed that the average mid-term scores from PPS and PSA courses were not different with confidential 95%, p value 0.089. Whereas, the average final scores from PPS were different from those of PSA with confidential 95%, p-value 0.00005.

4. Lesson Learned

Lesson learned from these two courses is described below:

- The contents in PSA course were more complex. Students must analyze many thinking process. More exercises and activities were needed. Learning by doing in class with coaching was necessary. The key principles should be learned slowly. Since time in classroom was too short, students did not have sufficient time to learn each content in detail slowly. Thus, students should be encouraged to study video clips before attending class room. Then, activities to support learning contents in classroom should be performed. Flipped classroom should be employed. It must be ensured that students understand key principles correctly. In addition, questions in examination should be reviewed carefully.

- The contents in PPS course were direct forward. Each design was based on international standard. It was a step by step calculation process. It was easy to understand. Design process was followed standard guidelines. In addition, questions in examinations were clear.

- More education trips to power plants and substations were necessary before the beginning of design in project assignment. Questions should be prepared for students for each trip to stimulate them and make them more interested. Students should be eager to notice, analyze and integrate knowledge from each trip.

- There should be an appropriate treatment for each student group. Facilitator should notice and analyze the learning progress and team work of each group. Additional classes for explaining in detail should be set for students who need more time to develop thinking and calculation process.

- Student should be motivated to do self-test for each content.
• Lecturer had experience in PSA course for many years. Text book was written and published in 2014. Whereas, the lecturer has just been assigned to teach PPS course for two years. Lecturer was keener in PSA course. Coaching for assignment in PSA course was better than that in PPS course. Thus, learning contents were much deeper in detail. Questions in examinations were more complex.

5. Conclusions

Assessments and learning outcomes of senior students from PSA course and PPS course were compared and analyzed. Student scores for both midterm and final examinations in PPS course were higher than those in PSA course. The reasons were the complexity of contents, assignments, clarity of questions in examinations and learning methods. More learning activities and exercises in classroom were needed. Student’s favorite learning methods are game based learning, learning via project assignments, doing exercises in classroom under coaching.

The survey and interview results showed that students were more eager to learn through activities than listening. Some improvement for learning methods should be further developed. Students should watch video clips before attending classroom. Activities in classroom under coaching could support student learning to make them understand correctly and more clearly. Flipped class room should be employed.

References


Bibliography

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