

Aerobic Biodegradation of Per-Treated Methyl Tert-Butyl Ether By Ozonation in an Up-Flow-Fixed-Bed Reactor

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Abstract: Problem Statement: MTBE is a common pollution of environmental and has become an issue of considerable concern in recent years. It is not readily amenable to remove MTBE by conventional techniques in water treatment. In the present study, the feasibility of the continuous aerobic biodegradation of MTBE, was evaluated in an Up- Flow Fixed Bed Reactor (UFBR). **Approach:** The UFBR at a constant Hydraulic Retention Time (HRT) of 24 h was used as a biological process that receives the intermediates due to partial oxidation of MTBE. The UFBR coupled to ozonation process as a survey system after a primary operation phase that was necessary for creatory of an initial microbial film on the carriers. Residual concentration of MTBE and its major degradation intermediates were measured by gas chromatography. Aqueous concentration of ozone in the reactor and ozone average concentration in off- gas were determined according to the indigo blue method. The COD reduction and BOD₅ to COD ratio were selected as biodegradability indexes. **Results:** Results showed an effective degradation of MTBE in the coupled ozonation-UFBR continuous flow reactor of ten days of operation time. A partial degradation of MTBE in AOPs increases its biodegradation [The BOD₅ to COD ratio increased from lowest (0.01) up to a maximum of 0.72] that corresponds to an ozone consumption of 0.62mg per each mg of COD initially present in the solution. The results showed when $m. \text{Mol}[\text{MTBE}]^0/m. \text{Mol}(\text{o}_3) = 0.611$, the COD removal efficiency was 89% and as this ratio increased up to 1.25, the of COD removal efficiency decreased to 80%. 46-68% removal of the COD was needed before the mixture was considered biodegradable. The highest removal rate of MTBE, 82.91 mg day⁻¹ achieved through out the UFBR runs (87% removal efficiency, In this study, the removal efficiency of MTBE using integrated-process (ozonation followed biological treatment) was from 78.5-86.5%. In order to determine of biological removal rate of MTBE, another UFBR system used as a blank reactors. Results showed that the efficiency of the COD removal (by stripping with the biological degradation) was 5-8% which implies insignificant biological removal of MTBE without pre-ozonation. Solid produced in the proposed integrated process was 0.27-0.35 kg TSS kg⁻¹ COD removed which is approximately in down range of conventional biological system (0.3-0.5 kg TSS kg⁻¹COD). **Conclusion:** Present study showed that we can treatment of the polluted aqueous solutions to MTBE without microbial incubation used to integrated process.

Key words: Methyl tert-butyl ether, biodegradation, aerobic upflow Fixed-bed reactor, ozonation, integrated process.

INTRODUCTION

Methyl Tertiary Butyl Ether (MTBE) is one of the several fuel oxygenates added to gasoline to replace tetra ethyl lead and reduce harmful tailpipe emission.

The present guideline limit established by the US Environmental Protection Agency (EPA) is 20-40 µg L⁻¹ for MTEB in drinking water^[1]. The EPA also classifies MTEB as a possible human carcinogen^[2]. In spilt of its relatively recent usage, MTEB has been

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frequently detected in the urban groundwater^[3-8]. It has become the second most common contaminant of urban aquifers with concentrations rising in many areas the levels which gives to the water both an unpleasant taste and odor poses a significant health threat^[7,9,10]. Due to its high water solubility, low Henry's law constant the commonly relatively low concentrations in the environment, it is not readily amenable to remove MTBE by conventional techniques in water treatment^[11]. MTBE is a common pollution of significant environmental impact and has become an issue of considerable concern in recent years^[12].

Recent developments suggest that integration of chemical and biological oxidation processes may be economically competitive with other more established treatment technologies for a wider range of recalcitrant compounds removal such as MTBE, which is chemically resistant^[13,14]. However, combined chemical and biological processes for degradation of MTBE were not addressed in the previous study.

In the present study, we have evaluated the feasibility of the continuous aerobic biodegradation of MTBE, in an Up-Flow-Fixed-Bed Reactor (UFBR). We have used the UFBR because of its ability to control solid retention time and to operate, in general, at biomass concentrations up to one order of magnitude,

which is higher than that of conventional suspended growth reactors' conditions that offer an economic advantage by producing an equivalent effluent quality at reduced reactor volumes. Here, we demonstrate that O_3 and OH° radicals can also induce substantial enhancement in the aerobic biodegradation of MTBE.

MATERIALS AND METHODS

Ozone generated from filtered, dried air by an ozonation (Model OZN5R). Methyl tert-butyl ether (MTBE MW = 88.15, >99.9%, MERCK Co.) Was used as purchased. Deionized water (resistivity < $5\mu\text{cm}^{-1}$), was used for all the experiments. Stock and working indigo blue solutions were prepared from potassium indigo tri-sulfonate ($C_{16}H_7N_2O_{11}S_3K_3$ at 100% purity, ACROS CO.) as per Standard Methods^[15]. Other chemicals were reagent grade and purchased by MERCK Co. The lab-scale UFBR (Fig. 1) consisted of two identical plexiglass cylindrical columns (1.06 m high, 6 cm i.d. for each) operating at $27\pm 2^\circ\text{C}$ was used. One biofilter was fed by pre-ozonated MTBE(a) and the other was selected as blank reactor (b) which was fed by a mixture solution of MTBE and glucose plus Diethylene glycol. The active liquid volume in any one of reactors was 2.5 L including the recycling loop.

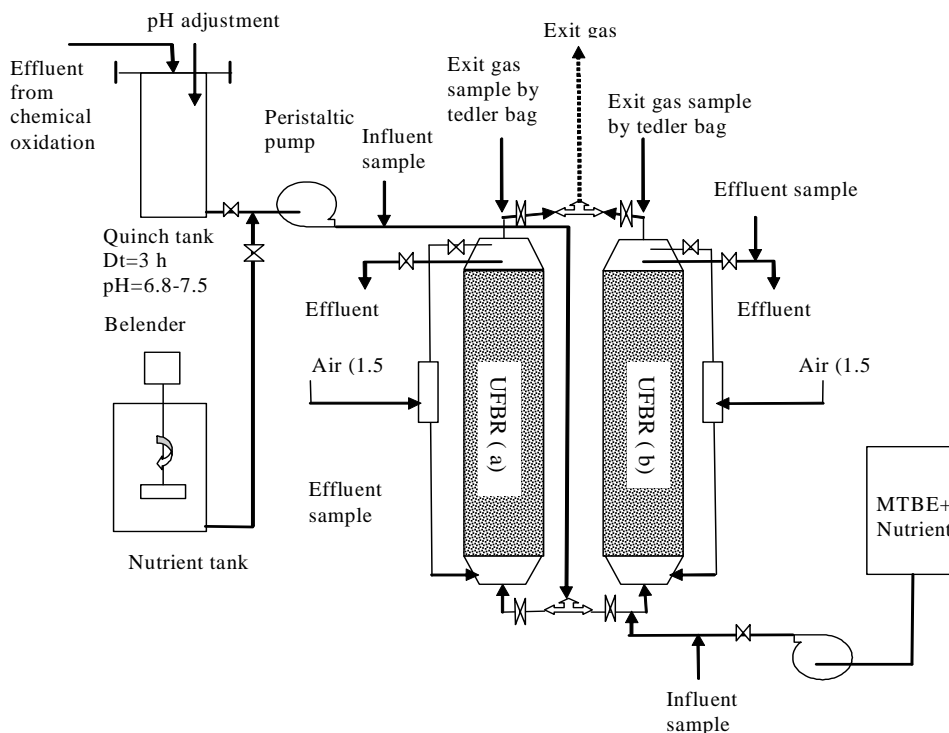


Fig. 1: Laboratory up-flow-fixed-bed reactor experimental set-up

About 20% of the total reactors volume seeded with pvc-rings which was used as biomass carriers. PRs have 80% of pore volume and about $555.7 \text{ m}^2 \text{ m}^{-3}$ of surface area. The recycle flow rate was set at 1.2 L day^{-1} . Air was introduced at 1.5 L min^{-1} in the recycling loop which was enough satisfies the dissolved oxygen concentration in the reactor up to 3 mg L^{-1} . Such aeration set-up was chosen to minimize the MTBE and its intermediates stripping. The microbial consortium that used in this study for the reactor inoculating was obtained from a petrochemical wastewater treatment plant mixed with the sediments in the bank of a clay stream. Microorganisms were initially grown onto the PVC-Rs (in both “a” and “b” reactors) and adapted to working conditions before the biodegradation experiment. This enrichment culture used the intermediates of the MTBE ozonation in the main reactor and the MTBE plus glucose (with constant concentration 500 mg L^{-1}) in the blank reactor, as sole source of carbon and energy in aerobic conditions. Reactor feed solution an intermediate mixture consisting of following mineral salts medium were added to the medium (g L^{-1} of deionized water): 6 of Na_2HPO_4 , 3 of KH_2PO_4 , 1 of NaCl ; 1 of NH_4Cl ; 0.5 of $\text{MgSO}_4 \cdot 7 \text{ H}_2\text{O}$, 0.011 of CaCl_2 , and 0.001 of $\text{FeCl}_3 \cdot 6 \text{ H}_2\text{O}$.

Experimental strategy of the reactor operation: The experimental strategy was defined by two operation phases. The first one corresponds to the reactor start-up (0-22 days) to permit the development of the initial microbial film. During the second (22-120 days) operation phase we investigated the effect of the ozonation on biological degradation of oxygenate in a continuous treatment system and optimizing the oxidation conditions. For all runs, steady-state conditions were assumed to be achieved when the efficiency of the both biofilter at organics removal was constant with $\pm 5\%$ fluctuation at least two consecutive residence times. The recycled flow was increased to a high rate for about 3min once a day in order to prevent the reactor clogging. All the measurements for the whole experimental runs were done in triplicate.

Residual concentration of MTBE and its major degradation intermediates, were measured by gas chromatography (GC-FID, PU4410-PHILIPS) equipped with a flame ionization detector and a SE30 column. The carrier gas was nitrogen. The oven and injection/detection port temperatures for the analysis in liquor phase were 250 and 200°C and in gas phase were 200 and 180°C, respectively. The cells were removed from the sample filtration through $0.2 \mu\text{m}$ pore size

polyether sulfone filters (Schleicher and Schuell), prior the injection of $2 \mu\text{L}$ of the sample. Dissolved oxygen concentration in the liquid phase, at the top of the reactor (3 cm under the liquid surface) was determined with an oxygen-meter equipped with an oxygen electrode which was 3 mg L^{-1} after 30 min aeration stopping. Aqueous concentration of ozone in the reactor and ozone average concentration in off-gas (with 2% errors in sampling) were determined according to the indigo blue method describe earlier. For pH measurements an orion pH electrode pH/Tc° model 520 A was used. pH probe was checked for true readings before any run of the test. BOD_5 was measured according to the procedures stipulated in standard methods^[16] section 5210 B and to this subject, Inoculum was taken from the refinery wastewater plant in Esfahan (Iran). Chemical Oxygen Demand (COD) was also followed according to dichromate reactor digestion hach method 8000 by reagents for low COD).

RESULTS

The continuous degradation of glucose and Diethylene glycol mixture in the UFBR, in order to microbial film fixation and receiving steady- state condition in the bioreactor, was determined by measuring the soluble COD in the influent and effluent of the reactor during the primary operation phase (22 days). The experiment was started with a hydraulic loading rate of about $1.88 \text{ cm}^3 \text{ m}^{-2} \text{ h}^{-1}$ at an HRT of 24 h. The variation of COD in the bioreactor is shown in Fig. 2.

Figure 3 shows average residual concentration of MTBE in the influent and effluent of the bioreactor after its partial oxidation with $1.25 \text{ mg ozone mg}^{-1}$ of initial COD at a pH of 11.5^[17].

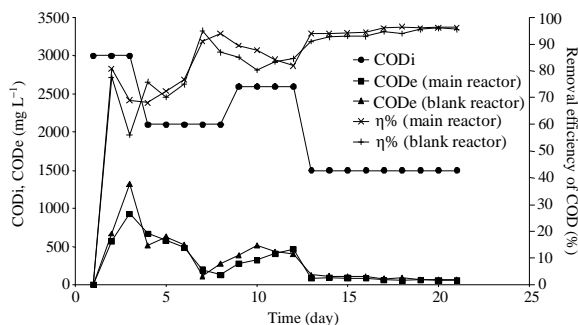


Fig. 2: Variation of COD in the Biological reactors, vs. time of operation (SOR = $1.88 \text{ cm}^3 \text{ cm}^{-2} \text{ h}^{-1}$, Dt = 24 h)

Removal of soluble COD versus MTBE; O₃ ratio and its rate versus the time of operation is shown in Fig. 4 and 5, respectively.

The biodegradability of the solution was also tested throughout the experiment. BOD₅/COD ratio and the COD reduction have been chosen as biodegradability indicators (Fig. 6).

During the whole of the second phase, when biological treatment was coupled with ozone oxidation, the intermediate effluent was partially ozonated as proved (Fig. 7) by the profiles of the ozone amount in the gas effluent as a function of time (mg O₃ out min⁻¹) recorded during a typical ozonation test for the initial MTBE, 100-350 mg⁻¹, at pH 11.5.

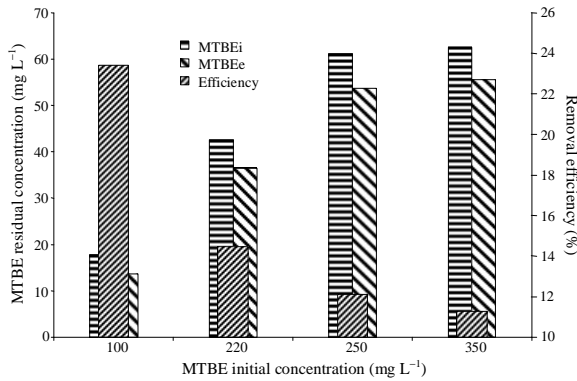


Fig. 3: Average residual concentration of MTBE in the influent and the effluent of the bioreactors, vs. various initial MTBE that arriving integrated process

The performance of the blank reactor in order to determine of the COD due to MTBE by stripping with any biological activities during the runs operation throughout 96 hr shown in Fig. 8.

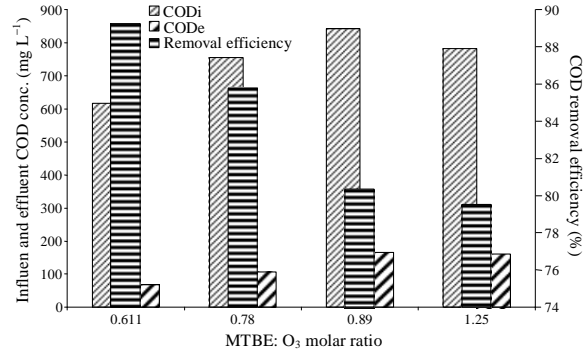


Fig. 4: Removal of soluble COD, vs. m Mol MTBE/m Mol O₃ in integrated process

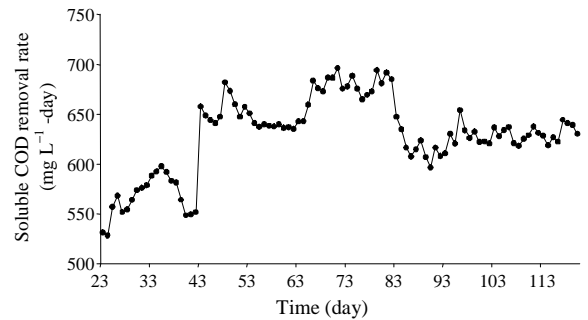


Fig. 5: Soluble COD removal rates vs. time of operation

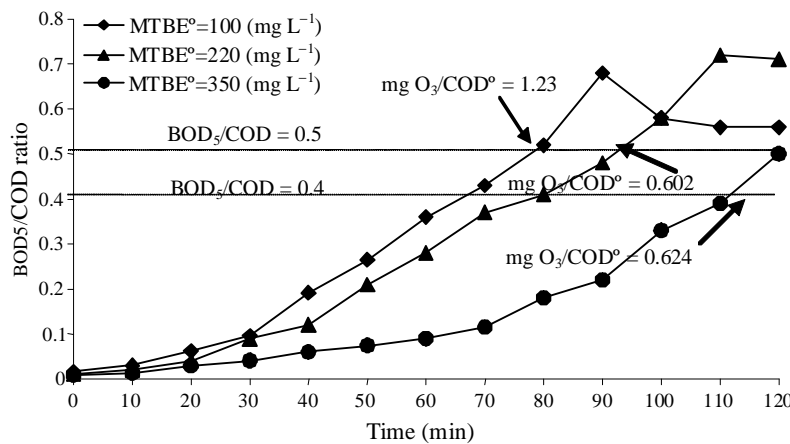


Fig. 6: Variation in biodegradation (measurement base on BOD₅/COD ratios for various MTBE concentration and impact of two parameters O₃ demand concentration compare to initial COD and ozonation time for minimum MTBE chemical oxidation before biodegradation

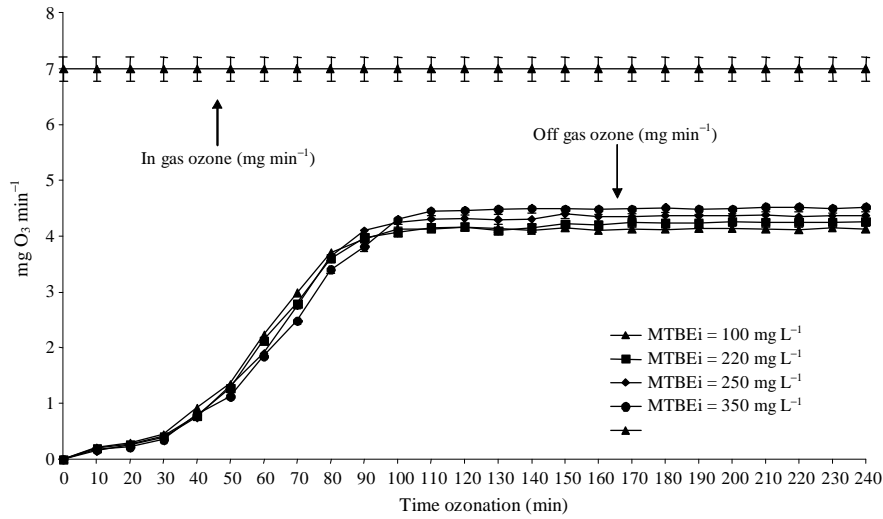


Fig. 7: Typical profile of ozone amount in the influent (with 0.2 Mg L⁻¹ error) and off gas (with 2% minus errors detected during an ozonation test at PH 11.5

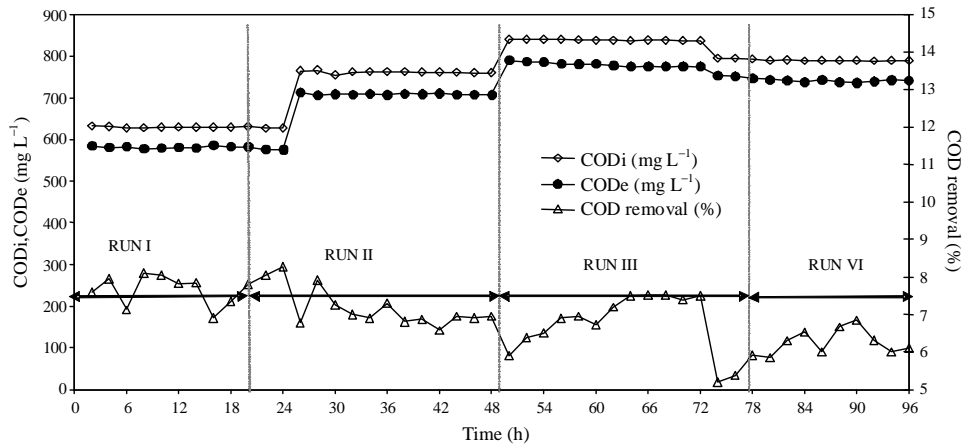


Fig. 8: COD concentration in the influent and effluent samples during 96 h on blank reactor

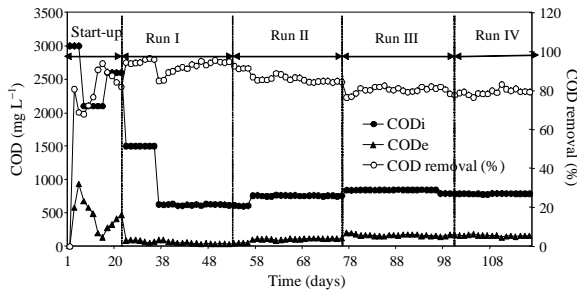


Fig. 9: COD concentration in the influent and effluent samples during 120 days on preozonation-UFBR process

The performance of the integrated process (pre-ozonation-UFBR) during the four runs of the second

period is shown in Fig. 9. The continuous degradation of the pre-ozonation liquor mixture in the UFBR was determined by measuring the soluble COD in the influent and effluent throughout 120 days.

DISCUSSION

The results showed that for the both of reactors after two weeks, a thick biofilm stuck on the media was observed and the efficiency of soluble COD removal achieved up to 95%.

As shown, in Fig. 2 the MTBE feed concentration (between 100-350 mg L⁻¹ at a constant HRT of 24 h) to ozonation reactor increased, the residual concentration into the bioreactor was also increased and the MTBE removal efficiency (mostly by stripping) was decreased.

During the second operation phase (22-120 days) of the integrated process, MTBE feed concentration was increased at a constant HRT of 24 h. As shown in Fig. 3, the concentration of MTBE degraded in the influent and effluent of the bioreactor, was increased as to the increased initial MTBE reaches 3.5-fold higher than the initial concentration and thus the removal efficiency of the soluble COD was decreased. As it is shown in the Fig. 4, when $\text{m. Mol}[\text{MTBE}]^0/\text{m. Mol}(\text{O}_3)$ ratio was 0.611, the COD removal efficiency was 89% and as the ratio increased up to maximum of possible limit (i.e., 1.25, almost double), the efficiency was decreased to 80%.

Removal rate of the whole of intermediates was about $628 \pm 25 \text{ mg}^{-1} \text{ day}^{-1}$. The results are shown in Fig. 5.

As it can be observed in Fig. 6, an increase in the BOD of a sample due to the pretreatment would indicate its greater amenability to biodegradation. Thus, an increase in BOD_5/COD and a decrease in the COD concentration after pre-treatment is indicate of improved biodegradability due to an enhance in the proportion of COD amenable to biological mineralization. The results evidenced that if based BOD_5/COD equals 0.4-0.5 proper biodegradation, for solution contain of organic compounds used to conventional treatment, minimum time necessary of ozonation, for initial MTBE equal to 100 mg^{-1} , was 60 min before biodegradation, until $\text{mg O}_3/\text{COD}_{\text{initial}}$ is equal 1.23 and with increase of MTBE in solution the time increased. That cause of it, is obligate decrease of proportion of usable ozone to COD initial ($\text{mg O}_3/\text{COD}$), caused efficiency limited, in Ozone transition from gas phase to liquid phase and design structure and problems of ozonation reactors.

The pattern showed in Fig. 7, indicates that in the whole process of the ozonation, the ozone amount in the gas effluent reaches to a constant rate after 90-100 min, i.e., the time length that is necessary to the ozonation reactor changes from semi-batch to steady state condition. From the pattern reported in Fig.7, it is also possible to calculate the Transfer Efficiency (TE) and the transferred ozone dosage. The total ozone amount calculated out of the reactor, resulted in 795.5 mg O_3 . Accordingly, TE and the transferred dose resulted in 52.6% and $115.3 \text{ mg O}_3 \text{ L}^{-1}$, respectively.

The experiments were carried out on the blank reactor to examine the effect of sparging (in the absence of bio-film) on the rate of removal COD equal to MTBE due to stripping in off gas during the period 96 h. MTBE feed concentration was increased stepwise from 100 to 350 mg^{-1} at a constant HRT of 24 h. The results shown in Fig. 8 reveal that averagely about 7% of COD strips out.

As shown in Fig. 9, the performance during runs I and II (average 89% COD removal) were better than runs III and IV (average 80% COD removal) that its cause was $\text{m Mol O}_3 \text{ m}^{-1} \text{ Mol MTBE}$ ratio (i.e., these ratios were 1.45 and 0.93, respectively).

The experiments carried out for determination of sludge production showed that solid produced, expressed as $\text{kg TSS kg}^{-1} \text{ COD}_{\text{removed}}$, in the start-up period, the blank reactor (when only MTBE was as sole source of carbon and energy) and in the proposed integrated process, that the intermediates from MTBE degradation was as sole source of carbon and energy, were 0.23-0.85, zero 0.27-0.35, respectively.

CONCLUSION

The results of the present study showed a continuous high-rate degradation of MTBE in an integrated process including of pre-treatment by ozonation with an aerobic up-flow-fixed-bed reactor. Also this research showed that we can treatment of the polluted aqueous solutions to MTBE without microbial incubation used to integrated process.

ACKNOWLEDGEMENT

The researchers would like to express their thank and appreciation for Professor L. Mesdaghinia, A. Badkoubi, A. Khavanin for their great help and assistance during the research.

REFERENCES

1. Chi, W.L., H.C. Lin and C.Y. Lai, 2007. MTBE biodegradation and degrader microbial community dynamics in MTBE, BTEX and heavy metal-contaminated water. *Int. Biodeteriorat. Biodegradat.*, 59: 97-102. DOI: 10.1016/J.IBIOD.2006.08.002
2. Johnson, R., J. Pankow, D. Bender, C. Price and J. Zogorsky, 2000. MTBE: To what extent will past releases contaminate community water supply wells? *Environ. Sci. Technol.*, 34: 210A-217A. <http://bases.bireme.br/cgi-bin/wxislind.exe/iah/online/?IsisScript=iah/iah.xis&src=google&base=REPDISCA&lang=p&nextAction=lnk&exprSearch=10558&indexSearch=ID>
3. Bacher, A.L., P.E. Stackelberg and R.J. Baker, 1999. Evaluation of the atmosphere as a source of volatile organic compound in shallow ground water. *Water Resour. Res.*, 35: 127-136. DOI: 10.1029/1998WR900030

4. Klinger, J., C. Sticler, F. Sacher and H.J. Branch, 2002. MTBE (methyl tertiary-butylether) in ground waters: Monitoring results from Germany. *J. Environ. Monitor.*, 4: 276-279. <http://www.ncbi.nlm.nih.gov/pubmed/11993769>
5. Schmidt, T.C., E. Morgenroth, M. Schirmer, M. Effenberger and S.B. Haderlein, 2002. Use and Occurrence of Fuel Oxygenate in Europe. In: *Oxygenate in Gasoline: Environmental Aspects*, Diaz, A. and D.F. Drogos (Eds.). ACS Press, Washington DC., ISBN: 0841237603, pp: 58-79.
6. Schmidt, T.C., M. Schirmer, H. Weiss and S.B. Haderlein, 2004. Microbial degradation of methyl tert-butyl ether and tert butyl alcohol in the subsurface. *J. Contam. Hydrol.*, 70: 173-203. <http://www.ncbi.nlm.nih.gov/pubmed/15134874>
7. Squillance, P.J., J.S. Zogorski, W.G. Wilber and C.V. Price, 1996. Preliminary assessment of the occurrence and possible sources of MTBE in groundwater in the United States, 1993-1994. *Environ. Sci. Technol.*, 30: 1721-1730. <http://cat.inist.fr/?aModele=afficheN&cpsid=3066468>
8. Kharoun, M., A. Pauss and J.M. Lebeault, 2001. Aerobic biodegradation of an oxygenates mixture: ETBE, MTBE and TAME in an up flow fixed bed reactor. *Water Res.*, 35: 1665-1674. <http://www.ncbi.nlm.nih.gov/pubmed/11329668>
9. Capino, L. and G.I. Togna, 1998. Potential health effects of gasoline and its constituents: A review of current literature (1990-1997) on toxicological data. *Environ. Health Perspect.*, 106: 115-125. <http://www.ncbi.nlm.nih.gov/pubmed/9452413>
10. Hoffert, S.P., 1998. Haze of uncertainty surround gas additive. *Scientist*, 12: 1-7. <http://cat.inist.fr/?aModele=afficheN&cpsid=10498380>
11. Erping, Bi., S.B. Haderlein and T.C. Schmidt, 2005. Sorption of Methyl Tert-Butyl Ether (MTBE) and tert-butyl alcohol LTBA to synthetic resins, 2005. *Water Res.*, 39: 4164-4176. DOI: 10.1016/J.WATRES.2005.07.035
12. Alexander, O., D.A. Jefferson, M. Tikhov and R.M. Lambert, 2007. Enhancement of MTBE photocatalytic degradation by modification of Tio with gold nanoparticles. *Catal. Commun.*, 8: 821-824. DOI:10.1016/J.CATCOM.2006.08.040
13. Jon, P., Scott and F.O. David, 1995. Integration of chemical and Biological oxidation processes for water treatment: Review and recommendations. *Environ. Prog.*, 14: 88-103. DOI: 10.1002/ep.670140212
14. Flores, A., A. Stocking and M. Kavanaugh, 2000. Synthetic Resin Sorbents. In: *Treatment Technologies for Removal of Metyl Tertiary Butyl Ether (MTBE) from Drinking Water: Air Stripping, Advanced Oxidation Processes, Granular Activate Carbon, Synthetic Resin Sorbents, IniMelin*, G. (Ed.). National Water Research Institute, California, pp: 261-333.
15. Ganlzer, C.J., 1989. Inhilitory substrate utilization by steady state biofilm. *J. Environ. Eng.*, 155: 302-319. <http://cedb.asce.org/cgi/WWWdisplay.cgi?8900806>
16. Greenberg, A.E., L.S. Clesceri and A.D. Eaton, 1992. *Standard Methods for the Examination of Water and Wastewater*. 18th Edn., American Public Health Association, USA., ISBN: 08-755-32071.
17. Sadeghi, M., A. Mesdaghghinia, A. Badkoubi, R. Nabizadeh and A. Khavani, 2005. Application of the ozonation pre-treatment for biodegradation of aqueous solutions of methyl tert-butyl ether. *Am. J. Environ. Sci.*, 7: 41-45. <http://www.doaj.org/doi?func=abstract&id=115515>

Electroosmotic Phenomena in Organic Soils

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Abstract: Organic soils or peat represent an accumulation of disintegrated plant remains which have been preserved under condition of incomplete aeration and high water content. In order to develop a fundamental understanding of electroosmotic phenomena in peat, initially microelectrophoresis studies were carried out to conceptualize the electrokinetic phenomena. Then electroosmosis experiments were conducted on rigid cube samples containing 0.0001 M NaCl-water saturated peat. The open-anode and open-cathode systems were employed to the soil samples. Distilled Water (DW) were used as anolyte and catholyte. The experiments were carried out via applications of different DC electrical potentials. The results of microelectrophoresis study showed changes of zeta potential due to the effect of HCl and NaOH. The correlations between zeta potential and pH were found. The negative charge of peat is high pH dependent and the surface charge was dropped to zero at pH around 3. The high degree of decomposition resulted in the higher zeta potential in peat. It was also experimentally found that the electroosmotic flow in peat is feasible. The direction of electroosmotic flows were from the anode to cathode.

Key words: Electroosmotic flow, humification, organic content, zeta potential

INTRODUCTION

In 1809, Reuss, a researcher from Russia, was the first to observe water flow in soils as a result of a direct electric current passing through it. Electroosmosis (EO) is one of the electrokinetic phenomena where the pore fluid moves due to application of DC current (or voltage) by electrodes in a soil mass^[1].

Geotechnical and environmental engineers have been interested in electroosmosis for many years as a method of soil improvement including electroosmotic dewatering, ion injection, contaminant removal, electrobioremediation and electrochemical remediation^[2].

Soils with organic content of greater than 20% are generally termed organic soil. Peat is described as a naturally occurring highly organic substance derived primarily from plant materials. The definition of peat overtime and to different people has differed, although essentially all are agreed that it is primarily an organic soil^[3]. In Malaysia about 8% of the country's land area is

covered with peat and generally termed basin and valley peat^[3,4]. Peat and organic soils are extremely soft. These soils are geotechnically problematic due to their very high compressibility and very low shear strength^[3,5].

According to colloidal theory, a soil particle, when suspended in water, has a negatively charged surface. Surrounding the particle is double layer of positive ions. Most rigidly attached to the surface is the first layer of positive ions, with greater distance from the solid particle, the attractive force diminishes, giving rise to an increasingly diffuse ionic atmosphere (the second layer), where the ions are relatively free to move. The electroosmotic permeability is dependent on zeta potential, ζ , which is defined as the electrical potential at the junction between the fixed and mobile parts of electrical double layer. Beyond the double layer, the ion concentration is equal to that of the free pore water. Because of the polar nature of water molecules they are oriented around cations. In the presence of water, the radius of an ion may thus increase to several times its original, nonhydrated

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dimension^[6]. Applying an electrical potential to the saturated soil causes the hydrated positive ions to move toward the negative electrode (the cathode), dragging free water with them. The movement is primarily generated in the diffuse double layer, also called soil moisture film, where the cations dominate. The higher the soil particle surface area, the more soil moisture film transfer will occur. Other important are the magnitude of the electrical potential applied and the viscosity of the pore fluid^[7].

The rate of water flow is controlled by the balance between the electrical force causing water movement in one direction and friction between the liquid and the wall in the other. The overall flow (q_A) generated by the application of a potential difference (D) may be expressed as:

$$q_A = k_e (V/L)A \quad (1)$$

Where:

- k_e = The electro osmotic permeability of the soil
- V/L = The electrical potential gradient
- A = The cross-sectional area of the soil sample across which the potential difference is applied

As such this is analogous to Darcy's Law of hydraulic flow. Where Q is the flow rate; k_h is the hydraulic permeability; i_h is the hydraulic gradient and A is the cross sectional area of the soil^[7]:

$$Q = k_h i_h A \quad (2)$$

The overriding benefit of electroosmosis is that k_e is independent of pore size and has a relatively constant value in soils.

This study is devoted to describe a study on the zeta potential behaviour and the electroosmotic phenomena in organic soil and peat. To our knowledge, no research has been conducted on this subject. It is believed that study of electroosmosis phenomena in organic soils is crucial to extend its applications in geotechnical aspects.

MATERIALS AND METHODS

Peat: The peat samples were taken from Kg. Jawa, Klang, Selangor, Malaysia. Loss of moisture from samples was prevented during transportation, preparation and storage (BS 1377-1: 1990). The sample for electroosmosis experiment was characterized physically and chemically, with results being shown in Table 1. Mineralogical analysis of the clay fraction showed the presence of kaolinite.

Table 1: Characteristics of the peat used in this study

Variable		Value
Liquid limit (%)	BS 1377-2:1990	280.0
Specific gravity	BS 1377-2:1990	1.4
Moisture content (%)	BS 1377-2:1990	480.0
Organic content (%)	BS 1377-3:1990	83.0
pH	BS 1377-3:1990	6.4
Cation exchange capacity (meq/100 g)		86.0

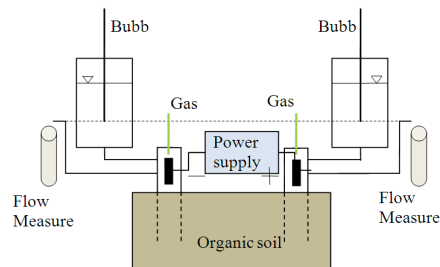


Fig. 1: Experimental set-up of the EK cell

Experimental setup: The EK cell consists of an acrylic cube measuring 10 cm in length, 5 cm in width and 5 cm in height Fig. 1. Two glass tubes, 1 cm in internal diameter with electrodes were pushed into the soil sample (the distance between two tubes was 6 cm). The electrodes were made of graphite rod^[8]. However, the electrodes were replaced at every test due to degradation. The electrodes have a pin that goes out of the glass tubes and are connected to the power supply. Each glass tube was connected to a bubble tube. The bubble tube maintained the water level across the specimen constant and therefore prevented development of any external hydraulic gradient across the specimen. The bubble tube was used to replenish water that may be lost in the electrode compartment due to any electroosmotic pore fluid flow. The opened anode and cathode systems were employed in this study.

Zeta potential of peat: Electrokinetics properties were determined by microelectrophoresis^[9]. The peat samples with different organic content 48, 65 and 87% were prepared by sieving through a sieve size No. 100 (150 μ m). For each sample, a solution of 0.10 g L⁻¹ of the pretreated soil in 0.0001 M NaCl was prepared. The samples were shaken overnight at room temperature before measurements. The zeta potential was measured with a zeta-meter (Zeta-meter System 3.0+ model) as a function of pH values ranging from 2-11. All measurements were made in 0.0001 M NaCl solutions and pH adjustments were made using dilute NaOH or HCl solutions. All solutions were made up with deionized water.

Electroosmosis experiments: Initially, the peat specimens were compacted at 85% maximum (standard Proctor) dry density. Then the soil specimens were saturated in 0.0001 M NaCl-water for 3 days. Distilled water was used as anolyte and catholyte in glass tubes. The measurements were carried out via applications of constant 50V and 70V DC electrical potential for 60 min. The electroosmotic flow rate, final pH values at the anode, cathode and soil were measured. The tests were carried out in the laboratory in which the temperature was maintained constant to within $\pm 4^\circ\text{C}$. All the tests were performed at least duplicate. If the test data for the duplicated samples were different more than 15%, additional measurements were performed and the averages were taken from the test data.

RESULTS AND DISCUSSION

Zeta potential and pH: The zeta potential, ζ , for the peat sample used in this study varied from -39 mV at pH 11.5 to almost zero at pH 3 (Fig. 2). Variations in ζ with pH is probably related to the nature of electrical energy field in organic soils, the negative charge of humus is generally believed to be due to the dissociation of H^+ from functional groups. All charge on humus is strongly pH-dependent, humic acids behaving like polyprotonated weak acid. Many carboxylic groups are sufficiently acid to dissociate below pH 7 leaving a negative charge on the functional group:



Here R represents any number of organic species whose differing electronegativities alter the tendency for H^+ to dissociate. Thus the various R-COOH units dissociate at different pH values. As the pH of the system increases above 7, still weaker carboxylic groups and other very weak acids dissociate^[9,10].

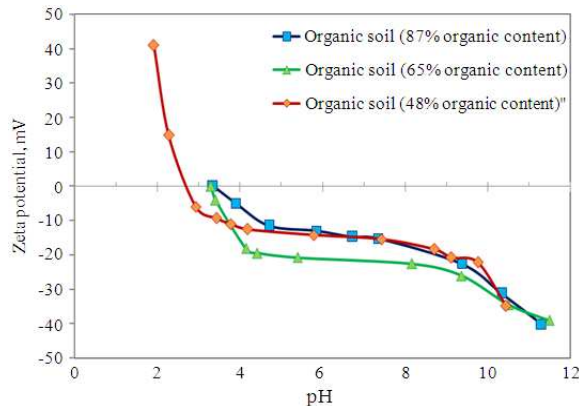


Fig. 2: Zeta potential-pH relationship

Protonated groups such as $(\text{R-OH}_2)^+$ and $(\text{R-NH}_3)^+$ may yield positive charges but the overall charge on humus remains negative. Quaternary nitrogen compounds carry positive charges which can alter the behavior of predominantly charged peat colloids^[9].

At a certain pH, the soil surface charge could drop to zero rendering a zero zeta potential or what is called the iso-electric point^[11]. The organic soils surface charge were dropped to zero at pH 2-3.5. Negative surface charge of particles (negative zeta potential) causes electroosmosis to occur from anode to cathode while positive surface charge causes electroosmosis to occur from cathode to anode^[11]. The electro-osmotic flow can virtually be eliminated at the iso-electric point. When the net charge is zero, organic soil particles in soil water will not repel each other but will tend to aggregate and form larger particles. This in turn will contribute to an increase in soil hydraulic conductivity through the soils. In contrast, negatively charged soil particles repel each other, resulting in dispersion and decrease in soil hydraulic conductivity^[12]. Figure 3 shows typical values of pH at iso-electric point of some minerals by comparison with the peat.

Zeta potential and degree of decomposition: Figure 4 indicates the correlation between zeta potential and degree of decomposition. The undecomposed organic soils were more acidic (high fibrous content), as charge in organic soil is strongly pH dependent, thus the decomposed peat had more negative charge and high zeta potential. However, not only composition and structure of soil humus is complex and incompletely known but also clay and organic fractions strictly affect on electrical properties of organic soils.

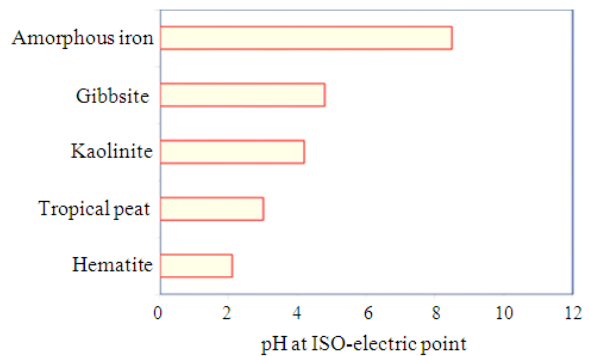


Fig. 3: Iso-electric point of organic soil in comparison with some minerals

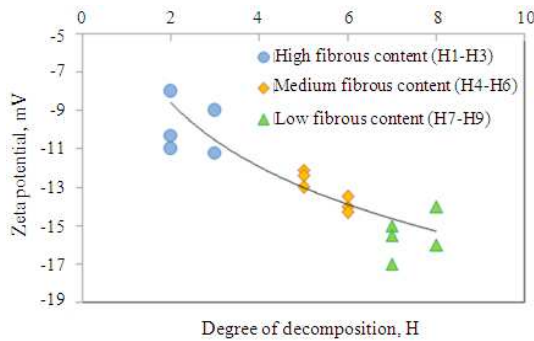


Fig. 4: Zeta potential-degree of decomposition (Van Post scale)

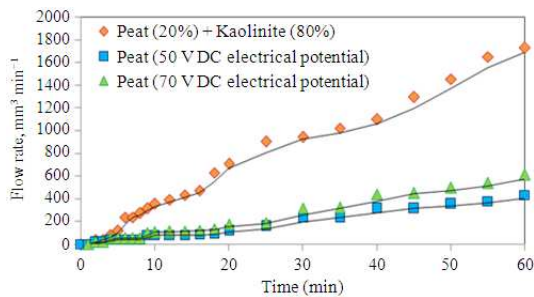
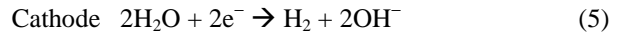
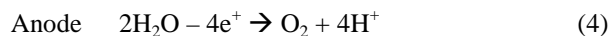


Fig. 5: Electroosmotic flow rates Vs time

Electroosmosis experiments: The cumulative electroosmotic flows in the tested organic soils were toward the cathode Fig. 5. No flow toward the anode was taking place. This is meant no changes in the sign of zeta potential of the soil occurred during the course of experiment^[13]. Figure 5 also shows the cumulative electroosmotic flows as a function of the time under various applied electric voltages in the tested peat. Increasing the flow rate that resulted from increasing the intensity of electric field can be explained by the Eq. 1, electroosmotic flow rate is proportional to the electric potential. However, further research is required to study the effect of operation time on electroosmotic flows in organic soils.

The final pH values with experimental condition of 50 V DC electrical potential at the cathode, anode and peat were 7.3, 5.2 and 5.9, respectively while the final pH values with experimental condition of 70 V DC electrical potential at the cathode, anode and peat were 7.6, 5 and 5.6, respectively. It can be explained by electrolysis of water at the anode and the cathode^[14]. Electrolysis of water produces oxygen and hydrogen which can be represented by the following equations:



While the acid generated at the anode moves through the cathode by ionic electroosmosis and ionic migration the base develops at the cathode. However, since ionic mobility of H^+ is about 1.76 times that of OH^- , as a consequence, the acid controls over the chemistry across the soil and the pH at the middle of the soil sample decreases^[15]. It is noteworthy that intensity of electrical potential is proportional with electrolysis of water at the cathode and anode.

CONCLUSION

Experiments were performed to investigate electroosmotic phenomena on organic soils. Several findings can be drawn specifically for the organic soil and peat used in this study.

- Negative charge in the organic soil is high pH dependent
- The ζ for organic soils varies from -39 mV at pH 11.5 to almost zero at pH 3
- The high peat degree of decomposition resulted in the higher zeta potential in the organic soil
- The net electroosmotic flows for the organic soil were toward the cathode. This was due to negative sign of zeta potential during EK processing
- Electroosmotic flow rate in organic soil is proportional to the intensity of electric field. The electroosmotic flow rate increase with increasing the intensity of electric field

ACKNOWLEDGMENT

Financial assistance from the Research Management Center (RMC) of University Putra Malaysia for conducting this study is gratefully acknowledged. We would like to warmly thank Professor Mohd Raihan Taha and Dr. Kamarudin Ahmad for their technical helps and fruitful discussions.

REFERENCES

1. Mitchell, J.K., 1993. Fundamental of Soil Behavior. 2nd Edn., John and Sons, New York, ISBN: 0471856401, pp: 437.
2. Asadi, A., B.K. Huat and T.A. Mohamed, 2007. Electrokinetic and its applications in geotechnical and environmental engineering. Proceedings of the Congress on World Engineering, Aug. 5-9, Penang, Malaysia, pp: 1-7. <http://eng.upm.edu.my/wec2007/congressprogram me.pdf>

3. Huat, B.K., 2004. Organic and Peat Soils Engineering. University Putra Malaysia Press, Serdang.
4. Huat, B.K., S. Maail and T.A. Mohamed, 2005. Effect of chemical admixtures on the engineering properties of tropical peat soils. *Am. J. Applied Sci.*, 2: 1113-1120.
<http://www.scipub.org/fulltext/ajas/ajas271113-1120.pdf>
5. Duraisamy, Y., B.K. Huat and A.A. Aziz, 2007. Compressibility behavior of tropical peat reinforced with cement columns. *Am. J. Applied Sci.*, 4: 786-791.
<http://www.scipub.org/fulltext/ajas/ajas410786-791.pdf>
6. Hunter, R.J., 1981. Zeta Potential in Colloid Science. Academic Press, New York, ISBN: 10: 0123619602, pp: 386.
7. Das, M.B., 2008. Advanced Soil Mechanics. 3rd Edn., Routledge, New York, ISBN: 0415420261, pp: 567.
8. Alshawabkeh, A., T. Sheahan and X. Wu, 2004. Coupling of electrochemical and mechanical processes in soils under DC fields. *Mech. Mater.*, 36: 453-465. DOI: 10.1016/S0167-6636(03)00071-1
9. Fuchsman, C.H., 1986. Peat and Water. Springer, ISBN: 1851660097, pp: 374.
10. Ahluwalia, V.K. and R.K. Parashar, 2006. Organic Chemistry. Vinod Vasishtha, New Delhi.
11. Ahmad, K., K.A. Kassim and M.R. Taha, 2006. Electroosmotic flows and electromigrations during electrokinetic processing of tropical residual soil. *Malaysian J. Civil Eng.*, 18: 74-88.
12. Fang, H.Y. and J.L. Daniels, 2006. Introductory Geotechnical Engineering: An Environmental Perspective. 1st Edn., Taylor and Francis, London and New York, ISBN: 10: 0415304016, pp: 546.
13. Karim, B., F.C. Teddy, D. Andre, B. Yves and D. Patrick, 2005. Role of pH in electro-osmosis: Experimental study on NaCl-water saturated kaolinite. *Transport Porous Media*, 61: 93-107. DOI: 10.1007/s11242-004-6798-9
14. Beddiar, K., T.F. Chong, A. Dupas, Y. Berthaud and P. Dangla, 2005. Role of pH in electro-osmosis: Experimental study on NaCl-water saturated kaolinite. *Transport Porous Media*, 61: 93-107.
<http://cat.inist.fr/?aModele=afficheN&cpsidt=16747584>
15. Ahmad, K., K.A. Kassim and M.R. Taha, 2005. Influence of electrokinetic processing of tropical soils on the pHs of electrolytes. *J. Kejuruteraan Awam*, 17: 39-48.
http://web.utm.my/ipasa/images/stories/MJCE/2005/vol_17_no_1/Influence%20of%20Electrokinetic%20Processing%20of%20Tropical%20Soils%20on%20the%20pHs%20of%20the%20Electrolytes.pdf

Effect of Environmental Comfort Factors in Enclosed Transitional Space toward Work Productivity

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Abstract: Problem statement: The investigated area in this study was the enclosed lift lobby, which distinguishes itself as a unique form of region categorized under building transitional spaces. Such region may act upon on the work performance of occupants, as occupants are sensitive towards the conditions of immediate surroundings. The objective of this study was to investigate the occupants' perceptions of environmental comfort in the enclosed transitional region with identification of current thermal, visual and acoustic conditions, as well as the effect of the environmental conditions towards work performance. **Approach:** This survey was performed using both objective and subjective assessments, where comfort related parameters were measured using electronic sensors and the outcomes were analyzed concurrently with results from questionnaire. **Results:** The results showed that thermal comfort prevails over other two parameters in defining human comfort in the enclosed building area and presumed by most respondents to have more significant impact on work performance. Besides, the environmental factors of the enclosed transitional space exert different level of influences towards work productivity of building occupants. **Conclusion:** It was necessary to maintain the environmental conditions in the enclosed transitional space, similar to the commonly occupied areas within a building. Further investigation on the individual behavior of occupants in the enclosed region of a building was suggested.

Key words: Enclosed transitional space, thermal comfort, visual comfort, acoustic comfort, work performance

INTRODUCTION

Environment comfort comprises of four research fields: Thermal, visual, acoustic and ergonomic comfort. The environmental factors of a teaching institution itself have significant impact on the learning and teaching process^[1]. For building services designers, focuses are made on achieving thermal, visual and acoustic comfort in a built environment. To ensure permanence of a healthy environment and productivity for occupants, conditions of indoor environment must be adjusted to ensure environmental comforts^[2,3]. Transitional spaces are defined as the architectural area situated between the outdoor and indoor environments and acting as both buffer spaces. Some of the examples are lift lobby, foyer, passageway as well as other ancillary spaces not directly occupied by occupants in relation to activity of buildings^[4,5]. Also, these spaces are referred as the parts of buildings where have close links to the external environment and conditions in such

areas may be perceived differently compared to commonly occupied rooms^[6]. Some thermal comfort studies had been directed to the transitional spaces^[7,8]. The current thermal comfort standards such as ASHRAE Standard 55^[9] and ISO 7730^[10] do not distinctly specify the thermal comfort requirements in the transitional spaces^[11]. Due to that reason, it is essential to study the environmental comfort in transitional spaces as such areas are often occupying a substantial portion of total building space. This study attempts to evaluate the occupants' perception of thermal, visual and acoustic comfort in an enclosed transitional space of an educational institution in Malaysia by means of both objective and subjective approaches. Another objective of this study is to identify the effect of each environmental comfort conditions towards the performance of students and staffs via results gained from field survey. Besides, the comparison of the results for three comfort parameters and effect on work productivity were made in this

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study. For assessment of thermal comfort parameters, the values of air temperature, relative humidity and air flow rate were measured. The acoustic, solar heat gain and luminance level in the investigated area were recorded concurrently by using suitable measuring equipments. As for subjective assessment, questionnaire which consisted of questions related to physical environmental comforts were presented to the respondents. The outcomes of the subjective assessment were gathered and analyzed alongside with the objective measurements.

Features of enclosed transitional space: The term “enclosed transitional space” refers to regions inside a building which are not normally occupied by human, subjected to certain degree of building services requirements and not directly linked to the external environment. One of the most easily identified of such region is the enclosed lift lobby, which is known as the place where people assemble and wait for the arrival of elevators. Figure 1 shows the enclosed lift lobby in the department of mechanical and manufacturing engineering, UPM. In some cases, this region may have several features that are similar to commonly occupied spaces in a building, where activities such as setting up of sales and promotion counters, meeting point and others are being performed. For enclosed-type of lift lobby in buildings, it is available in two forms, which are classified as protected or non-protected according to local fire protection specifications. Figure 2 shows the enclosed lift lobby which is built between indoor and external environment and Fig. 3 shows position of the lift lobby bounded within interior environment. These two forms of lift lobby are widely found in the tropical high-rise buildings. Referring to by-law 124 of the Uniform Building by-laws^[12], enclosed lift lobbies in Malaysia must be equipped with smoke detectors. Both protected and non-protected lift lobbies are sharing a similar requirement in cooling, where thermal environment in such areas should be controlled by mechanical means. In some of the transitional spaces, improving indoor environment via natural ventilation is encouraged^[13], but it is not practical to be applied in the enclosed lift lobby as possible effect on functionality of detectors which leads to interruption of fire fighting system may occur. Besides providing cooling sensation to the user of elevators, the air conditioning system in the lift lobby also serves as an apparatus to allow for air-change with the external environment. Artificial lighting is also required in such enclosed region to comply with the requirements of MS 1525: 2007.

Environmental factors of the transitional area could have substantial effect towards sensation of occupants.



Fig. 1: Enclosed lift lobby of the department of mechanical and manufacturing engineering, UPM

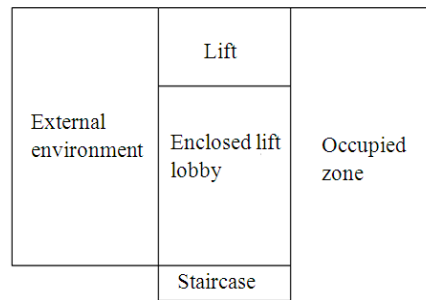


Fig. 2: Enclosed lift lobby connecting outdoor and indoor environment

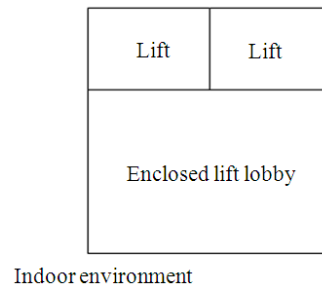


Fig. 3: Enclosed lift lobby bounded within indoor environment

This is due to the fact that human body is very sensitive towards changes in surrounding temperature and air flow rate^[14]. Also, acoustic and illuminance level in a particular space may have considerable influence towards human comfort^[1]. By that means, the work performance of building occupants may be affected due to the environmentally discomfort in the enclosed transitional space, as effect from immediate displeasing experience may last for a particular period of time. On

behalf of that reason, the necessity of investigating the effect of each environmental comfort parameter towards work productivity is required as under most circumstances poor work performance may result in severe consequences.

MATERIALS AND METHODS

A field assessment was performed at the enclosed lift lobby of the Department of Mechanical and Manufacturing Engineering, University of Putra Malaysia (UPM) which is also a part of the administration building for a period of 4 months, from August to November 2008. This building has a total of 7 floors in which every floor has its own lift lobby. The enclosed lift lobbies have common dimensions of 7.94 m in length, 3.16 m in width and 2.7 m in height and not linked to the external environment. Ceiling type centralized air-conditioning split units are installed in the lift lobbies to provide cooling and dehumidification of indoor air. Artificial lighting is available as well, due to local code of practice for buildings^[12]. Throughout the period of this survey, the thermostat temperature set-point of air conditioners in the lift lobbies was maintained at 26°C and natural daylight was applied without artificial means. This is to achieve energy saving purposes^[13] and to examine the comfort perceptions of occupants. In order to comply with the provisions of fire safety requirements, the windows of the enclosed lift lobby were not opened for interaction of external and indoor environment^[12]. Nearly all of the respondents entered the enclosed lift lobby from the administration offices and classrooms which were air-conditioned with temperature setting of 16-18°C, while others moved into from external environment where the temperature may exceed 30°C. Therefore, the test subjects were assumed to have experienced such changes in surrounding temperature, illuminance and acoustic level.

The results obtained from questionnaire surveys and objective measurements for thermal, visual and acoustic comfort are presented in this study. Both assessments were conducted concurrently. Pilot studies were made to obtain useful information regarding the dimensions and characteristics of the investigated area. All information obtained from the pilot studies served as guidelines for this research, such as placement of measuring devices and development of relevant questions for enclosed transitional space conditions. There were 113 individuals participated in this survey, Only subjects who had stayed in the lift lobby for more than 30 sec are invited to participate in the survey,

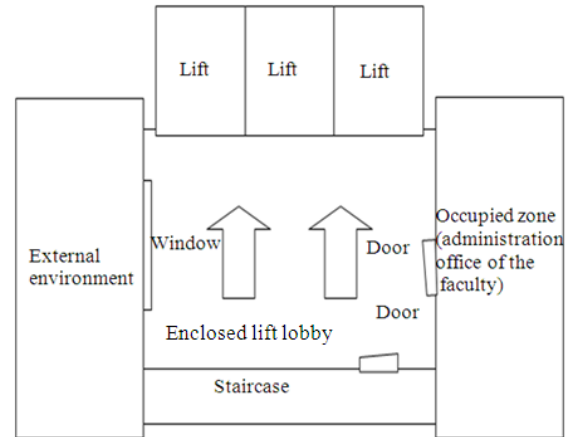


Fig. 4: Brief layout plan of investigated lift lobby

as the average waiting time for users of elevator in this area is calculated based on observation as 33 sec during peak hours, with variance of ± 17 s.

Objective measurement: The parameters of thermal, luminous and acoustic comfort were measured concurrently in this survey. For thermal environment measurements, methods and specifications of conducting field measurements are based on ASHRAE Standard 55^[9], where parameters relating to human thermal balance like air temperature, air velocity and relative humidity were measured at 1.1 m above the floor level and 1.0 m inward from the window of the enclosed lift lobby. Upon observation made on users' behavior in the lift lobby, most users occupied the two regions in between lift entrances, which are in front of lift control panels as indicated by block-arrows in Fig. 4 which is near to the measuring point. Air temperature was measured using electronic temperature sensor connected to the data logger. A precision digital-thermometer was employed to measure the relative humidity. For determining the rate of air flow, a thermo-anemometer with low friction vane probe attached was used.

Identification of luminance and acoustic levels are essential in environmental comfort studies. In this study, as natural daylight is available and being applied in the enclosed lift lobby, a digital luxmeter was applied as it is a suitable apparatus in checking and measurement of luminance level in the built environment. For measurements of acoustic level in this survey, a precision digital sound level meter which able to measure within range of 30-130 dB was applied. All the electronic sensors applied are as shown in Fig. 5. The indoor environment was continuously measured and recorded from 9.00 am-5.00 pm for each day of the survey and all data were transferred to the portable computer.



Fig. 5: Data logger and electronic sensors

Table 1: Rating scale for the subjective measurements

ASHRAE scale	Work performance	Acoustic level	Luminance level	Acceptability vote	McIntyre scale
-3 cold	Not at all	Quiet	Dim	Acceptable	Warmer
-2 cool	Fairly	Somewhat	Less bright	Unacceptable	No change
-1 slightly cool	Much	Noisy	Bright		Cooler
0 neutral			Very bright		
+1 slightly warm					
+2 warm					
+3 hot					

Subjective assessment - questionnaire surveys: To gain users' perceptions of environmental comfort, subjective assessment which applying questionnaire surveys were performed. The questionnaire consists of several sections, where the first part is the subjective ratings on a variety of thermal scales and questions of human preferences towards thermal comfort, as shown in Table 1. In addition, the effect of thermal sensation towards work productivity of staff and student of an educational institution was investigated in the field survey. The following parts of the questionnaire require participants to note down their perceptions on lighting intensity and acoustic level and possible effect on their work performance in the university. Several technical terms were translated into the Malay language to allow a better understanding for the respondents regarding the contents in the questionnaire.

In later sections of the questionnaire, test subjects were required to note down their respective demographics which included gender, age, height, weight, clothing, footwear, data and time when they were being interviewed and finally acquired their opinions on the environmental conditions of enclosed lift lobby which are not covered in the questionnaire.

RESULTS

Thermal comfort evaluation in enclosed lift lobby: The measured values of thermal comfort parameters are

as shown in Table 2. During this survey being conducted, two recruitment activities for new members from local students' organizations were being organized on 10-Oct and 17-Oct of year 2008, which was simultaneous with the field assessment in the enclosed lift lobby. The air temperature as measured was within 23-32°C, with mean value of 28.1°C. The range of relative humidity in the lift lobby was within 63 and 78 and with the mean value of 72.6. As for indoor air velocity, the measured value was from 0.1-0.20 and mean value of 0.15 m sec⁻¹ received. An equation derived by ASHRAE Handbook-Fundamentals^[15] is used for calculation of mean radiant temperature. These parameters were recorded with the purpose of determining the operative temperature of the investigated area. In some occasions, the maximum value of operative temperature in the lift lobby rise above 30°C, which exceeded the upper limit of the acceptable operative temperature range, recommended by ASHRAE standard 55^[9]. Similar to other tropical countries, the highest indoor air temperatures attained in a particular day are within 11 am-2 pm.

ASHRAE scale of thermal sensation was applied with presumption of people finding their thermal environment acceptable if they place their votes within the three central categories (-1. 0. 1). From the data obtained from field survey, it is identified that most of the subjects found the thermal environment acceptable for them. Referring to Fig. 6, 72% of the subjects were feeling comfortable with their thermal environment. Besides, 14% of the respondents indicated that the surrounding was too warm and only 6% of them felt 'cool' or 'cold' during the survey. From the thermal acceptability vote, 80% of the respondents were pleased with the thermal environment, while the remaining of them found the conditions unacceptable. An 8% difference is identified between the acceptability vote and sensation vote, as some of the respondents who voted their thermal perception as "cold" expressed that such thermal environment is acceptable for them. From the results, it is clearly shown that a high percentage of respondents preferred to be cooler in the lift lobby, where 58% of them claimed such. 36% of the subjects indicated that changes in thermal environment are not required, whereas only 6% of them stated that they prefer to be warmer.

Thermal sensation and work productivity: The main purpose of performing this portion of study was to figure out the possible influence of extreme thermal conditions in the lift lobby for the study performance of occupants. The respondents were required to note down their personal view on how greatly the extreme climatic

Table 2: Thermal comfort parameters and operative temperature

Date (08)	T _{op} (°C)	Thermal sensation vote							Thermal preference vote			Thermal acceptability vote	
		-3	-2	-1	0	1	2	3	Warmer	No change	Cooler	Acceptable	Unacceptable
17-Aug	27.34	0	1	2	5	0	1	0	2	3	4	9	0
13-Sep	27.31	0	0	3	2	2	0	1	0	4	4	7	1
21-Sep	27.95	2	1	2	5	2	0	0	1	8	3	12	0
10-Oct	28.01	0	0	3	4	8	4	3	1	6	15	17	5
11-Oct	27.80	0	1	2	5	2	0	1	0	6	5	9	2
17-Oct	27.66	0	0	2	7	11	8	3	1	5	25	18	13
3-Nov	26.66	0	1	0	3	3	2	0	0	3	6	8	1
4-Nov	25.89	1	1	4	1	3	1	0	1	6	4	10	1

T_{op}: Operative temperature

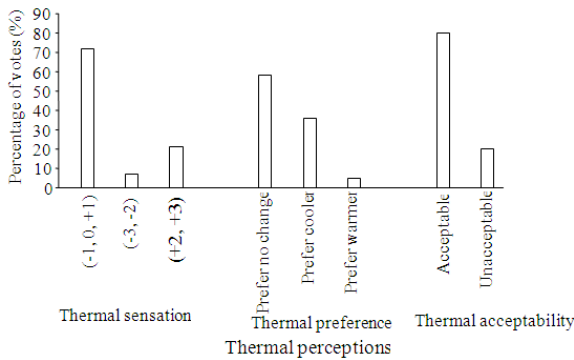


Fig. 6: Distribution of subjective thermal perceptions vote

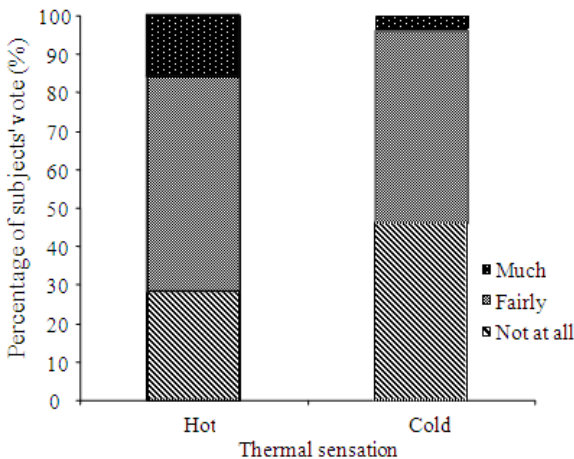


Fig. 7: Thermal sensation and work productivity

conditions may affect their emotions and work productivity. Referring to Fig. 7, higher number of respondents regarded cold environment would not have any effect on their emotions as compared to hot environment, where 45% of them claimed such. In this survey, 72% of the respondents considered hotter environment to cause disturbance in their work

efficiency. The percentage of respondents stated hot atmosphere may cause much discomfort to them is about 12% higher than similar effect from colder one. In general, absolute majority of the test subjects which constituted an average of 63% stated the thermal environment has certain level of impact on their work performance.

Visual comfort evaluation in enclosed lift lobby: The luminance factor in a building could have significant effect on human comfort, although it is not as easily sensed by the occupants as compared to thermal conditions. Referring to field survey performed by Steward^[19], visual comfort may have certain level of influence towards general comfort of students and amount of daylight as a possible influence upon behavior was notified. Natural lighting is available via windows in the location being surveyed, as solar emission into buildings is normally encountered in the tropical countries^[20]. The enclosed lift lobby is installed with artificial lighting, as required by local building standards. Throughout this survey, only natural lighting from external environment was being applied and measured. This is to reduce the energy consumption as operation of artificial light may increase required cooling load^[21] and to investigate the sufficiency of daylight towards providing comfortable environment to the occupants. There were no shading devices such as blinds or curtains for the windows.

Table 3 shows the results obtained from field survey. The illuminance (Lux) level measured was within the range of 87-255, with a total averaged value of 165. This value is higher than the recommended average illuminance levels by MS 1525: 2007^[13], where 100 lux level is suggested for entrance hall, lobbies and waiting room. From Fig. 8, the acceptability rate of respondents to the current illuminance environment is found to be 64%. Slight majority of the respondents preferred to have lower illuminance level in the enclosed lift lobby during the survey being performed.

Table 3: Visual comfort parameters and illuminance (lux) level

Date (08)	Avg lux level	Highest lux level	Lowest lux level	Luminous response vote			Luminous preference vote			Luminous acceptability vote		
				Dim	Less bright	Bright	Very bright	Darker	No change	Brighter	Acceptable	Unacceptable
17-Aug	177	230	97	0	4	5	0	6	1	2	7	2
13-Sep	151	219	92	0	1	7	0	2	0	6	2	6
21-Sep	163	238	89	2	3	7	0	3	2	7	5	7
10-Oct	176	243	97	0	8	14	0	12	2	8	14	8
11-Oct	165	252	91	1	2	8	0	8	0	3	8	3
17-Oct	173	242	93	0	16	14	1	13	6	12	19	12
3-Nov	167	255	87	0	5	4	0	6	2	1	8	1
4-Nov	157	231	93	1	3	7	0	8	0	3	8	3

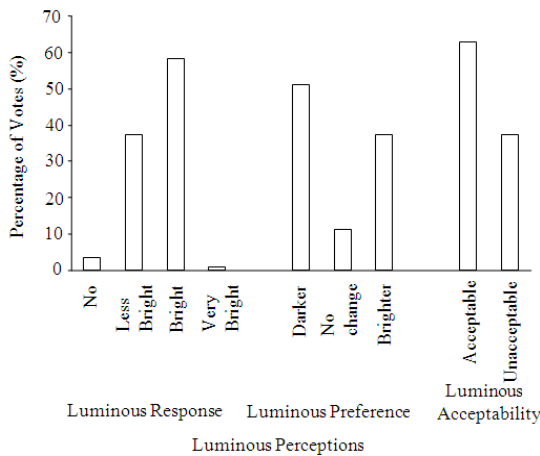


Fig. 8: Distribution of subjective luminous perceptions vote

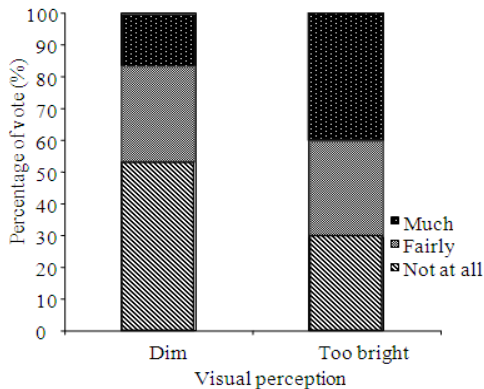


Fig. 9: Visual perception and effect on work productivity

As luminous comfort without artificial lighting is often based on the brightness of environment and emission from external daylight^[20], the luminous acceptability of respondents was based on the preference vote, where subjects who prefer darker and no-change to the existing environment were termed to be satisfied.

Visual perception and work productivity: A large portion of the respondents expressed that the perceived unsatisfactory luminance level in the enclosed region may have significant effect on their emotions and work productivity, even though most of them may not stay in the area for long. An average value of 59% was obtained for respondents who considered the luminance conditions in the enclosed transitional space may affect their work efficiency. As comparing the conditions of “too dark” and “too bright” in the investigated area, most of the respondents stated that the darker environment may not have any notable effect on their work productivity, as shown in Fig. 9. Conversely, 71% of the respondents marked in their questionnaires that an environment with higher illuminance level may have remarkable influence on their working performance and majority of them who claimed such selected that influence towards their work productivity as “much”.

Acoustical comfort evaluation in enclosed lift lobby: Noise is often being defined as unwanted sound. For educational institution, the acoustic comfort is one of the important factors in ensuring proper delivery of events. For measurement of acoustic related parameters, it is suggested by Kruger and Zannin^[1] that critical noise levels and the urban noise frequencies should be measured during peak hours. In this study, the critical periods for noise level as observed in the enclosed lift lobby were before office hours (7.30-8.00 am), during lunch hours (12.00-2.00 pm) and after office hours (5.30-6.00 pm). The focuses were placed on the two former periods during the survey being conducted, as consideration on acoustic comfort for human exiting the working place was not applicable in this study.

The acoustical level in the built environment is difficult to be improved without large sum of funds, as the improvement may required some level of building re-construction and introduction of sound insulation materials. Besides, the external sources which are able to create changes in acoustical level in the transitional space are often difficult to be controlled.

Table 4: Acoustical comfort parameters, sound pressure level (dBA)

Date (08)	Lowest dB (A)	Highest dB (A)	Mean Sound Level	Acoustical reception vote			Acoustical acceptability vote	
				Quiet	Somewhat	Noisy	Acceptable	Unacceptable
17-Aug	43.4	67.5	45.93	7	2	0	9	0
13-Sep	43.3	66.8	45.33	6	2	0	8	0
21-Sep	42.9	67.5	46.52	5	7	0	12	0
10-Oct	43.6	68.4	47.35	10	8	4	18	4
11-Oct	43.4	67.9	47.04	7	4	0	10	1
17-Oct	43.0	69.2	48.55	15	13	3	25	6
3-Nov	43.1	68.3	45.60	6	3	0	9	0
4-Nov	42.9	68.6	45.71	7	3	1	10	1

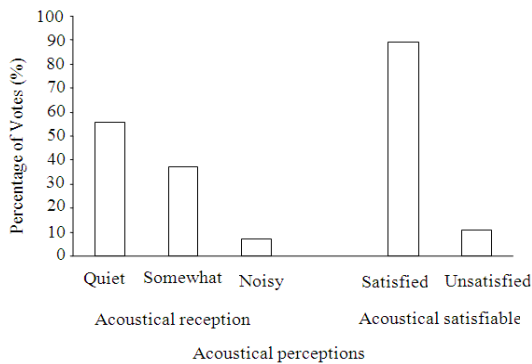


Fig. 10: Distribution of subjective acoustical perceptions vote

As the region being surveyed is a protected area according to UBBL: 1984, changes to the acoustic level are impractical and preference towards desirable acoustic conditions is not to be taken into account. Koenigsberger *et al.*^[25] affirmed that noise control in the tropics is impractical and noted the conflict between thermal and aural requirements especially in tropical climatic conditions due to lightweight construction of buildings. The results obtained from field survey are as shown in Table 4.

For objective measurement, the mean equivalent noise level which signifies the average value of the resultant noise levels obtained from sound level measurement was determined in daily basis. The mean pressure noise levels were calculated based on the equivalent noise level measured. The range of the measured sound level was between 40-70 dBA and the mean values within range of 45-51 dBA were obtained in each respective day of the survey being conducted. These values are within the recommended range of 45-55 dBA according to ARI Standard 885: 1998^[26] for such area. Most of the time, the sound pressure level did not exceed 45 dBA except when the alert bell for elevators rang or when heavy vehicles passed by. It is to be remarked that the difference in noise level in about 3 dBA creates no significant influence on acoustic receptions.

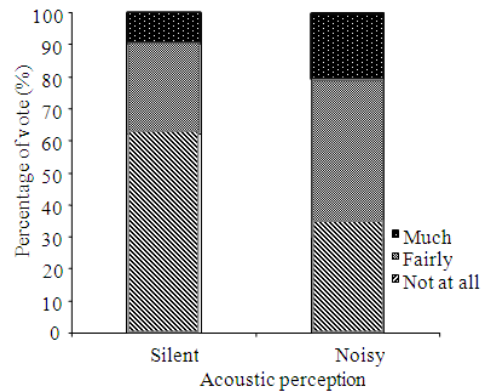


Fig. 11: Acoustical perception and effect on work productivity

The results from field survey are as shown in Fig. 10. It is found that 56% of the respondents termed the acoustic condition as “Quiet” and only a handful of them selected the opposed option. Besides, it is observed that human occupancy level in the enclosed lift lobby has certain degree of influence on the perception of acoustic comfort, in which some respondents termed the surrounding as “Noisy” during 10 and 17 October.

Acoustical effect towards work productivity: From the outcomes obtained from field assessments, most of the respondents stated that the acoustical conditions of the enclosed transitional space plays some influences towards their ability in performing their respective tasks. This is agreeable to the results of survey conducted in regions which are commonly occupied by people, where noise level and stress factor of occupants are correlated^[27]. It is distinctly shown in Fig. 11 that a good number of the respondents declared work performance will not be affected by any means if the surrounding is silent, which doubled as compared to number of votes for noisy environment. Meanwhile, it is identified in this survey that most of the people find noisy environment annoyed as such condition may

affect the work performance of about 72% of them. During this survey being conducted, some of the respondents entered the investigated region during peak hours and termed the immediate acoustical surrounding to have more significant influence than people engaged throughout other periods. Based on Fig. 11, an average of 53% of the test subjects alleged that the acoustic level in the enclosed transitional space may act as an important factor in determining their effectiveness in working and studying.

DISCUSSION

Thermal comfort assessment: In this survey, a self-contradictory phenomenon was discovered as a significant number of subjects voted on the utmost point of the thermal sensation scale, but rated their perceptions as comfortable. More over, some of the respondents stated that the thermal environment is acceptable to them, but preferred to be cooler/warmer in the thermal preference scale. These findings reflect the research done by Feriadi and Wong^[16], where people in the hot and humid climate generally prefer cooler environmental condition. As shown in Table 2, the respondents' thermal sensation move towards the warmer side as number of occupants increased in the enclosed lift lobby. This shows that the human occupancy level in the enclosed transitional region is one of the major elements which greatly affect thermal comfort perception of occupants. This is mostly due to the amount of heat generated by human body^[17], which in certain extent causes a rise in internal temperature of the lift lobby during survey being performed. Besides, some underlying factors which possibly contributed to this phenomenon, such as perception of human in crowded places and personal fondness within a building were encountered during the survey being conducted. These findings reveal that people in the tropics are generally more tolerant towards cooler surroundings than the opposed condition and the work of Wong and Khoo^[18] in tropical classrooms showed similar results in thermal preference. Besides, thermal comfort plays a more significant role in defining general human comfort as compared to other environmental factors. This has proposed the importance of air conditioners in controlling temperature within the enclosed transitional spaces. A concealed fact that leads to excessive usage of air conditioning system in the transitional spaces of the tropical educational institutions is revealed and an opportunity for energy efficiency for such facility may be looked into in the future.

Visual comfort assessment: A noteworthy occurrence discovered in this survey was a portion of respondents

whom did not feel comfortable with the "bright" environment of the enclosed lift lobby and preferred to have darker surroundings. This proves that not only insufficient lighting may have deleterious effect on human comfort in buildings^[22], but excessive natural lighting as well. Meanwhile, another fact pointed from this result was natural daylight is sufficient in providing visually comfortable environment to most of the occupants of educational building while this survey being conducted. The higher percentage of subjects' vote on preferring darker environment indicated that luminance level in the enclosed transitional space is to be controlled. The work of Li *et al.*^[23] suggested control of luminance level may be made via shading devices, glazing or by other means in high illuminance area to provide a better thermally and visually comfortable environment.

High luminance level in indoor environment is found to be undesirable by some respondents. Such phenomenon is partly due to the high luminance level at the external environment, which is common for tropical countries^[24]. People who entered an indoor space from external environment may presume that gloomier surroundings are more visually comfortable for them. Besides, another cause for obtaining these results is due to higher number of participants who joined the survey during lunch hour (12 am-2 pm) and outdoor solar emission into the building was extremely high. As the visual environment may induce some effect on work performance, glazing materials are to be introduced to the fenestrations available for improvement and sustainability of human visual comfort in the enclosed transitional area^[23]. This finding proves to be a useful guide for energy efficiency purpose in tropical buildings, as operation of artificial lighting is not required during certain period of a day.

Acoustical comfort assessment: External sources may act upon on acoustic comfort of human-beings^[28], but did not pose as significantly in the enclosed transitional space. Differ from the commonly occupied region; the most possible factor which may cause changes in acoustic level is the human occupancy. This is evidenced in Table 4, where the environment was termed by more respondents as "Noisy" when the number of occupants increased.

A number of respondents also felt slightly disturbed acoustically during peak hours. Also, external sources such as vehicles' sound which penetrated the wall and windows in the transitional space, does not affect the respondents much in terms of acoustic comfort. This has suggested that people passing through the transitional space in a building generally pay less

attention to the acoustical condition as compared to other environmental factors. Similar results were obtained from survey conducted in the occupied zones, where the work of Chew *et al.*^[27] suggested that correlation between noise level and stress factors is generally lower as compared to lighting level and work size area. The percentage of influence for acoustical comfort is comparatively lower than the results for thermal and visual comfort, as people tend to place less focus on the sound level of their surroundings. Thus, it can be concluded that the importance of acoustic comfort in defining total comfort is less significant compared to other comfort parameters. Some other efforts can be made to control the acoustic level due to human occupancy in the enclosed lift lobby, similar to the thermal environment.

CONCLUSION

Field survey was conducted in the enclosed lift lobby of a higher educational institution to investigate the environmental comfort perceptions of occupants and consequences of each environmental comfort factors towards work performance. The environmental environment of the enclosed transitional space is equally important as the normally occupied spaces in an educational building, as some activities which require human occupation are occasionally being carried out in such area. The findings prove that although people do not stay in the transitional space for long, the environmental conditions do exert a certain level of effect towards work productivity. It is identified in this survey that thermal comfort prevails over other comfort parameters in defining significance of effect towards occupants' work performance in the enclosed region, as percentage of presuming influence for thermal, visual and acoustic comfort is 64, 59 and 53% respectively. Hence, more focus can be given to sustain thermal comfort of travelers in the enclosed transitional spaces as it also forms a better opportunity in energy efficiency. Besides, from the analyzed results, it is proven that the thermal and acoustic comfort in the transitional space is directly proportional to the level of human occupancy per period of time, while visual comfort is not affected with similar event. For this reason, good employee management system can be proposed to control the level of human occupancy in the lift lobby. The air conditioner temperature setting of 26°C and natural daylight are able to provide most of the occupants with a comfortable surrounding, without much interference towards their work performance.

Further studies are recommended on determining the individual perceptions of environmental comforts

and more information can be gathered to provide a more statistically significant results. Besides, similar work may be performed at other building transitional spaces with different features and usages to investigate the effect of environmental conditions on emotions of occupants.

ACKNOWLEDGEMENT

The author would like to thank the Institute of Advanced Technology, University of Putra Malaysia and the FRGS fund for the financial support provided.

REFERENCES

1. Kruger, E.L. and P.H.T. Zannin, 2004. Acoustic, thermal and luminous comfort in classrooms. *J. Build. Environ.*, 39: 1055-1063. DOI: 10.1016/j.buildenv.2004.01.030
2. Oral, G.K., A.K. Yener and N.T. Bayazit, 2004. Building envelope design with the objective to ensure thermal, visual and acoustic comfort conditions. *J. Build. Environ.*, 39: 281-287. DOI: 10.1016/S0360-1323(03)00141-0
3. Srinavin, K. and S. Mohamed, 2003. Thermal environment and construction workers' productivity: Some evidence from Thailand. *J. Build. Environ.*, 38: 339-345. DOI: 10.1016/S0360-1323(02)00067-7
4. Chun, C. and A. Tamura, 2005. Thermal comfort in urban transitional spaces. *J. Build. Environ.*, 40: 633-639. DOI: 10.1016/j.buildenv.2004.08.001
5. Pitts, A. and J. Saleh, 2007. Potential for energy saving in building transition spaces. *J. Energ. Build.*, 39: 815-822. DOI: 10.1016/j.enbuild.2007.02.006
6. Pitts, A. and J. Saleh, 2006. Transitional space and thermal comfort-opportunities for optimizing energy use. *Proceeding of the 23th Conference on Passive and Low Energy Architecture*, Sep. 6-8, Geneva, Switzerland, pp: 1-6. http://www.unige.ch/cuepe/html/plea2006/Vol1/PL_EA2006_PAPER740.pdf
7. Jitkhajornwanich, K. and A. Pitts, 2002. Interpretation of thermal responses of four subject groups in transitional spaces of buildings in Bangkok. *J. Build. Environ.*, 37: 1193-1204. DOI: 10.1016/S0360-1323(01)00088-9
8. Hwang, R.L., K.H. Yang, P.C. Chen and S.T. Wang, 2008. Subjective responses and comfort reception in transitional spaces for guests versus staff. *J. Build. Environ.*, 43: 2013-2021. DOI: 10.1016/J.Buildenv.2007.12.004

9. American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2004. ASHRAE Standard 55. Thermal Environment Conditions for Human Occupancy. American Society of Heating, Ventilating and Air-Conditioning Engineers, Inc.
10. ISO Standard 7730, 1994. Moderate thermal environment-Determination of the PMV and PPD indices and specification of the conditions for thermal comfort. International Organization for Standardization. ICS: 13.180
11. Chun, C., A. Kwok and A. Tamura, 2004. Thermal comfort in transitional spaces-basic concepts: Literature review and trial measurement. *J. Build. Environ.*, 39: 1187-1192. DOI: 10.1016/J.BUILDENV.2004.02.003
12. Uniform Building By-Law (UBBL), 1984. Legal Research Board, International Law Book Services. ISBN: 967-89-1579-0
13. Malaysian Standard, MS 1525, 2007. Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings. Department of Standards Malaysia. ICS: 91.040.01
14. Hwang, R.L., T.P. Lin and N.J. Kuo, 2006. Field experiments on thermal comfort in campus classrooms in Taiwan. *J. Energ. Build.*, 38: 53-62. DOI: 10.1016/J.ENBUILD.2005.05.001
15. American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2001. "Thermal Comfort" ASHRAE Handbook-Fundamentals. American Society of Heating, Refrigerating and Air-Conditioning Engineers.
16. Feriadi, H. and N.H. Wong, 2004. Thermal comfort for naturally ventilated houses in Indonesia. *J. Energ. Build.*, 36: 614-626. DOI: 10.1016/J.ENBUILD.2004.01.011
17. Colon, J.A., R.G. Montañez and H.P. Santiago, 2004. Biomass transfer in the human body system. Proceeding of the Congress on Biofluid Dynamics of Human Body Systems at University of Puerto Rico, July 10-10, Mayaguez, 1-30. <http://academic.uprm.edu/~mgoyal/fluidsJuly2004/biomass2004.pdf>
18. Wong, N.H. and S.S. Khoo, 2003. Thermal comfort in classrooms in the tropics. *J. Energ. Build.*, 35: 337-351. DOI: 10.1016/S0378-7788(02)00109-3
19. Stewart, D.M., 1981. Attitude of school children to daylight and fenestration. *J. Build. Environ.*, 16: 267-277. DOI: 10.1016/0360-1323(81)90005-6
20. Chaiyapinunt, S., B. Phueakphongsuriya, K. Mongkornsaksit and N. Khomporn, 2005. Performance rating of glass windows and glass windows with films in aspect of thermal comfort and heat transmission. *J. Energ. Build.*, 37: 725-738. DOI: 10.1016/J.ENBUILD.2004.10.008
21. Ahmed, Z., K. Sopian, M.Y.H. Othman, A.A.M. Sayigh and P.N. Surendran, 2002. Daylight as a passive solar design strategy in tropical buildings: A case study of Malaysia. *J. Energ. Convers. Manage.*, 43: 1725-1736. DOI: 10.1016/S0196-8904(01)00007-3
22. Heerwagen, J., 1990. Affective functioning, 'light hunger,' and room brightness preferences. *J. Environ. Behav.*, 22: 608-635. DOI: 10.1177/0013916590225003
23. Li, D.H.W., T.N.T. Lam, S.L. Wong and E.K.W. Tsang, 2007. Lighting and cooling energy consumption in an open-plan office using solar film coating. *J. Energ.*, 33: 1288-1297. DOI:10.1016/J.ENERGY.2008.03.002
24. Edmonds, I.R. and P.J. Greenup, 2002. Daylighting in the tropics. *J. Solar Energ.*, 73: 111-121. DOI: 10.1016/S0038-092X(02)00039-7
25. Koenigsberger, O.H., T.G. Ingersoll, A. Mathews and S.V. Szoklay, 1973. Manual of Tropical Housing and Building, Part One: Climatic Design, Longman, London. ISBN: 0582445450
26. Air-Conditioning and Refrigeration Institute, ARI Standard 885, 1998. Procedure for Estimating Occupied Space Sound Levels in the Application of Air Terminals and Air Outlets. Air-Conditioning and Refrigeration Institute. www.krueger-hvac.com/lit/pdf/885-98.pdf
27. Chew, K.W., W.C. Poon and M.F.A. Rahim, 2006. Working environment and stress: A survey on Malaysian employees in commercial banks. <http://mgv.mim.edu.my/mmr/0606/060603.htm>
28. Environmental Australia, 1998. Noise, Vibration and Airblast Control: Best practice environmental management in mining. http://www.natural-resources.org/minerals/cd/ea_noise.htm

Analysis of Some Pesticide Residues in Cauliflower by High Performance Liquid Chromatography

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Abstract: Problem statement: Increased use of chemicals on vegetables started gaining momentum and continued its up-trend in Bangladesh. Wide spread use of pesticides in agriculture concern of residue accumulation, which may remain in food and agricultural environment causing concern of human health and risking ecological balance. Attempt made to ensure that their applications were correct and safe and result in no residues in food beyond codex developed maximum residue limits. **Approach:** This study reported a method based on High Performance Liquid Chromatography (HPLC) for determination of pesticide residues used in Cauliflower. Cauliflower sprayed with, 4 different pesticides (diazinon, malathion, chlorpyrifos and cypermethrin) at recommended dose and double of recommended dose were analyzed for their residual contents. Samples were collected at same day after application of pesticide. Commercial samples of cauliflowers were collected from different markets of Dhaka city. Reversed-phase HPLC system with UV detection was used for the separation, identification and quantification of all these analytes using acetonitrile-water (70:30, v/v) as mobile phase. **Results:** Limit of detection of 0.02 mg kg⁻¹ was obtained. Calibration curves that constructed for the analytes spiked into samples followed linear relationships with good correlation coefficients ($R^2 > 0.990$). In the analysis, from vegetables treated with diazinon and chlorpyrifos at recommended and double of recommended doses, residual amounts above respective MRL values were found. **Conclusion:** Method used permitted the determination of these pesticides in cauliflower at concentration level demanded by current legislation. Attention paid on excess use or abuse of pesticides by judicious application for safety of public health in Bangladesh. Additional data to monitor residues in food and to fill gaps in current knowledge would be helpful in assessing human exposure risks from ingestion of contaminated cauliflower or other vegetables.

Key words: Pesticide residues, cauliflower, high performance liquid chromatography, maximum residue limits

INTRODUCTION

Bangladesh is predominantly an agricultural country with an area of 1, 47,570 sq. km. Agriculture plays an important role in the lives of Bangladeshi people. The major crops grown in the country are rice, wheat, jute, potato, sugarcane, vegetables and tea. Cauliflower (*Brassica oleracea* var *Botrytis*) is produced in many areas of Bangladesh. The acreage of cauliflower cultivation in Bangladesh is about 9,400 ha and the annual production amounts to about 73,000 m

tons^[1]. Cauliflower is low in fat, high in dietary fiber, contains water and vitamin C, possessing a very high nutritional density. The warm and humid climatic condition of the country, increase use of modern high yielding varieties of crops and more use of chemical fertilizers are highly favorable for development and multiplication of pests and diseases. In Bangladesh context, the cauliflower growers have been using the pesticides frequently to have the higher yield. But the overdoses of pesticides make the residue problem, which might pollute our food and be harmful for our

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health. It has been reported that some of the pesticides are being used on northern part of the country where no pre-harvest time frame after application is maintained. What is most alarming is that pesticide use is very indiscriminate in Bangladesh. There are areas where pesticides are used in excessive quantities. Such situations make monitoring and assessment of pesticide contamination very difficult. Therefore, pesticide residue is becoming a major food safety concern of consumers and governments.

Although the government is concerned about pesticide residues in the food and the environment, staff and facilities to conduct the necessary monitoring programs are not available. In addition the country is not yet established legal limits for residues and depends upon Codex allowable limit which are not always proposed for all crops and major pesticides used with in the country. So in order to remove residual effect of pesticides, which are toxic, we should know the exact dose which should be recommended to the farmer and the harvest time after spray of each pesticide so that the amount of residual pesticides in vegetables might be lower than the acceptable range.

The extraction and quantitation of pesticide residues in food matrix mostly involved liquid-liquid extraction with a great variety of solvents and adsorbents for clean up. Analytical techniques such as Gas Chromatography (GC) and High Performance Liquid Chromatography (HPLC) are widely used to monitor the presence of these compounds in water, soils, foods, fruits and vegetables. Several recent papers have reported advances in this field^[2,3-8].

In the present study, a method employing HPLC with UV detection for the separation, identification and quantification of four widely used pesticides on cauliflower was developed and validated. The compounds studied were diazinon, malathion, chlorpyrifos and cypermethrin. Finally, the method was applied to the determination of these pesticides in commercial samples collected from the local markets. Therefore, the purpose of this study was to develop an analysis scheme for determination of some pesticides in cauliflower by HPLC. And this method provides accurate results for a variety of pesticides present in cauliflower.

MATERIALS AND METHODS

Sample material: Cauliflower was grown in the experimental field of Bangladesh Agricultural Research Institute (BARI). Four different areas were selected for application of 4 modern pesticides, diazinon, malathion,

chlorpyrifos and cypermethrin before harvesting the samples. The matured Cauliflower bearing plants sprayed with the recommended dose (1.7 L h^{-1}) and double of the recommended dose (3.4 L h^{-1}) were collected from the field at the same day 6 h after spraying diazinon in the field. Samples of cauliflower sprayed with the recommended dose (1.12 L h^{-1}) and double of the recommended dose (2.24 L h^{-1}) were collected from the field at the same day 6 h after spraying malathion in the field. Likewise, samples of cauliflower sprayed with chlorpyrifos at the recommended dose (0.25 L h^{-1}) and double of the recommended dose (0.5 L h^{-1}) and another set of samples of cauliflower treated with cypermethrin at the recommended dose (0.6 L h^{-1}) and double of the recommended dose (1.2 L h^{-1}) were collected from the field at the same day 6 h after spraying pesticide in the field. Commercial samples of cauliflower were collected from different markets of Dhaka city (Nondon, Minabazar, Agora and PQS). The analysis conducted from January 2005 to May 2005.

Chemicals and reagents: The organic solvents, acetonitrile, ethyl acetate used were HPLC grade and were purchased from E. Merck. Technical grade pesticide standards were obtained from Bangladesh Agricultural Research Institute (BARI) with a purity of 95-99%. The standards were stored in a freezer at -5°C . Ultra high quality water was obtained from Milli-Q water purification system (Millipore, Bedford, MA, USA). Milli-Q Water and acetonitrile were degassed by vacuum suction. All samples and solvents were filtered through Millipore membrane filters (Polysulfone membrane and $0.45 \mu\text{m}$ pore size) before injection on the column. Anhydrous sodium sulphate for residue analysis, 12-60 mesh, was maintained at 300°C overnight. A source of pure nitrogen was used for evaporation to dryness in the extraction step.

Standard preparation: For preparation of stock solution, standards were dissolved in acetonitrile and four levels of intermediate standard solutions of each pesticide were prepared maintaining the same matrix concentration for the preparation of calibration curve and stored at 4°C in the dark. Working solutions were prepared daily by appropriate dilution with acetonitrile.

Extraction: Edible part of each vegetable sample (75 g) was cut into small pieces and homogenized by means of a kitchen blender and kept in a freezer by wrapping with clean airtight polythene bag (zip lock) at temperature below -15°C . The blended cauliflower

sample (75 g) was mixed with anhydrous sodium sulphate (50 g) and extracted with ethyl acetate^[9] (200 mL) in a conical flask using an Ultra-Turrax (IKA-WERK) for 4-5 min. The content was allowed to settle down for about half an hour and the ethyl acetate extract was then filtered through a Buchner-funnel fitted with a filter paper covered by 20 g of anhydrous sodium sulphate. After filtration, the extract was evaporated to dryness and re-dissolved in 5 mL of acetonitrile (MeCN) and finally the volume was made up to 2 mL using rotary vacuum evaporator. The extract was then transferred to a graduated test tube and the final volume was adjusted at exactly 2 mL by adding a few drops of acetonitrile. Solutions were then centrifuged and filtered. The clean organic layers were taken and were analyzed by a high performance liquid chromatography having UV/Visible detector.

HPLC systems: A Shimadzu SCL-10AVP, Version 5.22 High performance liquid chromatography having UV/visible detector was used for identification and quantification of pesticides. Separation was performed on reversed phase C-18 column (Nova pack). Samples were injected manually through a Rheodyne injector. Detector was connected to the computer for data processing. The working condition of HPLC was binary gradient, mobile phase was acetonitrile: water; (70:30), flow rate was 1 mL min⁻¹, injection volume was 20 µL and the wavelength of the UV/visible detector was fixed at 254 nm for the residual analysis of Diazinon and 230 nm for the analysis of other three pesticides i.e., malathion, chlorpyrifos and cypermethrin.

Identification and quantification: The compound was identified by comparing its retention time with respect to technical grade reference standard. The quantitative determination was carried out with the help of a calibration curve drawn from chromatographic experiments with standard solution. For quantification an external calibration curve with four different concentrations of each pesticide, with matrix matching were made. The standard solutions for the calibration curves were prepared in control matrix because samples may possess co extractants in the matrix which may affect the peak area of the unknown samples.

Recovery: Recovery studies were performed to examine the efficacy of extraction and clean up. Untreated cauliflowers were spiked with known concentration of the pure insecticide standard solution of each type of pesticide and extraction and clean-up were performed as described earlier. The concentration of each pesticide in the final extracts was calculated.

Statistical analysis: External calibration and recovery tests were performed. The residue results were the means from three replicates of each treatment and all data's were analyzed using simple descriptive statistics such as means, standard deviations, using Kaleidagraph version 4 for windows.

RESULTS

Limit Of Detection (LOD) was calculated from the peak intensity at 0.1 mg kg⁻¹ and blank levels in recovery tests. LOD was defined as S/N>4 so that it is in the linear range of the standard calibration. The LOD of diazinon, Malathion, chlorpyrifos and cypermethrin was 0.02 mg kg⁻¹. Recoveries which were obtained by triplicate analysis of cauliflower sample spiked with each type of pesticide at one fortification level were satisfactory for residue analysis and are of the same order as those obtained by using more complicated methodologies. The percent recoveries for diazinon, malathion, chlorpyrifos and cypermethrin were 106.0, 91.0, 81.7 and 93.6, respectively. Residues were corrected according to the average of recovery. Linear calibration curves were found between peak areas and analyte concentration in the whole range studied. The linear regression (y = a+bx) parameters for method calibration are shown in Table 1. The determination coefficients (R²) of analytical curves were near 0.99, with linearity for each compound, which allows the quantitation of these compounds by the method of external standardization.

Diazinon and chlorpyrifos were detected in all samples (Table 2). It is found that diazinon was detected above Maximum Residue Limit (0.01 mg kg⁻¹ of sample)^[10] in the samples where diazinon was sprayed at the recommended dose and double of the

Table 1: Retention Times Windows (RTWs) and typical calibration parameters of the method in cauliflower matrix

Compound	RT (Min)	Calibration range (mg kg ⁻¹)	Calibration parameters		
			Slope	Intercept	R ²
Diazinon	8.1	0.066-1.46	1.3×10 ⁵	65000	0.998
Malathion	5.7	0.080-1.66	4.5×10 ⁴	43000	0.992
Chlorpyrifos	12.9	0.076-1.15	3.9×10 ⁴	54000	0.991
Cypermethrin	9.8	0.064-0.99	8.27×10 ⁴	18400	0.988

Table 2: Amounts of residues detected in cauliflower samples treated with the respective pesticide

Dose	Residue (mg kg ⁻¹)			
	Diazinon	Malathion	Chlorpyrifos	Cypermethrin
Recommended dose	1.085	ND	1.628	ND
Double of the Recommended dose	1.64	ND	2.243	ND

ND = Not detected i.e., below detection level of 0.02 mg kg⁻¹

Table 3: Amounts of residues in the four different samples of cauliflower collected from different markets area of sample

Collection	Residue (mg kg ⁻¹)			
	Diazinon	Malathion	Chlorpyrifos	Cypermethrin
Nondon	ND	ND	ND	ND
Minabazar	ND	ND	ND	ND
Agora	ND	ND	ND	ND
PQS	ND	ND	ND	ND

ND = Not detected i.e., below detection level of 0.02 mg kg⁻¹

recommended dose. The amount of the residues of diazinon at the recommended dose was 1.085 mg kg⁻¹ and the double of the recommended dose was 1.64 mg kg⁻¹. Similarly chlorpyrifos was detected above the Maximum Residue Limit (0.05 mg kg⁻¹ of sample)^[11] in the samples where chlorpyrifos was sprayed at the recommended dose and double of the recommended dose. The amount of the residues of chlorpyrifos present at the recommended dose is 1.62 mg kg⁻¹ and the double of the recommended dose is 2.243 mg kg⁻¹. According to the results, malathion and cypermethrin were not detected in the samples because they were present in the samples below our detection level (0.02 mg kg⁻¹). It is found that no pesticide residues were present in the commercial samples collected from different markets of Dhaka city (Table 3).

DISCUSSION

Diazinon may decompose in plants in two directions. One of them may be oxidation of the phosphorothioate to the corresponding phosphate (diazinon) followed by hydrolysis of the P-X bond with the formation of non toxic diethylphosphoric acid and 2-isopropyl -4-methyl-6-Oxypyrimidine and the another direction of the decomposition of diazinon may be the oxidation of the side isopropyl group of the ring with the subsequent hydrolysis of the phosphorus halogen bond with decomposition of the heterocyclic ring and the liberation of carbon dioxide gas. Diazinon is highly toxic to humans and animal. So the recommended dose which is applied by the farmer in the field to control the pests in cauliflower should be lower. Chlorpyrifos may decomposes in plants and may produce chlorpyrifos-oxon and 3, 5, 6-trichloro-2-pyridinol, which is further degraded to 3, 5, 6-trichloro-2-methoxy pyridine and carbon dioxide^[12]. Chlorpyrifos are highly toxic to human and animal. So, the recommended dose of the chlorpyrifos in cauliflower should be lower.

Traces of malathion are commonly found on regions of the plants having a high fat or lipid content.

Degradation on plants increased with moisture content. In plant's tissues, malathion may intensively hydrolyzed by phosphatases and carboxyesterases along the P-X bond and ester to form dimethyl phosphorothioic and others acids having a low toxicity. The rapid losses which occur on the plant before harvesting appear to be due to a number of factors including evaporation, chemical decomposition of surface deposits and metabolism within plant^[13]. Cypermethrin may photo degrades rapidly. After photo degradation cypermethrin may produce DCVA, 3-phenoxybenzaldehyde and 3-phenoxybenzoic acids^[14]. Cypermethrin may also subject to microbial degradation. To avoid any contamination malathion and cypermethrin sprayed cauliflower should be harvested after few days. Factors mentioned above, may contribute to increasing degradation of malathion and cypermethrin resulting on residues below detection limit.

Since the organophosphorus and pyrethroid pesticides residues are not degraded into non toxic products in short period of time. They still persisted in vegetable. So the recommended dose, which is applied by the farmer in the field to control pests in cauliflower, should be lower or pre-harvest interval should be longer.

CONCLUSION

In Bangladesh context, the Cauliflower growers have been using the pesticides frequently to have the higher and insect free yield. But the overdoses of pesticides make the residue problem, which might pollute our food and environment. Appropriate use of pesticides in agriculture needs to be addressed in Bangladesh and other countries. Although the Government is concerned about pesticide residues in the food and the environment, staff and facilities to conduct the necessary monitoring programs are not available. In addition the country is not yet established legal limits for residues and depends upon Codex allowable limit which are not always proposed for all crops and major pesticides used with in the country. So in order to remove residual effect of pesticides which are toxic, we should know the exact dose which should be recommended to the farmer and the harvest time of each pesticides so that the amount of residual pesticides in vegetables might be lower than the present time. And an attractive method was provided by this approach with detection limits at parts per million concentrations and could be extended to additional crops and pesticides.

ACKNOWLEDGEMENT

Researchers gratefully acknowledge Dr. Katsumi Ishikawa for his advice and critical reading of the Manuscript.

REFERENCES

1. Cauliflower, 2005. Banglapedia: National Encyclopedia of Bangladesh. http://banglapedia.search.com.bd/HT/C_0062.htm
2. Melo, L.F.C., C.H. Collins and I.C.S.F. Jardim, 2004. New materials for solid-phase extraction and multiclass high-performance liquid chromatographic analysis of pesticides in grapes. *J. Chromatogr. A.*, 1032: 51-58. DOI: 10.1016/J.CHROMA.2003.10.101
3. Blasco, C., G. Font and Y. Pico, 2004. Determination of dithiocarbamates and metabolites in plants by liquid chromatography-mass spectrometry. *J. Chromatogr. A.*, 1028: 267-276. DOI: 10.1016/J.CHROMA.2003.12.002
4. Singh, S.B., G.D. Foster and S.U. Khan, 2004. microwave-assisted extraction for the simultaneous determination of thiamethoxam, imidacloprid and carbendazim residues in fresh and cooked vegetable samples. *J. Agric. Food Chem.*, 52: 105-109. DOI: 10.1021/jf030358p
5. Gennaro, M.C., E. Marengo, V. Gianotti, S. Angioi and G. Copeta, 2003. Intercalibration of chromatographic methods for auxino phytochemicals in *Solanaceae*. *J. Chromatogr. A.*, 993: 111-119. DOI: 10.1016/S0021-9673(03)00332-7
6. Habib, J., I. Hofer and J.M. Renaud, 2003. Analysis of multiple pesticide residues in tobacco using pressurized liquid extraction, automated solid-phase extraction clean-up and gas chromatography-tandem mass spectrometry. *J. Chromatogr. A.*, 1020: 173-187. DOI: 10.1016/J.CHROMA.2003.08.049
7. Caballo-lopez, A. and M.D.L. De Castro, 2003. Continuous ultrasound-assisted extraction coupled to on line filtration-solid-phase extraction-column liquid chromatography-post column derivatisation-fluorescence detection for the determination of N-methyl carbamates in soil and food. *J. Chromatogr. A.*, 998: 51-59. DOI: 10.1016/S0021-9673(03)00646-0
8. Oetero, R.R. and B.C. Grande, 2003. Multiresidue method for fourteen fungicides in white grapes by liquid-liquid and solid-phase extraction followed by liquid chromatography-diode array detection. *J. Chromatogr. A.*, 992: 121-131. DOI: 10.1016/S0021-9673(03)00317-0
9. Islam, S., M.S. Hossain, N. Nahar, M. Mosihuzzaman and M.I.R. Mamun, 2009. Application of high performance liquid chromatography to the analysis of pesticide residues in Eggplants. *J. Applied Sci.*, 9: 973-977. DOI: 10.3923/jas.2009.973.977
10. MRL Status Report, 2009. Agri business systems international. <http://www.nda.agric.za/docs/Plantquality/Info%20HUB/Brassica%20Veg%20files/Cauliflower%20MRL%20Datashet.pdf>
11. FAO/WHO Standards, 2008. Pesticide residues in food. Maximum residue limits. CODEX Alimentarius. http://www.codexalimentarius.net/mrls/pestdes/jsp/pest_q-e.jsp
12. Racke, K.D., 1993. Environmental fate of chlorpyrifos. *Rev. Environ. Contam. Toxicol.*, 131: 1-154. <http://www.ncbi.nlm.nih.gov/pubmed/7678349?dopt=Abstract>
13. Kovistoinen, P., A. Karinppa and M. Kononen, 1964. Insecticide Residues, Disappearance Rates of Malathion Residues as Affected by Previous Treatments with Paraoxon, Parathion and Malathion. *J. Agric. Food Chem.*, 12: 555-557. DOI: 10.1021/jf60136a020
14. Otieno, D.A. and Gerald Pattenden, 1980. Degradation of the natural pyrethroids. *Pesticide Sci.*, 11: 270-278. DOI: 10.1002/ps.2780110220

Computable General Equilibrium Techniques for Carbon Tax Modeling

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Abstract: Problem statement: Lacking of proper environmental models environmental pollution is now a solemn problem in many developing countries particularly in Malaysia. Some empirical studies of worldwide reveal that imposition of a carbon tax significantly decreases carbon emissions and does not dramatically reduce economic growth. To our knowledge there has not been any research done to simulate the economic impact of emission control policies in Malaysia. **Approach:** Therefore this study developed an environmental computable general equilibrium model for Malaysia and investigated carbon tax policy responses in the economy applying exogenously different degrees of carbon tax into the model. Three simulations were carried out using a Malaysian social accounting matrix. **Results:** The carbon tax policy illustrated that a 1.21% reduction of carbon emission reduced the nominal GDP by 0.82% and exports by 2.08%; 2.34% reduction of carbon emission reduced the nominal GDP by 1.90% and exports by 3.97% and 3.40% reduction of carbon emission reduced the nominal GDP by 3.17% and exports by 5.71%. **Conclusion/Recommendations:** Imposition of successively higher carbon tax results in increased government revenue from baseline by 26.67, 53.07 and 79.28% respectively. However, fixed capital investment increased in scenario 1a by 0.43% and decreased in scenarios 1b and 1c by 0.26 and 1.79% respectively from the baseline. According to our policy findings policy makers should consider 1st (scenario 1a) carbon tax policy. This policy results in achieving reasonably good environmental impacts without losing the investment, fixed capital investment, investment share of nominal GDP and government revenue.

Key words: Emission, environmental general equilibrium, Malaysian economy

INTRODUCTION

There has been growing concern among environmentalists and economists over the linkage between economic development and the environment. Higher awareness has led to greater scrutiny being placed on development policies in order to assess the long-term negative effects of further economic development on the environment and its sustainability^[1,2]. Some studies that have addressed the role of trade in the development and how that affects the environment are Bullard and Herendeen^[3] Herendeen and Bullard^[4] Herendeen^[5] Stephenson and Saha^[6] Strout^[7] Han and Lakshmanan^[8] Ferraz and Young^[9] Wier^[10] Antweiler *et al.*^[11] Munksgaard and Pedersen^[12] Kakali and Debesh^[13] Al-Amin *et al.*^[14]. The methodologies employed in these studies are varied, however results of most of these studies indicate that economic development harms environment unless appropriate environmentally friendly policy put in place.

Although a number of previous studies have given a detailed evaluation of economic development and environment in the world perspective, little attention has been given to enquiring about these relationships in the newly industrializing countries of Southeast Asia, in particular Malaysia.

Adopting an export-led growth strategy, Malaysia has increasingly diversified its exports in terms of products and markets resulting in large changes in the composition of exports and experiencing strong economic growth over the last three decades (Table 1 and Fig. 1). Economic growth could affect the environment in two ways; -firstly it encourages industrialization and manufacturing of production, leading to increased pollution. Secondly, industrialization and manufacturing of production lead to increased overuses of environmental resources (energy) and results in environmental degradation. All goods and services produced in Malaysia are directly or indirectly associated with uses of power and energy

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Table: 1 Direction of Malaysian trade in the world economy from 1990-2005

Direction	RM million (US\$1 = RM3.50)						Percentage of total (RM)					
	Exports			Imports			Exports			Imports		
	1990	2000	2005	1990	2000	2005	1990	2000	2005	1990	2000	2005
ASEAN	23065.5	99028	139208	15085.0	74940	110823	29.0	26.5	26.1	19.1	24.1	25.5
Singapore	18052.1	68574	83333	11800.0	44696	50828	22.7	18.4	15.6	14.9	14.4	11.7
Indonesia	920.7	6484	12580	850.8	8623	16566	1.2	1.7	2.4	1.1	2.8	3.8
Thailand	2788.0	13485	28723	1881.2	11987	22889	3.5	3.6	5.4	2.4	3.8	5.3
Philippines	1054.6	6558	7476	427.3	7562	12192	1.3	1.8	1.4	0.5	2.4	2.8
European Union	12204.5	51019	62629	12494.4	33527	50512	15.5	13.7	11.7	15.8	10.8	11.6
United Kingdom	3136.0	11566	9470	4312.3	6080	6522	3.9	3.1	1.8	5.5	2.0	1.5
Germany	3096.8	9336	11259	3389.2	9282	19265	3.9	2.5	2.1	4.3	3.0	4.4
USA	13487.0	76579	105033	13232.5	51744	55918	16.9	20.5	19.7	16.7	16.6	12.9
Canada	-	3043	2847	-	1445	2133	-	0.8	0.5	-	0.5	0.5
Australia	-	9210	18042	-	6052	8171	-	2.5	3.4	-	1.9	1.9
Selected NEA ¹	-	103784	149105	-	117828	169236	-	27.8	27.9	-	37.8	39.0
Japan	12588.9	48770	49918	23584.5	65513	62982	15.8	13.1	9.4	16.7	21.0	14.5
China	-	11507	35221	-	12321	49880	-	3.1	6.6	-	4.0	11.5
Hong Kong	2523.1	16854	31205	1497.5	8557	10797	3.2	4.5	5.8	1.9	2.7	2.5
Korea Rep.	3677.0	12464	17945	2033.6	13926	21604	4.6	3.3	3.4	2.6	4.5	5.0
Taiwan	1728.1	14189	14813	4323.0	17511	23974	2.2	3.8	2.8	5.5	5.6	5.5
South Asia	-	10529	21245	-	3030	4504	-	2.8	4.0	-	1.0	1.0
India	-	7312	14972	-	2748	4164	-	2.0	2.8	-	0.9	1.0
CSA	-	5633	6169	-	2587	6786	-	1.5	1.2	-	0.8	1.6
Africa	-	2996	7649	-	1421	2511	-	0.8	1.4	-	0.5	0.6
Others	-	11449	21866	-	18886	23415	-	3.1	4.1	-	6.1	5.4
Rest of the world	10372.3	-	-	11478.8	-	-	13.0	-	-	14.5	-	-

Source: Government of Malaysia^[15]; ¹: North East Asia

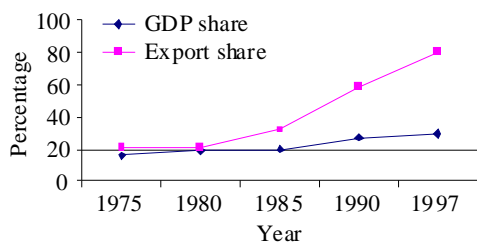


Fig. 1: Manufacturing share in the Malaysian economy 1970-1997

(petroleum oil, coal and gas)^[20]. According to the types of fuel utilized, emissions of that energy are obvious as well. Moving towards sustainable development and for better environmental performance, there is a policy goal in the Malaysian 9th Development Plan^[15]. However due to lack of efficiency of environmental policy options, Malaysia failed to achieve the environmental goal. The existing Malaysian environmental tax policies have lack of effectiveness and the present level of pollution charge is very low as most of the cases it found insignificant^[16]. The main reason is that the environmental tax is not appropriate. It should be mentioned that currently there is no carbon tax policy model in Malaysia and environmental monitoring system does not cover all polluting sectors. Therefore, the model developed for this study is

applied Computable General Equilibrium (CGE) model for imposing carbon taxation policy in the Malaysian economy. The model captures the changes in factors of production, industry output, consumer demand, trade, private consumption, public consumption and other macroeconomic variables resulting from environmental policy changes. Specifically, a minimum carbon tax policy developed for Malaysia to reap the maximum benefit of trade, economic development as well as to reduce the further environmental degradations.

MATERIALS AND METHODS

A static Computable General Equilibrium (CGE) model of the Malaysian economy is constructed for this study^[21]. The model consists of ten industries, one representative household, three production factors and rest of the world. The CGE technique is an approach that models the complex interdependent relationships among decentralized actors or agents in an economy by considering the actual outcome to represent a 'general equilibrium'. Briefly, the technique expresses that the 'equilibrium' of an economy is reached when expenditures by consumers exactly exhaust their disposable income, the aggregate value of exports exactly equals import demand and the cost of pollution is just equal at the marginal social value of damage that it causes.

Table 2: Sectoral aggregation of Malaysian SAM 2000 ('000 RM)

		1	2	3			4	5		
		Commodities /activities (1-94)	Factors	Institutions			Capital account	Rest of the world	Total	
Incomes/Expenditure			Labor	Capital	Household	Firms	Government			
1	Commodities /activities (1-94)	Intermediate inputs 271,699,945			Household consumption 116,582,745		Government consumptions 34,861,875	Investment 74,303,819	Exports 399,379,409	Domestic demand 896,827,793
2	Factors								Factor incomes from abroad 0	GNP at factor cost 345,270,111
	Labor	Value added 99,138,139								
	Capital	Value added 246,131,970								
3	Institutions									
	Household		Household income from labor 99,138,140	Household income from capital 42,289,296		Transfers 10,890,000	Transfers 3,700,138		Transfers from abroad 0	Household income 156,017,574
	Firms			Farm cap. Income 154,100,045	Transfers		1,940,000			Firms income 158,699,045
	Government	Tariffs, indirect taxes 8,406,755			Income taxes 7,015,000	Taxes 22,141,000		Others 1,771,839	Borrowing 11,357,419	Government income 50,692,013
4	Capital account				Households savings 32,419,829	Firms savings 125,668,045	Government savings 10,190,000			Total savings 168,277,875
5	Rest of the world	Imports 271,450,981		Inflow 49,742,630				Foreign capital 92,202,217	Capital transfer 14,028,333	Total row 427,424,161
	Total	Domestic Supply 896,827,792	Factor outlay 345,270,111		Household expenditure 156,017,574	Firms expenditures 158,699,045	Government expenditure 50,692,013	Total investment 168,277,875	Foreign exchange earnings 427,424,161	

The benchmark model representing the baseline economy is constructed using a SAM: Social Accounting Matrix (SAM matrix is estimated by the Authors using the Malaysian 2000 input-output table and 2000 national accounts of Malaysia). SAM is the snapshot of the economy and it reflects the monetary flow arising from interactions among institutions in the Malaysian economy. The Malaysian SAM of the year 2000 is shown in Table 2.

The Malaysian CGE model is comprised of a set of non-linear simultaneous equations and follows closely the specifications in Dervis *et al.*^[17] and Robinson *et al.*^[18] with some modifications in terms of functional form in the production technology to allow for pollution emission estimation incorporating carbon emission block into the model; where the number of equations is equal to the number of endogenous variables. The equations are classified in five blocks, i.e., (i) The price block, (ii) The production block, (iii) The institutions block, (iv) The system constraints block and carbon emission block.

Price block:

Domestic price: Domestic goods price by sector, PD_i is the carbon tax induced goods price, t_i^d times net price of domestic goods, $\bar{P}D_i$ can be expressed as follows:

$$PD_i = \bar{P}D_i (1 + t_i^d) \tag{1}$$

Import price: Domestic price of imported goods PM_i , is the tariff induced market price times Exchange Rate (ER) and can be expressed as:

$$PM_i = p_{wm_i} (1 + tm_i) \cdot ER \tag{2}$$

Where:

tm_i = Import tariff and

p_{wm_i} = The world price of imported goods by sector

Export price: Export price of export goods, PE_i , is the export tax induced international market price times exchange rate and is express as:

$$PE_i = p_{we_i} (1 - te_i) \cdot ER \tag{3}$$

Where:

te_i = Export tax by sector and

p_{we_i} = The world price of export goods by sector

Composite price: The composite price, P_i , is the price paid by the domestic demanders. It is specified as:

$$P_i = \left(\frac{PD_i D_i + PM_i M_i}{Q_i} \right) \tag{4}$$

Where:

D_i and M_i = The quantity of domestic and imported goods respectively

PD_i = The price of domestically produced goods sold in the domestic market
 PM_i = The price of imported goods and Q_i is the composite goods

Activity price: The sales or activity price PX_i is composed of domestic price of domestic sales and the domestic price of exports can be expressed as:

$$PX_i = \frac{PD_i \cdot D_i + PE_i \cdot E_i}{X_i} \quad (5)$$

where, X_i stands for sectoral output.

Value added price: Value added price PV_i is defined as residual of gross revenue adjusted for taxes and intermediate input costs, is specified as:

$$PV_i = \frac{PX_i \cdot X_i (1 - tx_i) - PK_i \cdot IN_i}{VA_i} \quad (6)$$

Where:

tx_i = Tax per activity and
 IN_i = Stands for total intermediate input
 PK_i = Stands for composite intermediate input price
 VA_i = Stands for value added

Composite intermediate input price: Composite intermediate input price PK_i is defined as composite commodity price times input-output coefficients:

$$PK_i = \sum_j a_{ij} \cdot P_j \quad (7)$$

where, a_{ij} is the input-output coefficients

Nomeraire price index: In CGE model, the system can only determine relative prices and solves for prices relative to a numeraire. In this model the numeraire is the gross domestic product price deflator (or gross national product can also be used). Producer price index and CPI are also commonly used as numeraire in applied CGE studies. In this model:

$$PP = \frac{GDPVA}{RGDP} \quad (8)$$

Where:

PP = GDP deflator
 $GDPVA$ = The GDP at value added price and
 $RGDP$ = The real GDP

Production block: This block contains quantity equations that describe the supply side of the model. The fundamental form must satisfy certain restrictions of general equilibrium theory. This block defines production technology and demand for factors as well as CET (constant-elasticity-of-transformation) functions combining exports and domestic sales, export supply functions and import demand and CES (constant elasticity of substitution) aggregation functions. Sectoral output X_i is express as: (The production function here is nested. At the top level, output is a fixed coefficients function of real world value added and intermediate inputs. Real value added is a Cobb-Douglas function of capital and labor. Intermediate inputs are required according to fixed input-output coefficients and each intermediate input is a CES aggregation of imported and domestic goods):

$$X_i = a_i^D \Pi_f FDSC_{if}^{\alpha_{if}} \quad (9)$$

Where:

$FDSC_{if}$ = Indicates sectoral capital stock and
 a_i^D = Represents the production function shift parameter by sector

The first order conditions for profit maximization as follows:

$$WF_f \cdot wfdist_{if} = PV_i \cdot \alpha_{if} \frac{X_i}{FDSC_{if}} \quad (10)$$

Where:

$wfdist_{if}$ = Represents sector- specific distortions in factor markets
 WF_f = Indicates average rental or wage
 α_{if} = Indicates factor share parameter of production function

Intermediate inputs IN_i are the function of domestic production and defined as follows:

$$IN_i = \sum_j a_{ij} \cdot X_j \quad (11)$$

On the other, the sectoral output is defined by CET function that combines exports and domestic sales. Sectoral output is defined as:

$$X_i = a_i^T [\gamma_i E_i^{\rho_i^T} + (1 - \gamma_i) D_i^{\rho_i^T}]^{\frac{1}{\rho_i^T}} \quad (12)$$

Where:

- a_i^T = The CET function shift parameter by sector
- γ_i = Holds the sectoral share parameter
- E_i = The export demand by sector and
- ρ_i^T = The production function of elasticity of substitution by sector

The sectoral export supply function which depends on relative price (P^e/P^d) can be expressed in the following functional form:

$$E_i = D_i \left[\frac{P_i^e (1 - \gamma_i)}{P_i^d \cdot \gamma_i} \right]^{1/\rho_i^T} \quad (13)$$

Similarly, the world export demand function for sectors in an economy, $econ_i$, is assumed to have some power and is expressed as follows:

$$E_i = econ_i \left[\frac{pwe_i}{pwse_i} \right]^{\eta_i} \quad (14)$$

Where:

- pwe_i = Represents the sectoral world price of export substitutes and
- η_i = The CET function exponent by sector

On the other, composite goods supply describes how imports and domestic product are demanded. It is defined as:

$$Q_i = a_i^C \left[\delta_i M_i^{-\rho_i^C} + (1 - \delta_i) D_i^{-\rho_i^C} \right]^{-1/\rho_i^C} \quad (15)$$

Where:

- a_i^C = Indicates sectoral Armington function shift parameter and
- δ_i = Indicates the sectoral Armington function share parameter

Lastly, the import demand function which depends on relative price (P^d/P^m) can be expressed as follows:

$$M_i = D_i \left[\frac{P_i^d \cdot \delta_i}{P_i^m (1 - \delta_i)} \right]^{1/1+\rho_i^C} \quad (16)$$

Domestic institution block: This block consists of equations that map the flow of income from value added to institutions and ultimately to households. These equations fill out the inter-institutional entries in the SAM.

First is the factor income equation Y_f^F defined as:

$$Y_f^F = \sum_i WF_f \cdot FDSC_{if} \cdot wfdist_{if} \quad (17)$$

Where:

- $FDSC_{if}$ = The sectoral capital stock
- $wfdist_{if}$ = Represents sector-specific distortion in factor markets and
- WF_f = Represents average rental or wage

Factor income is in turn divided between capital and labor. The household factor income from capital can be defined as follows:

$$Y_{cap^h}^H = Y_1^F - DEPREC \quad (18)$$

Where:

- $Y_{cap^h}^H$ = The household income from capital
- Y_1^F = Represents capital factor income and
- DEPREC = Capital depreciations

Similarly household labor income $Y_{lab^h}^H$ is defined as:

$$Y_{lab^h}^H = \sum_{f \neq 1} Y_f^F \quad (19)$$

where, Y_f^F is the factor income. Tariff equation TARIFF is expressed as follows:

$$TARIFF = \sum_i pwm_i \cdot M_i \cdot tm_i \cdot ER \quad (20)$$

Similarly, the indirect tax IND TAX is defined as:

$$INDTAX = \sum_i PX_i \cdot X_i \cdot tx_i \quad (21)$$

Likewise, household income tax is expressed as:

$$HHTAX = \sum_h Y_h^H \cdot t_h^H \quad (h = cap, lab) \quad (22)$$

Where:

- Y_h^H = Households income
- t_h^H = Represents household income tax rate

Export subsidy FXPSUB (negative of export revenue) is expressed as:

$$EXPSUB = \sum_i pwe_i \cdot E_i \cdot te_i \cdot ER \quad (23)$$

Total Government Revenue (GR) is obtained as the sum up the previous four equations. That is: (The sign for EXSUB depends on the economic policy on whether the government is receiving export tax revenue or giving export subsidies):

$$GR = \text{TARIFF} + \text{INTAX} + \text{HHTAX} + \text{EXPSUB} \quad (24)$$

Depreciation (DEPREC) is a function of capital stock and is defined as:

$$\text{DEPREC} = \sum_i \text{depr}_i \cdot PK_i \cdot \text{FDSC}_i \quad (25)$$

where, depr_i represents the sectoral depreciation rates

Household savings (HNSAV) is a function of marginal propensity to save (mps_h) and income. It is expressed as:

$$\text{HNSAV} = \sum_h Y_h^H \cdot (1 - t_h^H) \cdot \text{mps}_h \quad (26)$$

Government Savings (GOVSAV) is a function of GR and final demand for government consumptions (GD_i). That is:

$$\text{GOVSAV} = \text{GR} - \sum_i P_i \cdot GD_i \quad (27)$$

Lastly, the components of total savings include financial depreciation, household savings, government savings and foreign savings in domestic currency ($\text{FSAV} \cdot \text{ER}$):

$$\text{SAVING} = \text{HNSAV} + \text{GOVSAV} + \text{DEPREP} + \text{FSAVER} \quad (28)$$

The following equations (29-36) provide equations map that complete the circular flow in the economy and determining the demand for goods by various actors. First, the private consumption (CD) is obtained by the following assignments:

$$CD_i = \sum_h \left[\beta_{ih}^H \cdot Y_h^H (1 - \text{mps}_h) (1 - t_h^H) \right] / P_i \quad (29)$$

where, β_{ih}^H is the sectoral household consumption expenditure shares.

Likewise, the government demand for final goods (GD) is defined using fixed shares of aggregate real spending on goods and services (gdtot) as follows:

$$GD_i = \beta_i^G \cdot \text{gdtot} \quad (30)$$

where, β_i^G is the sectoral government expenditure shares

Inventory demand (DST) or change in stock is determined using the following equation:

$$\text{DST}_i = \text{dstr}_i X_i \quad (31)$$

where, dstr_i is the sectoral production shares.

Aggregate nominal fixed investment (FXDINV) is expressed as the difference between total investment (INVEST) and inventory accumulation. That is:

$$\text{FXDINV} = \text{INVEST} - \sum_i P_i \cdot \text{DST}_i \quad (32)$$

The sector of destination (DK) is calculated from aggregated fixed investment and fixed nominal shares (kshr_i) using the following function:

$$DK_i = \text{kshr}_i \text{FXDINV} / PK_i \quad (33)$$

The next equation translates investment by sector of destination into demand for capital goods by sector of origin (ID_i) using the capital composition matrix (b_{ij}) as follows:

$$ID_i = \sum_j b_{ij} \cdot DK_j \quad (34)$$

The last two Eq. 35-36 show the nominal and real GDP, which are used to calculate the GDP deflator used as numeraire in the price equations. Real GDP (RGDP) is defined from the expenditure side and nominal GDP (GDPVA) is generated from value added side as follows:

$$\text{GDPVA} = \sum_i PV_i \cdot X_i + \text{INDTAX} + \text{TARIFF} + \text{EXPSUB} \quad (35)$$

$$\text{RGDP} = \sum_i (CD_i + GD_i + ID_i + \text{DST}_i + E_i - \text{pwm}_i \cdot M_i \cdot \text{ER}) \quad (36)$$

Systems constraints block: This block defines the constraints that are must be satisfied by the economy as a whole. The model's micro constraints apply to individual factor and commodity markets. With few exceptions, in the labor, export and import markets, it is assumed that flexible prices clear the markets for all commodities and factors. The macro constraints apply to the government, the savings-investment balance and the rest of the world. For the government, savings clear

the balance, whereas the investment value adjusts to changes in the value of total savings.

Product market equilibrium condition requires that total demand for composite goods (Q_i) is equal to its total supply as follows:

$$Q_i = IN_i + CD_i + GD_i + ID_i + DST_i \quad (37)$$

Market clearing requires that total factor demand equal total factor supply (fs_f) and the equilibrating variables are the average factor prices which were defined earlier and this condition can be expressed as follows:

$$\sum_i FDSC_{if} = fs_f \quad (38)$$

The following equation is the balance of payments represents the simplest form: Foreign savings (FSAV) is the difference between total imports and total exports. As foreign savings set exogenously, the equilibrating variable for this equation is the Exchange Rate (ER). Equilibrium will be achieved through movements in ER that effect export import price. This balancing equation can be expressed as:

$$pwm_i M_i = pwe_i E_i + FSAV \quad (39)$$

Lastly the macro-closure rule is given as:

$$SAVING = INVEST \quad (40)$$

where, total investment adjusts to equilibrate with total savings to bring the economy into the equilibrium.

Carbon emission block: The aggregate CO₂ emission is formulated as follows:

$$TQ_{CO_2} = \phi_i^{coal} X_i^{coal} + \phi_i^{oil} X_i^{oil} + \phi_i^{gas} X_i^{gas} \quad \text{or} \quad TQ_{CO_2} = \sum_i \phi_i^k X_i^k \quad (41)$$

where, ϕ_i^k is carbon emission factors of k (coal, oil and gas) by sector and:

$$TQ_{CO_2} - \overline{TQ_{CO_2}} \leq 0 \quad (42)$$

Where:

TQ_{CO_2} = The total CO₂ emission

$\overline{TQ_{CO_2}}$ = The carbon emission limit

Total carbon tax revenue (T_{CO_2}) is given by the following equation:

$$T_{CO_2} = \sum_i t_i^d \cdot PD_i \cdot D_i + \sum_i t_i^m \cdot PM_i \cdot M_i \quad (43)$$

Where:

t_i^d = The carbon tax of domestic product by sector

t_i^m = The carbon tax of imported product by sector

These rates are in tern determined as follows:

$$t_i^d = P_{CO_2} \psi_i^d \omega_i^d \quad (44)$$

$$t_i^m = P_{CO_2} \psi_i^m \omega_i^m \quad (45)$$

Where:

ψ_i^d = The carbon emission coefficients per unit of (domestic) fuel use by sector

ω_i^d = A fossil fuel coefficients per unit of domestic goods by sector

ψ_i^m = The carbon emission coefficients per unit of (import) fuel use by sector

ω_i^m = The fossil fuel coefficients per unit of import goods by sector

P_{CO_2} = Indicates price of carbon emission

RESULTS

Results: The scenario (simulation) carried out is based on year 2000 SAM of the Malaysian economy where the production sectors have been aggregated to 10 sectors. The scenario details are shown in Table 3.

Scenario 1 represents the virtual carbon tax policy impacts. This scenario is carried out in three versions (1a, b and c) where an exogenously determined carbon tax was imposed on domestic economy. Implementation of this scenario would allow us to see the possible reduction in CO₂ emissions and its impact on various economic variables such as domestic production, exports, imports, private consumption, gross investment, government revenues, GDP, as well as other incomes, revenues and savings variables.

Table 3: Scenario codes and definition of the simulations

	Scenario codes	Simulation specifications
	Scenario 1a	Imposition of carbon tax of domestic product by sector
Scenario 1	Scenario 1b	2 times increase in carbon tax of domestic product by sector
	Scenario 1c	3 times increase in carbon tax of domestic product by sector

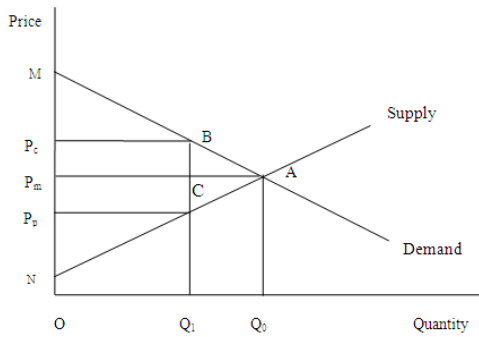


Fig. 2: Effects of a carbon tax

Table 4: Impact of carbon tax imposition on the Malaysian economy

Sectors	Baseline (100 million RM)	Percentage change from the baseline		
		Scen 1a	Scen 1b	Scen 1c
Carbon dioxide emission*	125.548	-1.212	-2.347	-3.401
Domestic production	8967.691	-1.213	-2.346	-3.400
Exports	4478.429	-2.079	-3.972	-5.707
Value added	3470.867	-2.393	-3.470	-4.736
Household consumption	1175.744	-2.316	-4.836	-7.477
Real GDP	3499.192	-0.817	-1.898	-3.166
Nominal GDP (nGDP)	3500.216	-0.817	-1.898	-3.167
Government revenue	356.898	26.668	53.072	79.281
Investment	968.273	0.555	0.278	-0.624
Fixed capital investment	706.323	0.430	-0.255	-1.788
Tariff	40.370	-2.175	-4.164	-5.992
Export tax	11.028	-2.503	-4.824	-6.955
Enterprise tax	204.856	-1.299	-2.924	-4.796
Household tax	67.843	-1.013	-2.357	-3.938
Enterprise savings	1162.722	-1.299	-2.924	-4.796
Household savings	303.704	-1.012	-2.357	-3.938
HH consumption share of nGDP**	33.078	-0.193	-0.466	-0.795
Investment share of nGDP**	27.62	1.385	-2.220	-2.625

*: Million tones; **: Percent

This study finds that the imposition of carbon tax on domestic production sectors reduce the carbon emissions (first row of Table 4). Simulations 1a, b and c indicate that imposition of carbon tax result in lower carbon emissions, domestic production, exports, value-added, household consumption, real and nominal GDP, tariff revenue, export tax revenue, enterprise tax revenue, household tax revenue, enterprise savings and household savings (Table 4). In contrast the government revenue is positive in all versions of scenario 1 and investment share of nominal GDP is positive (1.39%) in version a of scenario 1 but negative in version b (2.22%) and version c (2.63%) from the base level. However, investment and fixed capital investment are higher than the baseline level at low level of carbon tax (scenarios 1a) but is lower than the baseline as the carbon tax becomes higher (scenario 1c).

More specifically, imposition of successively higher carbon tax result in 1.21, 2.35 and 3.40% reduction in carbon emissions. However, these reductions are also accompanied by 0.82, 1.90 and 3.17% decrease in nominal and real GDP. Exports decreased by 2.08, 3.97 and 5.71% while value-added decreased by 2.39, 3.97 and 4.74%, respectively. Enterprise savings is lower from the baseline by 1.30, 2.92 and 4.80% respectively. However, government revenue increased from the baseline by 26.67, 53.07 and 79.28% respectively. On the other hand, investment and fixed capital investment increased in scenario 1a by 0.56 and 0.43% respectively and fixed capital investment decreased in scenarios 1b and 1c by 0.26 and 1.79% respectively from the baseline (Table 4).

Carbon tax lowers household consumption and savings. Specifically, the simulation results show that for each of the three successively larger carbon tax, household consumptions decreased by 2.32, 4.84 and 7.48% from the baseline, respectively. Household savings decreased by smaller percentages, i.e., 1.01, 2.36 and 3.94% respectively for shown in Table 4. For the respective sub-scenarios, household consumption share of nominal GDP decline by 0.19, 0.47 and 0.80%.

DISCUSSION

Uncertainties regarding the economic benefit of limiting carbon emissions breed hesitation. In particular, changes in economic activity due to carbon tax lead to significant changes in factor prices, factors of production, consumption pattern, terms of trade and consequently, consumer welfare and gross domestic product. It follows that policy makers would seek to determine how to minimize dampen to the economy while pursuing environmentally sound objectives. Figure 2 shows the outcome of imposing a unit carbon tax. Consider the supply and demand of a good where an equilibrium (partial) level prior to tax is point A.

The quantity produced and consumed is Q_0 and the relevant price is P_m . Total surplus is given by the area MNA. When a unit carbon tax is imposed, the new equilibrium will be B where only Q_1 units will be consumed at price P_c . (It is assumed that emission is linear function of outputs throughout this study) Total surplus is reduced; the consumer surplus is now MBP_c and the producer surplus is now CP_pN and the government collects revenues represented by the area P_cP_pCB .

To capture the economy-wide effects of an artificial environmental tax policy, a unit carbon tax is imposed on the model where the unit of carbon tax is calculated by multiplying the exogenous carbon tax

with the carbon content per unit domestic production. Changes in CO₂ emission is given by the difference between the baseline value and the simulated value. Table 4 shows the impact of carbon tax on carbon emissions and effects on macroeconomic variables. It should be noted that the effects of the carbon tax presented are for the short run. Generally substitution will occur in the long run thus resulting in changes in energy structure and resources will shift from energy intensive industries to less energy intensive industries.

CONCLUSION

Having developed a CGE model, three policy simulations were carried out to see the economic and environmental impact in the Malaysian economy. The simulation finds that 1.21% reductions of carbon emissions via carbon tax reduce the nominal GDP by 0.82%, domestic production by 1.21%, exports by 2.08%, enterprise savings by 1.30%, household consumptions by 2.32%, household savings by 1.01% and household consumption share of nominal GDP by 0.19%. However, the government revenue increases by 26.67% and fixed capital investment increases by 0.43%. Likewise, 2.35% reductions of carbon emissions via carbon tax reduce the nominal GDP by 1.90%, domestic production by 2.35%, exports by 3.97%, value added by 3.47%, enterprise savings by 2.92%, fixed capital investment by 0.25%, household savings by 2.36% and household consumption share of nominal GDP by 0.47% however, government revenue increases by 53.07%. Lastly 3.40% reductions of carbon emissions via carbon tax reduce the nominal GDP by 3.17%, domestic production by 3.40%, exports by 5.71%, value added by 4.74%, enterprise savings by 4.80%, household consumptions by 7.48% and household savings by 3.94% from the baseline.

Policy recommendations for reducing carbon emission: There are several ways of minimizing the negative effects of carbon emissions have been proposed by various researchers. These include: carbon taxation, energy taxation, tradable emission permits and regulations. Malaysia has experienced all policies like implemented energy taxation, tradable emission permits and environmental regulations except carbon taxation. Therefore, this study focuses on carbon taxation as an instrument for controlling the level of emissions. In practice, various tax schemes have been used in different countries in dealing with pollution problems, among others, includes i.e. taxing emissions, taxing inputs that cause pollution, taxing output of goods generating emissions; and providing subsidies

for abatement activities. Specifically this study sought to investigate the taxing of output of goods that generate emissions on domestic production in the Malaysian economy (Generally, the emissions of pollutants such as carbon dioxide emission generally are not measured directly and in many cases direct measurement is quite difficult. Instead the emissions are estimated on the assumption that they are proportional to the use of various types of fossil fuels in the production process. This assumption implies that emission reductions can be brought about only by reductions of the consumption of fossil fuels or by changes in the composition of fossil fuel consumption in the domestic production).

According to our model results, in the year 2000 total carbon emissions of Malaysia were 125.6 million tonnes^[22]. The model results illustrate that a larger cut in carbon emissions requires a higher carbon tax. Moreover an increasing carbon tax decreases GDP at an increasing rate. Different degrees of carbon tax increase the welfare losses in terms of losses of household consumption, household savings, enterprise consumption and enterprise savings and eventually total economic savings. The investment losses in the economy tend to rise more sharply as the degree of emission reduction increases (The carbon tax also falls of domestic production, exports, value-added, real GDP, tariff revenue, export tax revenue, enterprise tax, household tax and enterprise savings). The aggregate production tends to decrease at a proportional rate as the carbon emissions target becomes more stringent (drop by more than 3.4%, in scenario 1c) and the changes in gross production quite significant. Considering higher carbon tax policy such as version b and c of scenario 1, the simulation illustrates that the macroeconomic impacts could be strongly negative. Higher reductions of pollution emission such as a 2.35% of carbon emissions (scenario 1b) reduce the nominal GDP by 1.90%, domestic production by 2.35%, exports by 3.97%, fixed capital investment by 0.25%, household savings by 2.36% and enterprise savings by 2.92%. And, more reductions of pollution emission such as a 3.40% reduction of carbon emissions (scenario 1c) reduce the nominal GDP by 3.17%, domestic production by 3.40%, exports by 5.71%, household consumptions by 7.48%, household savings by 3.94% and enterprise savings by 4.80%. Therefore, policy-makers could consider first carbon tax policy (scenario 1a). Initial carbon tax reforms (1% CO₂ reduction) results in decrease real GDP 0.82%, however it increases fixed capital investment by 0.43% and investment share of nominal GDP by 1.39% and government revenue by 26.66%. And, revenues from

the carbon tax can be used for the following purposes: (1) The revenue can be used to offset the negative effect on consumption welfare levels; (2) They can be financed to adoption of technological change in the long run. This policy results in achieving reasonably good environmental impacts without losing the investment, fixed capital investment, investment share of nominal GDP and government revenue.

There is another way to substitute energy use coupe with economic growth. Government policy that promote economic growth relying on heavy use of fossil fuels need to be replaced due to their fiscal, efficiency and environmental effects. Correct pricing on energy, by reducing generalized subsidies may be one good alternative policy to promote energy-saving technological change and mitigate carbon pollutions. Malaysia has decided on the environmental actions that take to mitigate climate change (effects of carbon emissions) and relate them to the use of policy instruments. This research suggests that an initial carbon tax can be applied for the central purpose of reducing the rate of growth of carbon emissions. Even in the absence of technological change on the Malaysian economy a carbon tax induces general equilibrium effects that offset the further negative effects on the economy. Our findings provide several suggestions and message to policy makers, who are considering carbon taxation policy together with economic development. This study serves as a guide to selection of more feasible and appealing environmental policies, the responses of the Malaysian economy to each policy changes and the relative merits of the range of policies that might be considered for reducing emissions.

REFERENCES

1. Levinson, A. and M. Taylor, 2004. Trade and Environment: Unmasking the pollution Haven Effect. NBER working paper no. W10629: 1-44. <http://ssrn.com/abstract=565828>
2. Matthew, A. and E. Robert, 2005. FDI and the capital intensity of dirty sectors: A missing piece of the pollution haven puzzle. *Rev. Develop. Econ.*, 9: 530-548. DOI: 10.1111/j.1467-9361.2005.00292.x
3. Bullard, C. and R. Herendeen, 1975. The energy cost of goods and services. *Energ. Policy*, 3: 268-278. <http://ideas.repec.org/a/eee/enepol/v3y1975i4p268-278.html>
4. Herendeen, R. and C. Bullard, 1976. US energy balance of trade. *Energ. Syst. Policy*, 1: 383-390. http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=7249357
5. Herendeen, R., 1978. Energy balance of trade in Norway. *Energ. Syst. Pol.*, 2: 425-432. http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=6178408
6. Stephenson, J. and G. Saha, 1980. Energy balance of trade in New Zealand. *Energ. Syst. Policy*, 4: 317-326. DOI: 10.1002/er.4440040408
7. Strout, A., 1985. Energy-intensive materials and the developing countries. *Mater. Soc.*, 9: 281-330. http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=5492809
8. Han, X. and T. Lakshmanan, 1994. Changes in the energy cost of goods and services of the Japanese economy. *Ann. Reginal. Sci.*, 29: 277-302. DOI: 10.1007/BF01581781
9. Ferraz, Y., 1999. Trade Liberalization and Industrial Pollution in Brazil. United Nations Publications, Santiago, Chile. <http://www.eclac.org/publicaciones/xml/3/4353/lcl1332i.pdf>
10. Wier, M., 1998. Sources of changes in emissions from energy: A structural decomposition analysis. *Econ. Syst. Res.*, 10: 99-112. DOI: 10.1080/09535319808565469
11. Antweiler, W., R. Copeland and M. Scott, 2001. Is free trade good for the environment? *Am. Econ. Rev.*, 91: 877-908. <http://www.e-aer.org/archive/9104/91040877.pdf>
12. Munksgaard, J. and A. Pedersen, 2001. CO₂ Accounts for Open economies: Producer or consumer responsibility? *Energ. Policy*, 29: 327-335. DOI: 10.1016/S0301-4215(00)00120-8
13. Kakali, M. and C. Debesh, 2005. Is liberalization of trade good for the environment? Evidence from India. *Asia Pacific Develop. J.*, 12: 109-136. http://www.unescap.org/pdd/publications/apdj_121/5_kakali.pdf
14. Al-Amin, A., S. Chamhuri, H. Abdul and H. Nurul, 2008. Globalization and environmental degradation: Bangladeshi thinking as a developing nation by 2015. *IRBRP.*, 3: 381-395. <http://www.bizresearchpapers.com/30-Al-Amin.pdf>
15. Government of Malaysia, 2006. 9th Malaysia Plan, 2006-2010. Economic Planning Unit, Prime Minister's Department, Malaysia. <http://www.epu.gov.my/rm9/english/Index.pdf>
16. Government of Malaysia, 2001. Environmental Quality Report-2000. Ministry of Science Technology and the Environment, Malaysia, pp: 25-47.
17. Dervis, K., J. De Melo and S. Robinson, 1982. General Equilibrium Models for Development Policy. Cambridge University Press, Cambridge, ISBN: 0521270308, pp: 526.

18. Robinson, S., A. Yunez, R. Hinojosa, J. Lewis and S. Devarjan, 1999. From stylized to applied models: Building multisector CGE models for policy analysis. *North Am. J. Econ. Financ.*, 10: 5-38. DOI: 10.1016/S1062-9408(99)00014-5
19. Government of Malaysia, 1999. Economic Report, Various Issues. Ministry of Finance, Department of Statistics, Malaysia, pp: 12-27.
20. Government of Malaysia, 2003. National Energy Balance of 2000. Ministry of Energy, Communication and Multimedia, Malaysia, pp: 1-47.
21. Perroni, C. and R. Wige, 1994. International trade and environmental quality: How important the linkages? *Can. J. Econ.*, 27: 551-67. <http://www.jstor.org/stable/pdfplus/135783.pdf>
22. Earth Trends, 2003. World Resource Institute. Washington DC., USA., pp: 1-4.

The Effect of Air Entry Values on Hysteresis of Water Retention Curve in Saline Soil

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Abstract: Problem statement: The saline soil in Northeast Thailand is caused by saline groundwater rise in unsaturated zone to accumulate as salt at soil surface. **Approach:** This problem had been exacerbated in the last few decades by human activities e.g., deforestation and salt mining. This salinity problem can be solved by capillary rise control of saline groundwater flow. **Results:** The soil water retention curve formulation was essential for the control procedure design. In this study, the soil water retention curves of saline soil samples were derived by the hanging column and pressure plate apparatus techniques. The hysteresis of the curves together with air and water entry values were scrutinized from the primary wetting and drying retention curves. **Conclusion:** The experimental results showed that the degree of hysteresis varies with the air entry value of the soil. The new finding can be very useful in modeling for salinity control.

Key words: Capillary rise, Northeast Thailand, saline soil, unsaturated soil, water entry values

INTRODUCTION

The soil water retention curve is a relationship between pressure head of soil water and water content in unsaturated soil. The relationship varies with water flow process which flow into or out of the soil section. When water is flowing into the soil section it is called wetting process. The water retention curve of the wetting process from the initial stage of air-dry soil until saturated condition is a unique curve, called the primary wetting curve. Similarly, the primary drying curve is obtained from a draining process of saturated soil until the soil is very dry. Wetting and draining processes of soil water conditions between saturated and air-dry condition, produce the scanning curves. The two primary curves form the boundaries of all scanning curves as shown in Fig. 1. This phenomenon is called hysteresis.

The air-entry value is identified as the point at the largest pores which air can enter into the soil. When the suction is larger than the air-entry value then the soil starts to desaturate. The amount of water in soil decreases significantly with increasing suction in the

transition stage. Eventually a large increase in suction leads to a relatively small change in the water content and is the residual stage. The hysteresis can affect the accuracy of unsaturated flow calculations. The objective of the study is to relate air-entry value to the degree of hysteresis, which is the helpful to assess the accuracy of soil water flow calculation.

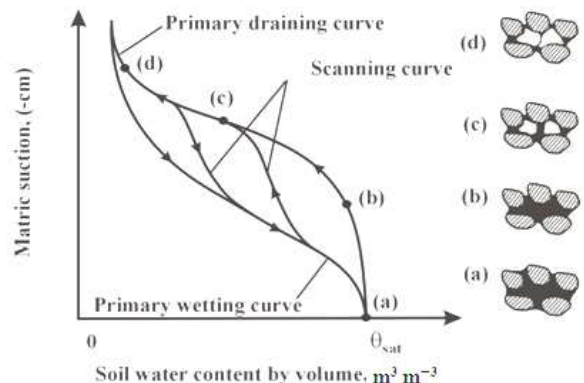


Fig. 1: The characteristics of hysteresis retention curve

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MATERIALS AND METHODS

Saline soil samples from six different sites around the city of Khon Kaen, northeast Thailand, were used in this study. Each soil sample was tested for its water retention curves for both primary drying and primary wetting curves. Then from the curves, we obtained the degree of hysteresis and the air entry value for each soil. The details are as follows.

Saline soil samples: We collected soil samples from six saline soil patches around the city of Khon Kaen, northeast Thailand. Both undisturbed and disturbed samples were collected from 5 cm below the soil surface. The disturbed samples were used for size distribution analysis and salinity measurement. The undisturbed samples were collected by stainless steel soil cores of 5 cm inside diameter and 5 cm length making up about 100 cm³ in volume. The undisturbed samples were measured for their soil water retention curves, porosity and saturated hydraulic conductivity.

The particle size distributions were analyzed using sieve analysis for the grain size coarser than 0.054 mm and sedimentation analysis for the finer grain size. From the particle size distribution curve, the fractions of sand: silt: Clay and d₅₀, were derived. The soil textures were also identified. The results of the fractions, d₅₀ and soil textures of the soil samples are in Table 1.

Soil salinity was measured for each disturbed soil sample. The air dried soil was mixed with distilled water at the ratio of 1:5 by weight for 24 h. The mixture was filtered and measured for electrical conductivity. The EC_{1:5} was converted to the value for the saturated extract EC_e by conversion factor^[11]. The salinity values for the samples are in Table 2.

Table 1: Soil distributions and textures of the experimental soils

Site	Size distributions (%)				Textures
	Sand	Silt	Clay	D ₅₀ (mm)	
St1	78.40	12.80	8.80	0.080	Sandy loam
St2	64.80	26.70	8.50	0.085	Sandy loam
St3	59.80	18.60	21.60	0.070	Sandy clay loam
kk1	60.00	31.00	9.00	0.072	Sandy loam
kk2	30.00	46.00	24.00	0.035	Loam
kk3	80.00	17.00	3.00	0.130	Loamy sand

Table 2: The physical properties of the experimental soils

Site	θ _r	Bulk density (kg m ⁻³)	Porosity	K _{sat} (cm day ⁻¹)	salinity (ms cm ⁻¹)
St1	0.062	1,676.00	0.330	113.68	38.40
St2	0.030	1,516.00	0.350	315.92	1.20
St3	0.069	1,609.00	0.480	4.27	36.90
kk1	0.030	1,429.00	0.400	137.30	11.76
kk2	0.070	1,282.83	0.450	25.99	13.10
kk3	0.020	1,697.93	0.480	201.60	17.60

The bulk density, porosity and hydraulic conductivity of the samples were measured from undisturbed samples by standard methods^[4,7]. The falling head method was used for K_{sat} measurement. These values are in Table 2. The saturated water content of soil can be taken as the porosity of the soil^[10]. However, the residual water content θ_r was measured gravimetrically from air dried soil then converted to volumetric value using bulk density. The values of θ_r are also in Table 2.

Water retention curve construction: The primary drying retention curves were constructed by two apparatus. The hanging column was applied for the saturated sample down to about -1.5 m pressure head. Then the pressure plate apparatus was used for the pressure head less than -1.5 m. However, this pressure plate method cannot be used for the wetting curve construction. Only the hanging column method can be applied to construct a scanning wetting curve in the pressure head range from -1.5 m to saturated condition. Fig. 2 shows the measurement primary drying curves by ‘o’ and the scanning wetting curves by ‘+’. From the guides of the primary drying curve and the scanning wetting curve then the primary wetting curve can be constructed as the dashed line in Fig. 2. Both primary curves (wetting and drying) were fitted by the van Genuchten equation^[2,8,13].

$$\theta = \theta_r + (\theta_s + \theta_r) \left(\frac{1}{1 + (\alpha|h|)^n} \right)^m \tag{1}$$

Where:

- θ = Water content of soil
- θ_r and θ_s = Water content of soil at air-dried and saturated conditions respectively
- |h| = Absolute value of pressure head of soil water
- α, n and m = Parameters determined by fitting the equation to experimental data and assuming m = 1-1/n

The resulting primary wetting and drying curves are shown as dashed and solid lines respectively in Fig. 3a-f.

Degree of hysteresis: The difference between the two curves (wetting and drying) is called hysteresis. At a particular pressure head, we get the different values of water content. The degree of hysteresis is therefore identified by the ratio of the maximum difference of water content (between wetting and drying curves) to the difference of θ_s and θ_r, written in an equation form as:

$$r = \frac{\Delta\theta_{\max}}{\theta_s - \theta_r} \quad (2)$$

Where:

r = Degree of hysteresis

$\Delta\theta_{\max}$ = Maximum difference of water content

$$h_c = \frac{1}{\alpha} \left[\frac{n-1}{n(m+1)-n+1} \right]^{1/n} = \begin{cases} m^{1/n} / \alpha & \text{for } m = 1 - 1/n \\ 1 / \alpha & \text{for } m = 1 - 2/n \end{cases} \quad (3)$$

Air entry value evaluation: Air entry value of the soil is the metric suction value that must be exceeded before air recedes into the soil pores. It is the critical pressure head at which air starts to displace water in a porous medium. On the other hand, the water entry value is the lowest suction that water can enter into the saturated soil (Fig. 2). Therefore, the infiltration process involves water-entry at the wetting front and the drainage process involves air-entry at the soil surface.

Since, water-entry value is the threshold for infiltration and air-entry value for drainage, they can be estimated from the soil water retention curves^[1,3,5,6]. According to the study of Wang *et al.*^[12], the values of water-entry (h_{we}) and air-entry (h_{ae}) correspond to the inflectional capillary pressure (h_c) for wetting retention curve and drainage retention curve, respectively. They can be determined from^[9]:

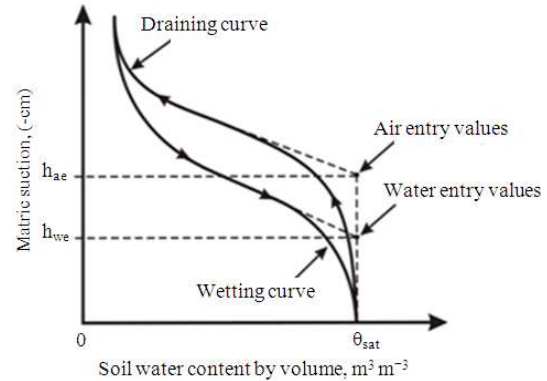
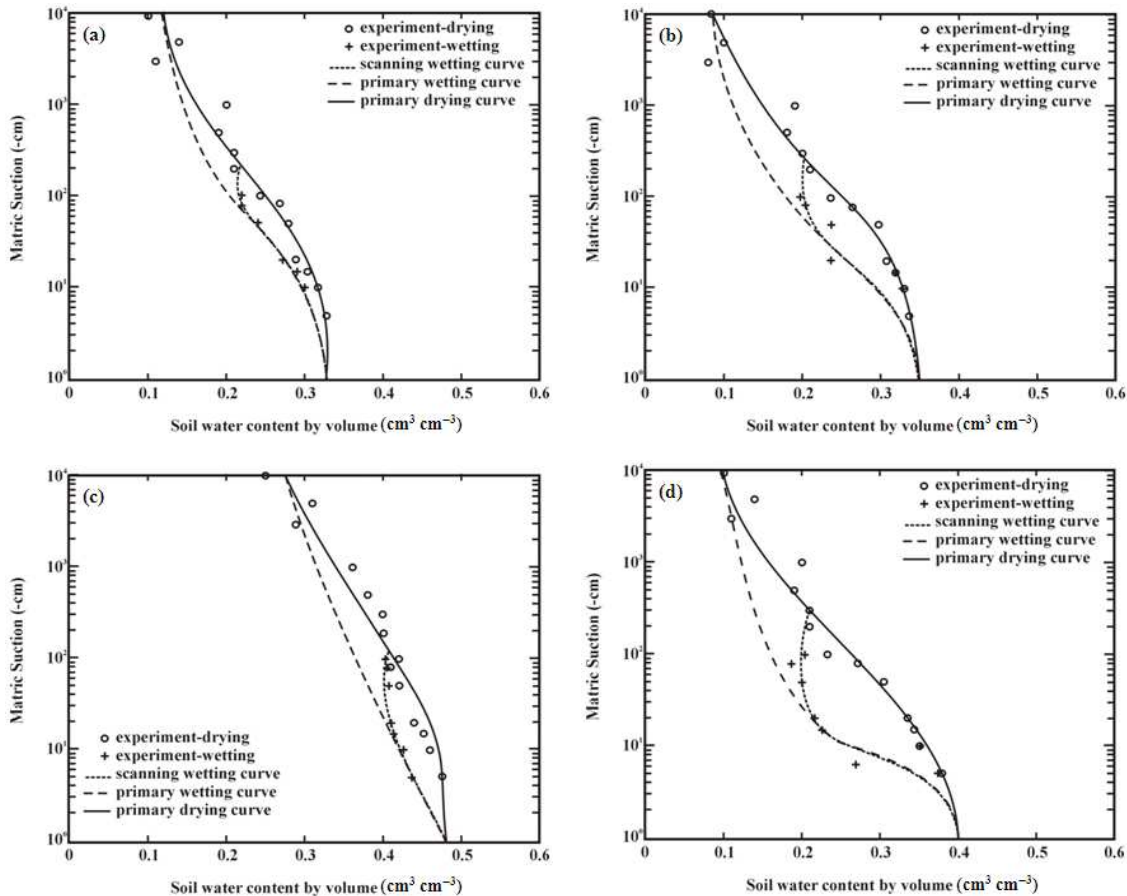


Fig. 2: The determination of air entry values (h_{ae}) and water entry value (h_{we}) by soil water retention curve



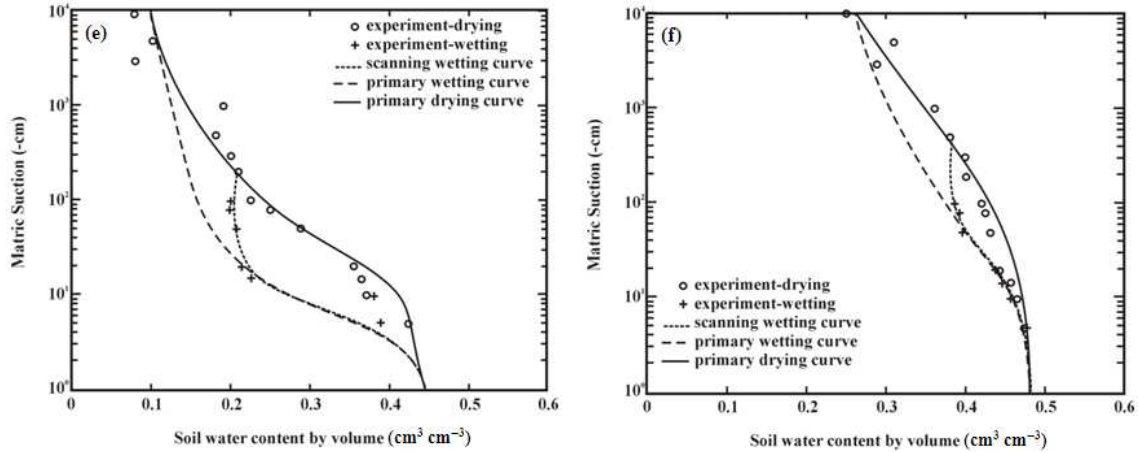


Fig. 3: Soil water retention curves for (a): Sandy loam, $D_{50} = 0.080$ (b): Sandy loam, $D_{50} = 0.085$ (c): Sandy clay loam, $D_{50} = 0.070$ (d): Sandy loam, $D_{50} = 0.072$ (e): Loam, $D_{50} = 0.035$ (f): Loamy sand $D_{50} = 0.130$

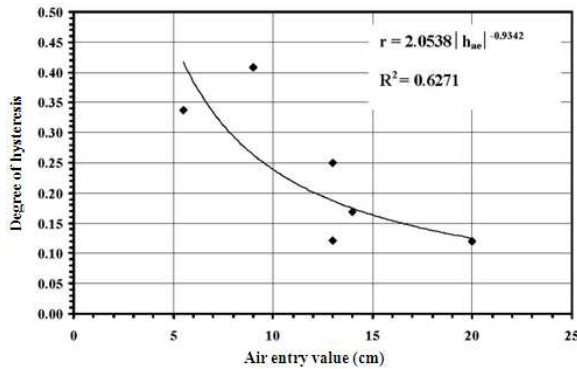


Fig. 4: The relationship between air entry value and degree of hysteresis

RESULTS

The measurement results of primary draining curves and scanning wetting curves are shown in Fig. 3 as 'o' and '+' respectively. The fitted van Genuchten equation (Eq. 1) for the primary wetting and drying curves are shown in Fig. 3 as dashed and solid lines, respectively. The parameters of the equation are in Table 3. The degree of hysteresis and the water and air entry values for each soil are shown in Table 4. And the air entry value is plotted with the degree of hysteresis in Fig. 4. The values of degree of hysteresis together with the suction heads at the maximum difference on hysteresis are in Table 4. The relationship can be written in an equation form as:

$$r = 2.0538 |h_{ae}|^{-0.9342} \quad (4)$$

where r is the degree of hysteresis and $|h_{ae}|$ is the absolute value of air entry head.

Table 3: Results parameter α and n in water retention curves

		Values from van Genuchten equation				
		Primary draining curve		Primary wetting curve		
Site	Textures	R^2	α	n	α	n
St1	Sandy loam	0.9616	0.032	1.280	0.099	1.240
St2	Sandy loam	0.9669	0.032	1.290	0.150	1.230
St3	Sandy clay loam	0.9449	0.035	1.120	0.700	1.080
kk1	Sandy loam	0.9676	0.052	1.280	0.890	1.190
kk2	Loam	0.9640	0.061	1.400	0.820	1.300
kk3	Loamy sand	0.9628	0.020	1.120	0.350	1.080

Table 4: Water content and suction head at maximum differences between the two primary curves

Site	Textures	Matric suction of h, (cm)	Degree of hysteresis	Water content, θ		Entry value (cm)	
				Primary draining curve	Primary wetting curve	Air	Water
St1	Sandy loam	95.0	0.168	0.255	0.210	14.0	6.5
St2	Sandy loam	70.0	0.250	0.270	0.190	13.0	3.8
St3	Sandy clay loam	16.0	0.122	0.460	0.410	13.0	1.0
kk1	Sandy loam	25.0	0.338	0.330	0.205	5.5	3.5
kk2	Loam	19.0	0.408	0.380	0.225	9.0	2.8
kk3	Loamy sand	18.0	0.120	0.410	0.355	20.0	7.0

DISCUSSION

Most of saline soil used in this study show some degree of hysteresis (Fig. 3). The degree of hysteresis varies inversely and nonlinearly with the absolute value of the air entry value as in Fig. 4 and Eq. 4. The soil with high air entry value are those of the finer pore space represented by high proportion of finer particles. The finer grain soils have more uniform pore space and then lower degree of hysteresis than the coarse grain soils.

This finding facilitates modeling of unsaturated flow through saline soil. Normally, the primary drying retention curve can be obtained directly from the experiment and allow to calculate the air entry value (Eq.3). The degree of hysteresis can now be obtained from Eq.4. The value of maximum difference between the primary drying and the primary wetting curves can be determined from Eq.2. By considering the maximum difference value, if the value is quite small, thus the effect of hysteresis can be neglected. For large value of maximum difference, the corresponding wetting curve can be constructed from the guide of the primary drying curve and the size of maximum difference.

One way to circumvent the hysteresis problem is using the average values of α and n in the van Genuchten equation (Eq. 1) from the primary drying and wetting curves. The primary wetting curve, however, can be obtained as discussed before.

CONCLUSION

The relationship of the air entry value to the degree of hysteresis of the six samples of saline soil shows that the higher the air entry value the lower the degree of hysteresis. This relationship is specifically applied for saline soil in northeast Thailand. To be generalized we need more experimental results of saline soils from many other places. However, our findings show that when dealing with coarser and well graded soils the air entry values are low therefore their degrees of hysteresis are high. As a consequence, the calculation of soil water flow in such soil without taking hysteresis of soil water retention curve into account can be inaccurate. For finer grain soils, the calculation of soil water flow by using a single water retention curve can be appropriate.

ACKNOWLEDGEMENT

The researchers would like to thank the Groundwater Research Center (GWRC), Faculty of Technology, Khon Kaen University for funding support. The Department of Agricultural Engineering and the Department of the Land Resources and Environment, Khon Kaen University for providing laboratory facilities

REFERENCES

1. Bear, J., 1972. Dynamics of Fluids in Porous Media. 1st Edn., American Elsevier, New York, ISBN: 10: 044400114X, pp: 764.

2. Guymon, G.L., 1994. Unsaturated Zone Hydrology. 1st Edn., Prentice Hall, Englewood Cliffs, New Jersey, ISBN: 10: 0133690830, pp: 224.
3. Hillel, D., 1980. Fundamentals of Soil Physics. 1st Edn., Academic Press, New York, ISBN: 0123485606, pp: 413.
4. Hillel, D., 1982. Introduction to Soil Physics. 1st Edn., Academic Press, New York, ISBN: 0123485207, pp: 392.
5. Hillel, D. and R.S. Baker, 1988. A descriptive theory of fingering during infiltration into layered soil. Soil Sci. Soc. Am. J., 146: 51-56. <http://journals.lww.com/soilsci/pages/articleviewer.aspx?year=1988&issue=07000&article=00008&type=abstract>
6. Jury, W.A., W.R. Gardner and W.H. Gardner, 1991. Soil Physics. 5th Edn., Wiley, New York.
7. Klute, A., 1972. The determination of hydraulic conductivity of unsaturated soil. Soil Sci. Soc. Am., 113: 264-276. <http://mdl.csa.com/partners/viewrecord.php?requester=gs&collection=ENV&recid=7212827&q=&uid=1245335&setcookie=yes>
8. Konyai, S., V. Sriboonlue, V. Trelo-ges and N. Muangson, 2006. Hysteresis of Water Retention Curve of Saline Soil. In: Unsaturated Soils 2006, Miller, G.A., C.E. Zapata, S.L. Houston and D.G. Fredlund (Eds.). Geotechnical Special Publication No. 147, The American Society of Civil Engineers, pp: 1394-1404.
9. Leong, E.C. and H. Rahardjo, 1997. Review of soil-water characteristic curve equations. J. Geotech. Geoenviron. Eng., 123: 1106-1117. <http://cat.inist.fr/?aModele=afficheN&cpsid=2086513>
10. Rawls, W.J., L.R. Ahuja, D.L. Brakensiek and A. Shirmohammadi, 1992. Infiltration and Soil Water Movement. In: Handbook of Hydrology, Maidment, D.R. (Ed.). McGraw-Hill, New York.
11. Taylor, S., 1993. Dryland Salinity. Introductory Extension Notes, Department of Conservation and Land Management. 2nd Edn., Soil Conservation Service of New South Wales, Australia.
12. Wang, Z., L. Wu and Q.J. Wu, 2000. Water-entry as an alternative indicator of soil water-repellency and wettability. Hydrol. Res., 231-232: 77-83. <http://cat.inist.fr/?aModele=afficheN&cpsid=1485846>
13. van Genuchten, M.T. and P.J. Wierenga, 1976. Mass transfer studies in sorbing porous media I. Analytical solutions. Soil Sci. Soc. Am. J., 40: 473-480. <http://soil.scijournals.org/cgi/content/abstract/40/4/473>