AJSTD

Vol. 31, No. 2, 2014
ISSN 0217-5460

A Journal of the ASEAN Committee on Science & Technology

ASEAN Journal on Science & Technology for Development

ABOUT THE ASEAN JOURNAL ON SCIENCE AND TECHNOLOGY FOR DEVELOPMENT

The ASEAN Journal on Science and Technology for Development is a refereed Journal of the ASEAN Committee on Science and Technology (ASEAN COST). It reports on science and technology policies and programmes, and research activities undertaken by COST in support of social and economic development of the ASEAN member countries.

The coverage is focused but not limited to, the main areas of activity of ASEAN COST, namely, Biotechnology, Non-Conventional Energy Research, Materials Science and Technology, Marine Sciences, Meteorology and Geophysics, Food Science and Technology, Microelectronics and Information Technology, Space Applications, and Science and Technology Policy, Infrastructure and Resources Development.

ABOUT THE ASEAN COMMITTEE ON SCIENCE AND TECHNOLOGY

The ASEAN Committee on Science and Technology was established to strengthen and enhance the capability of ASEAN in science and technology so that it can promote economic development and help achieve a high quality of life for its people. Its terms and reference are:

- To generate and promote development of scientific and technological expertise and manpower in the ASEAN region;
- To facilite and accelerate the transfer of scientific and technological development among ASEAN countries and from more advanced regions of the world to the ASEAN region;
- To provide support and assistance in the development and application of research discoveries and technological practices of endogenous origin for the common good, and in the more effective use of natural resources available in the ASEAN region and in general; and
- To provide scientific and technological support towards the implementation of existing and future ASEAN projects.

Information on the activities of ASEAN COST can be obtained at its website http://www.asnet.org

DISCLAIMER

While every effort is made to see that no inaccurate or misleading data, opinion or statement appears in the Journal, articles and advertisements in the Journal are the sole responsibility of the contributor or advertiser concerned. They do not necessarily represent the views of the Editors, the Editorial Board nor the Editorial Advisory Committee. The Editors, the Editorial Board and the Editorial Advisory Committee and their respective employees, officers and agents accept no responsibility or liability whatsoever for the consequences of any inaccurate or misleading data, opinion or statement.

Publisher

Universiti Putra Malaysia Press

Contents

ASEAN J. Sc. Technol. Dev.
Volume 31(2), 2014

ASEAN J. Sci. Technol. Dev., **31(2)**: 49 – 61

Drivers and Barriers for Going Green: Perceptions from the Business Practitioners in Malaysia

S-P. LOKE[1]*, K. KHALIZANI[2], S. ROHATI[1] AND A. SAYAKA[3]

The changes of global environmental conditions have placed great challenges to governments and societies. While it is not easy for the companies to go green, we need a renewed concern for our environment in order to revive the nation's economic growth, social cohesion and ecological balances. This article identifies the drivers and barriers for the business industry to adopt green practices. A total of 571 business companies from the Perak State participated in this study. Four variables: (1) Regulations (β=0.159, $p<0.05$); (2) Social responsibility (β=0.201, $p<0.05$); (3) Pro-environmental organizational culture (β=0.389, $p<0.01$); and (4) Organizational supports (β=0.369, $p<0.01$) were found to significantly affect the company's green initiatives. The results indicated that the main internal barriers were: it lacked of financial resources (66.2%) and skilled staff (63.9%); whereas the main external barriers were: the penalty imposed were not severe enough for making any extra efforts (64.8%) and the penalty was light for violation of environmental regulations (63.2%). This research had implications for the academics, practitioners and policy makers. It provided greater insights into the green practices in Malaysian firms. The research findings also urged the local governments to greatly enhance regulatory scrutiny on the production and manufacturing industries.

Key words: Green practices; going green; environmental strategy; regulations; social responsibility; barriers; industries

Today, all nations — regardless of whether they are developed economies or emerging economies — are challenged with highly visible ecological problems (Hart 2000). Pollution and climate changes have impacted not only the physical environment, but also the terrestrial and marine ecosystem as well as the society at large. While rapid economic development and population growth are some of the root causes, business organizations are often blamed mainly for these environmental problems.

Malaysia has become a more polluted country as reported by the Climate Change Performance Index (CCPI) 2014. This CCPI generally measures the climate protection performance of 61 countries aiming to enhance transparency in international climate politics. Malaysia together with countries like China and Singapore, appeared in the bottom-ranked group of newly industrialised countries for being one of the largest carbon dioxide emitters (*Figure 1*).

Although Malaysia has climbed from 55th position in 2013 to 51st this year, among the ASEAN member countries including India, China, Japan and Korean Republic, it has scored the lowest position based on the score of CCPI (*Figure 2*).

[1] Faculty of Business Management, Universiti Teknologi MARA, Perak Campus, Bandar Seri Iskandar, 36210 Bota, Perak
[2] Faculty of Business Management, Universiti Teknologi MARA Kedah, Kedah Campus, 08400 Merbok, Kedah
[3] Institute Darul Rizduan, B-1-9, Greentown Suria, Jalan Dato' Seri Ahmad Said, 30450 Ipoh, Perak
* Corresponding author (e-mail: lokesp@gmail.com; loke4529@perak.uitm.edu.my)

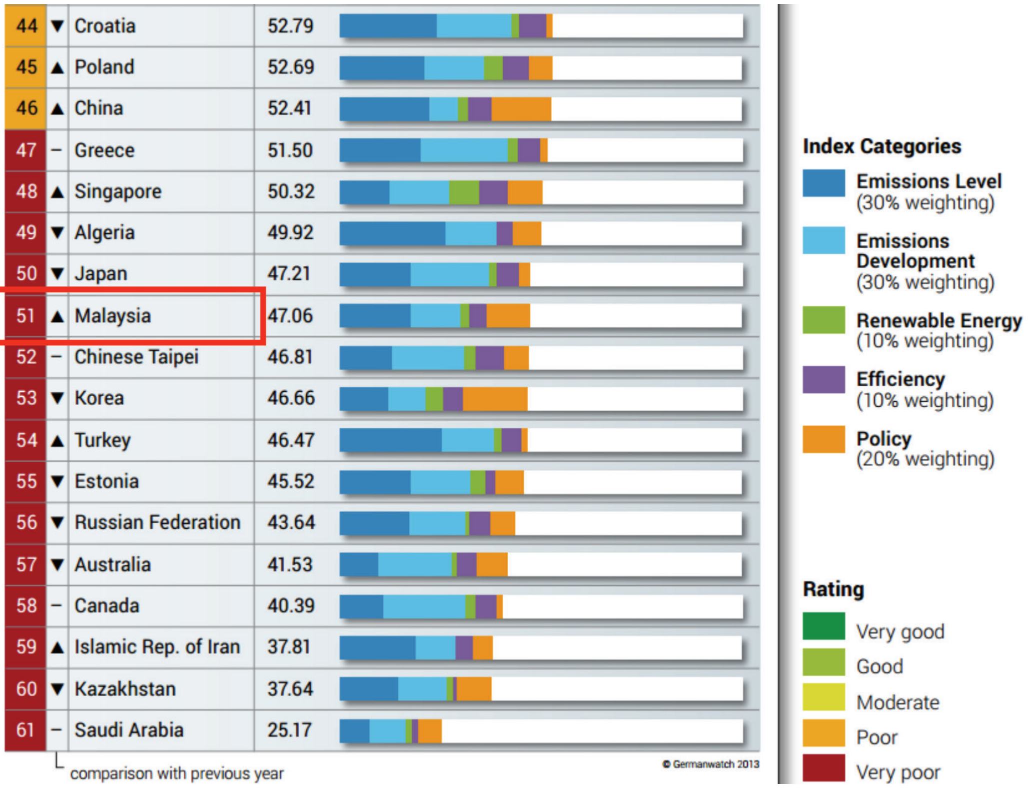

*Figure 1. Climate Changes Performance Index for Newly Industrialized Countries (*CCPI 2014*).*

Rank	Country	Score	Rank	Country	Score	Rank	Country	Score
30	India	57.16	46	China	52.41	51	Malaysia	47.06
34	Indonesia	56.24	48	Singapore	50.32	52	Chinese Taipei	46.81
38	Thailand	54.51	50	Japan	47.21	53	Korea	46.66

© Germanwatch 2013

*Figure 2. Climate Changes Performance Index for ASEAN countries including India, China, Japan and Korean (*CCPI 2014*).*

According to Perry and Singh (2001), the environmental problems of Malaysia are concentrated in the main centres of economic activity such as Kuala Lumpur, Klang Valley, Penang and Johor. A study conducted almost two decades ago on 3889 Malaysian manufacturing industries revealed that industries with foreign investment dominant in electronics and chemicals had higher compliance rate under the respective regulations (Perry & Singh 2001). Although as early as in 1974, the regulation framework was already in place to mitigate the industrial pollution problems, the monitoring and enforcement mechanisms were found to be limited.

Chen, Shih, Shyur, and Wu (2012) argued that the increased public attention of sustainability and environmental issues and those regulations such as Waste Electrical Electronic Equipment and Eco-design Requirement for Energy Using Product were established. Undoubtedly, the proliferation of research on renewable energy and environmental protection is largely due to the impacts of climate change and declining fossil fuel reserves. Hong, Roh and Rawski (2012) added that there is an urgency for firms to be responsive towards ecological or natural environment in order to sustain and preserve the wealth of natural resources for our next generations.

LITERATURE REVIEW

Businesses have increasingly embraced green concept in their marketing efforts (Raska & Shaw 2012). David (2012) added that consumers today are attracted to businesses that preserve nature's ecological balance and foster a clean and healthy environment. Thus, any green initiative should be sufficiently visible for gaining attention from the customers as there is an increased demand in green practices from them (Andic, Yurt & Baltacioglu 2012). For example, ElTayeb, Zailani and Jayaraman (2010) found that customer pressure is one of the drivers for green purchasing in Malaysia.

The triple focus on green productivity — environment, quality, and profitability — is aimed to ensure long-term survival of the firms (Diabat & Govidan 2011). More interestingly, smart companies could actually use environmental strategy to innovate, create value, and build competitive advantages. The business world has created numerous opportunities of innovation which firms have become the leading of sustainability movement in many ways.

> *Environmental leaders see their business through an environmental lens, finding opportunities to cut costs, reduce risk, drive revenues, and enhance intangible value. They build deeper connections with customers, employees, and other stakeholders. Their strategies reveal a new kind of sustained competitive advantages that we call Eco-Advantage (Esty & Winston 2009, p.14).*

As highlighted by the authors of *Green to Gold*, the eco-advantage mindset is a powerful motivator to help companies to face challenges and find new ways to seize advantages. In fact, the Green Wave has swept across the business world forcing the companies to react and these trends and forces will continue to evolve. Being eco-efficient is one of the crucial determinants to survive in a cost-conscious world. Such restructured landscape requires a new refined business strategy. Some companies and sectors have responded faster than others. Companies must be creative to break out of the pack. This is because those that do not will struggle to remain competitive in the marketplace.

The sustainability and sustainable development defined by the World Commission on Environment and Development as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Loucks, Martens & Cho, 2010). Similarly, Kleindorfer, Singhal, and Wassenhove (2005) stated that sustainability is the co-ordination of resources in meeting people's wants for a satisfying life, besides the necessity to respect the bottom line of three "Ps", which are planet, people and profit.

Environmental sustainability is related to the proper and efficient use of natural resources over time whereas the firm sustainability refers to its ability to gain long-term returns. These two concepts are closely related because environmental principles and guidelines can generate green innovations which are in fact, reducing cost, rising up the productivity and increasing the companies' competitive capabilities. Therefore, many different theories and empirical research have been dedicated to explore on the implementation and effects of green practices such as eco-design, cleaner production practices and waste management, environmental purchasing, and green/ reverse logistics.

In Malaysia, new controls on hazardous waste have been added to the *Environmental Quality (Amendment) Act 1996* (Perry & Singh (2001). Sani (1999) stated that this amendment has included substantial increases to penalties for a range of environmental offenses as to exert compliance pressure on the industry. Similarly, the Malaysian government has demonstrated an increased willingness to accept outside influence on environmental performance. For example, the international criticisms on domestic forestry have resulted in the establishment of the National Timber Certification Centre with the industry partners in order to create the Malaysian Criteria and Indicators for Sustainable Forest Management. Perry and Singh (2001) added that the growing public awareness and media coverage have placed increased emphasis on these environmental issues in the Seventh Malaysia Five-Year Plan.

Indeed, we must stabilize and reduce the environmental burdens in order to achieve sustainability. Under the New Economic Model, the Malaysian government has embarked on the green initiatives as one of the nation's new economic drivers and transforming the country to become a high income nation by year 2020. While driving Malaysia towards greater economic development, these initiatives provide a valuable framework on conservation and protection of the nation's heritage and natural environment.

Meanwhile, the National Green Technology Policy was successfully launched by the Prime Minister of Malaysia on 24 July 2009. The National Green Technology Policy is built on four pillars — Energy, Environment, Economy and Social. Green Technology is aimed to be the key driver in accelerating the national economy and promoting sustainable development in Malaysia. The Malaysia Green Technology Corporation or known as GreenTech Malaysia has been striking not only to develop green technology roadmap and standards, but also to promote an environmental friendly living culture at large.

We know anecdotally better environment management strategy enhances the competitiveness of a firm. The environmental mismanaging, however, can damage the brand reputation, destroy its competitiveness and sometimes can knock off the value of the company overnight. As such, a more positive attitude towards environmental issues, e.g. the adoption of green manufacturing would institutionalize the companies' awareness on environmental concerns which could bring indirect benefits through better quality of their manufacturing operations.

Businesses face challenges in implementation of environmental initiatives especially when striking the balance of profitability and corporate social responsibility. Pressures came from various sources so that their products are environmental friendly (ElTayeb *et al.* 2010). According to Orsato (2006), the difficult aspect of environmental initiatives is the basic reasoning on environmental protection because such a move is strongly known as a public good. Although literature demonstrates that effective environmental management generate eco-advantages for the companies, Esty and Winston (2009) argued that capturing these advantages require expertise and capabilities to master the whole range of related issues. Often, the company has struggled to push for green effort due to private costs of prevention and clean up which lead to higher operational costs and thus reduces its industrial competitiveness (Porter & Van Der Linde 2000).

The environmental effort does not always produce superior results. They may fail because of poor planning, an absence of commitment and not having the right people in the key roles. Some of the business strategies did not work well due to focusing on the wrong issues, marketplace is misunderstood, the customer responses towards green products are interpreted wrongly and therefore the implementation on the environmental thinking in the business was not successful.

Nevertheless, the consciousness of issues on environmental sustainability and the need to comply with the standards are critical to drive companies to embark on greater environmental commitment. However, there is a clear lack of empirical research in emerging economies. We need a greater understanding on the awareness of business industry's environmental management strategy particularly within the Malaysia setting. Based on this notion, the objective of this study was two-fold: (1) To examine the factors influencing the business firms' attitude towards environmental commitment, and (2) To identify the barriers that inhibit them to go green. Understanding the fundamental factors for business practitioners to go green is indeed crucial because these identified key factors can serve as a springboard to better promote the firm's commitment to go green. It is hoped that the research findings on sustainable development practices can shed lights for the nation especially for the State Governments to better manage the balance between economic growth and ecological sustainability.

METHODOLOGY

Research Design and Sampling

The study was designed to test a structural model whether these variables namely Regulations, Social Resposbility, Customer Pressure, Pro-Environmental Organizational Culture and Organizational Supports would lead to a greater level of company's commitment to venture into green initiatives. These variables were identified through a comprehensive review of the relevant literature. The research instrument was adapted from previous studies. A focus group was conducted with six industry panels to validate the questionnaire before data collection.

In this study, managers and executives from the manufacturing firms located within the state of Perak were targeted. The firms were selected from the *Federation of Malaysian Manufacturers Directory 2013*. Manufacturing firms were chosen because operations of these industrial companies are frequently and directly related to the environment — from pollution control to the most innovative green initiatives.

Questionnaires were personally hand-delivered to a sample of 1000 randomly selected companies located in the state of Perak. The researchers also contacted SME Corp. (Perak office) and Federal of Manufacturing Malaysia (FMM) (Perak Branch) to seek for their members' participation in this study. Data collection was carried out from August to October 2013. Based on these 1000 questionnaires originally distributed, a total of 571 of them were found completed and usable, yielding a response rate of 57.1%.

Profiling of the Participating Firms

There were a total of 571 companies (FMM directory and SMEs in Perak) which participated in this research: 561 manufacturer and 10 services companies. Majority of the participating companies were from the electrical, machinery and apparatus industries (31.2 per cent) followed by the food products and beverage industries (24.5 per cent) (*Figure 3*).

The participating companies mostly concentrated their businesses on both local and international markets with 63.8%. The

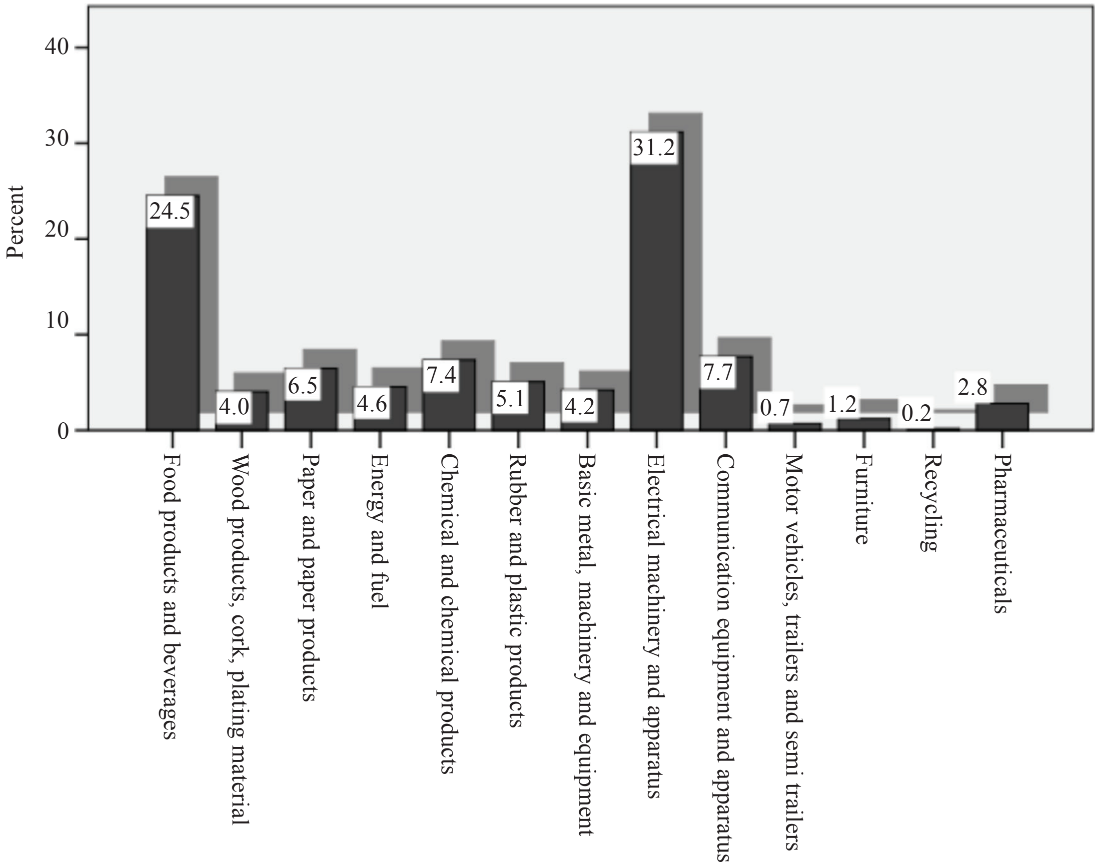

Figure 3. Industrial category of the participating firms.

participating companies were Malaysian-owned firms (78.6%) whereas the foreign-owned firms accounted for approximately 20 percent, and joint ventures accounted for less than 1 percent. Also, we found that most of these companies fell into the category of having workers between 21 to 100 employees and between 101 to 200 employees with 28.7% and 27.8%, respectively. In addition, when the responding companies were asked to indicate their certification of ISO for quality and environmental management, it was found that adoption for quality was much greater as compared to environmental management such as *ISO 14001* (Environmental Management System (Specifications with guidance for use).

DATA ANALYSIS

Before conducting the analysis for structural modelling, the validity and the relability of the survey instrument were generated. Data used for final data analysis was 562 after the data with outliners were eliminated. As shown in *Table 1*, the results indicated that all values for the validity and reliability tests were within the acceptable range. Except for item RG6, all factor loadings for each indicator were >0.5 indicating a high convergent validity. All cronbach alpha values were >0.70 demostrating a high consistency of the items used to measure each variable (i.e. regulations, social responsibility, customer pressure, pro-environmental organizational cultures,

Table 1. Results for validity and reliability test (n=562).

Variables and items	Indicators	Factor loadings	Total items	Cronbach Alpha
Regulations	RG1	0.69	6	0.807
	RG2	0.78		
	RG3	0.71		
	RG4	0.66		
	RG5	0.52		
	RG6	0.49		
Social responsibility	SR1	0.61	7	0.811
	SR2	0.63		
	SR3	0.64		
	SR4	0.62		
	SR5	0.70		
	SR6	0.59		
	SR7	0.53		
Customer Pressure	CP1	0.63	6	0.801
	CP2	0.61		
	CP3	0.70		
	CP4	0.67		
	CP5	0.61		
	CP6	0.58		
Pro-environmental organizational cultures	PE1	0.52	7	0.814
	PE2	0.65		
	PE3	0.66		
	PE4	0.72		
	PE5	0.73		
	PE6	0.51		
	PE7	0.57		
Organizational support	OS1	0.64	7	0.800
	OS2	0.65		
	OS3	0.63		
	OS4	0.55		
	OS5	0.61		
	OS6	0.64		
	OS7	0.50		
Green responsive initiatives (GRI)	GRI1	0.57	5	0.782
	GRI2	0.62		
	GRI3	0.59		
	GRI4	0.63		
	GRI5	0.59		

Note: GRI measures the company's willingness and current efforts to go green.

organizational supports and green responsive initiative. Thus, it was concluded that the survey instrument for measuring the variables were valid and reliable.

Structural Model Evaluation

Using the SPSS AMOS, the structural model was generated to examine these critical factors: regulations, social responsibility, pro-environmental organizational culture, organizational support and customer pressure on the company's proactiveness in environmental commitment. In this study, multiple fit indices were used: (1) chi-square (χ^2); statistics to the degree of freedom (*df*); (2) the Comparative Fit Index (CFI); and (3) RMSEA (Root Mean Square error of approximation) as suggested by Hair *et al*. (2010). The goodness of fit index measures if the model was adequately fit.

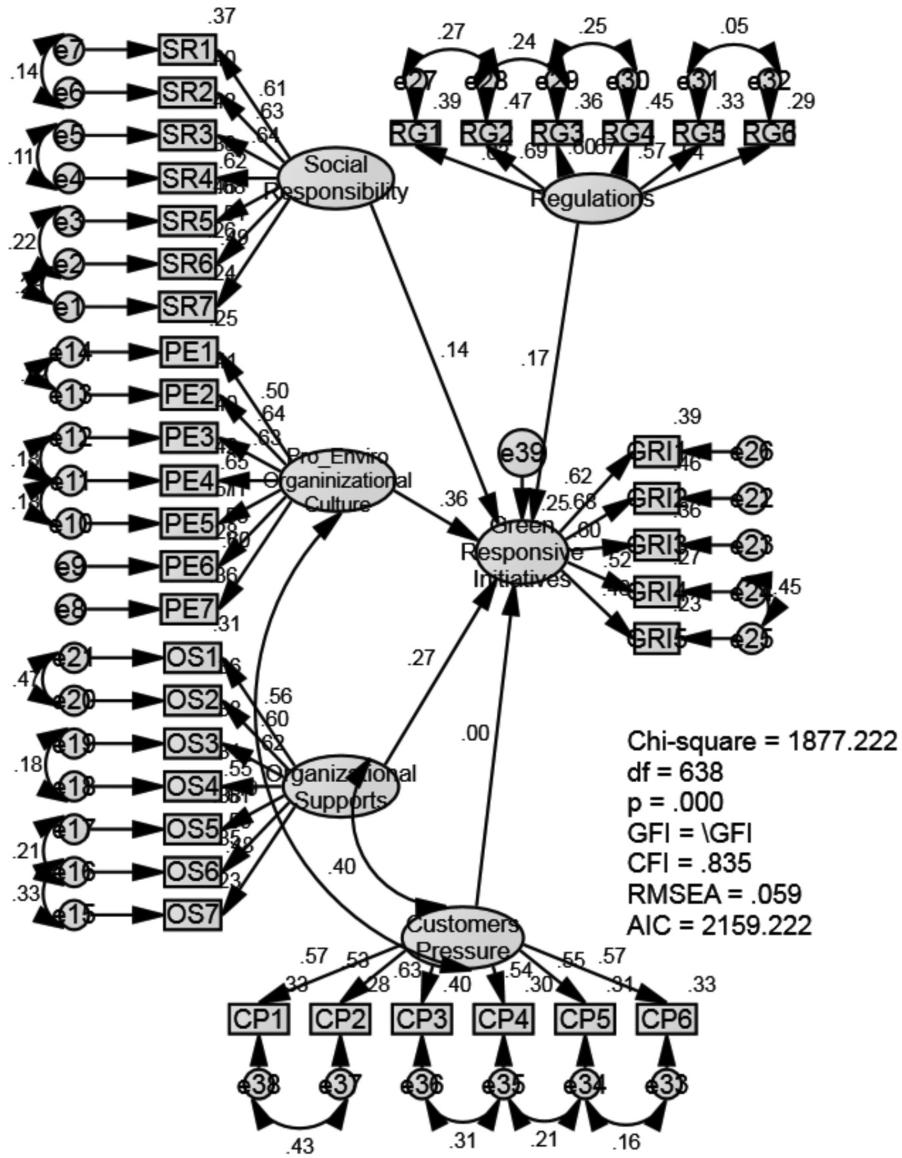

*Figure 4. The path diagram for structural model (*n=562*).*

The χ^2 statistics to *df* should be less than 3; goodness of fit indexes such as GFI, CFI and NFI should be as close to 1.00. The error indexes such as RMSEA and RMR should be as minimum as possible and values ranging 0.05 to 0.08 were deemed accepted. As shown in *Figure 4*, the results of the structural model analysis was deemed to have a reasonable good fit for the data collected [chi-square (χ^2) = 1872.222; degree of freedom (*df*) = 6338; chi-square (χ^2)/*df* = 2.934; CFI = 0.835; RMSEA = 0.059].

Drivers for Business to Go Green

The results have revealed that that only four variables: (1) Regulations (β=0.159, $p<0.05$); (2) Social responsibility (β=0.201, $p<0.05$); (3) Pro-environmental organizational culture (β=0.389, $p<0.01$); and (4) Organizational support (β=0.369, $p<0.01$) had significantly impacted the company's Green responsive initiative (GRI). However, customer pressure was not the driver that motivated the business industries in Perak to adopt go green initiatives.

Barriers for Business to Go Green

As illustrated in *Table 2*, a total of 18 barriers that determining the low commitments towards the environmental protection were identified.

These 18 factors were then divided into both internal and external barriers. The internal barriers were grouped into three categories: (1) Resources, (2) Implementation, and (3) Attitudes and company cultures. In this study, both human and financial resources were

Table 2. Internal and external barriers to go green.

	Resources	Implementation	Attitudes and company culture
Internal Barriers	• Excessive financial constraints. • Lack of management commitment and/or supports. • Lack of engagement/ commitment from staff. • Lack of time and resources to focus on environmental issues. • Insufficient training regarding the importance of pro-environmental behaviour. • Lack of availability of skilled staff.	• Unclear leadership strategy and goals towards environmental issues. • Unclear responsibility regarding who is in charge of environmental policy/ practice. • Lack of clarity among line managers regarding whether they are responsible for environmental issues.	• Focuses on cost savings. • Prioritizes on commercial needs above environmental concerns. • Complies with minimum criteria set by the relevant authority in order to lower the overall costs. • Low awareness on environmental issues. • All pro-environmental efforts were way too expensive to carry out. • Lack of organizational concern for environmental sustainability.
External Barriers	• Insufficient incentives in place to encourage environmental behavior. • Penalty for violation of government environmental legislations was light. • Penalty for violation of government environmental legislations was not severe enough for making any extra efforts.		

cited to be the major barriers for the company to go green. The financial constraint was the frequent reason why the company was having unfavourable attitude towards greater environmental management efforts. They strongly believed that the implementation of these green practices did not only cut into their profits but also required higher maintenance costs.

We found that there were companies that were more open and willing to go green, but the lack of specialized and technical skills had pulled them back. The belief of the management on the derived benefits from environmental practices would ultimately determine the level of commitment towards green efforts. This is because such commitment would create a climate to either deprive or support the environmental management e.g. consistency of these top management supports, revision of company's priority and allocation of resources. Thus, implementation process could be greatly interrupted without an appropriate corporate culture and full support from the management.

The shortcomings in the governmental framework were also found to have hindered the company to have greater commitment in green practices. The penalty for violation of environmental legislations was said to be light and did not warrant extra efforts from the management. Thus, the company often undertake the bare minimum to fulfil legislation requirements. While there were financial initiatives offered by the Malaysian government such as grants and corporate tax reductions to promote greater green initiatives, the respondents from the focus group had highlighted that these incentives were considered to be a weak motivator.

Figure 5 illustrates the top five barriers that inhibit the company to go green which were drawn from both the internal and external barriers. The percentage was derived from the scores on "very significant" and "significant" when the responding companies were asked to indicate the extent of these challenges they faced in initiating green efforts.

DISCUSSION AND RECOMMEDATIONS

Based on the research findings, it was found that the business industries faced both internal and external barriers when seeking to address their environmental issues and to embark on green practices. While the results had showed

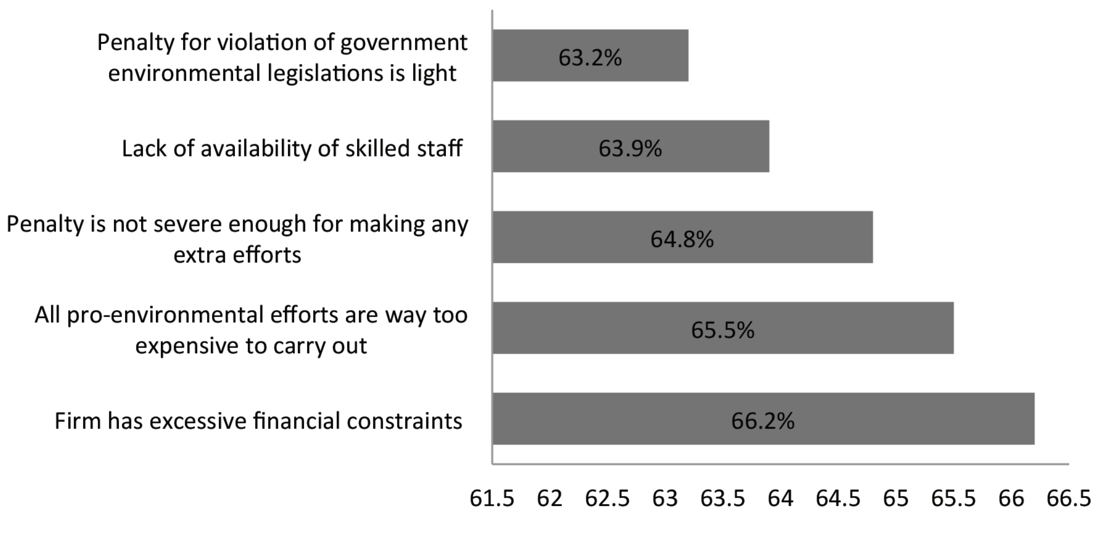

Figure 5. Top five barriers for participating firms to go green (n=571).

internal barriers such as lack of financial resources and skilled staff were of great hindrance, the participating firms also indicated that the penalty for violating the environmental regulations were not severe to justify greater efforts and commitment. In fact, it was cited as the 3rd most significant barriers for their green responsive initiative.

Previous findings e.g. ElTayeb *et al*. (2010) showed that the customer pressure was a driver for green purchasing among Malaysian customers. However, in this study, we found that such external pressure from the customers did not motivate the business industries in Perak to go green. The study by ElTayeb *et al*. (2010) focused on the green activities in relation to the suppliers meanwhile this current research went beyond the purchasing activity and looked into the overall green practices of the companies. As revealed in the path analysis results, the structural model had depicted the following four important drivers for green responsive initiative: requirement from regulations; the company's social responsibility; the pro-environmental organizational culture; and the organizational supports. Since the "pro-environmental organizational culture" was found to have the highest value of beta coefficient (β), it meant that this factor played the most significant role in promoting the firms to adopt green practices. Thus, new approaches should be developed to involve major internal stakeholders in participating in strategic environmental planning and defining concrete targets and deadlines for green practices.

Regulatory pressure was found to be another key driver for green responsive initiative. Therefore, regulatory programme should be set up to ensure the compliance of environmental requirement and standard. There was a greater need to strengthen (1) the liability legislation in order to better compensate for damages to the environment in line with the 'polluter pays' principle, and (2) the enforcement capacity of local government agencies to carry out their new environmental functions. Indeed, there appeared to be a widely held scepticism in the enforcement of environmental laws in our country. We urge the local government to enhance regulatory scrutiny on the production and manufacturing industries. However, we believe that the business owners and management should be proactive in taking positive environmental actions. They should be more sensitive not only on the awareness of legislation but also on the benefits of going green, both in their business sustainability and society at large.

Meanwhile, we also call to alleviate the public concern near waste disposal facilities by adopting stricter emission standards, improving monitoring of emissions and paying adequate compensation; reduce government subsidisation of recycling by shifting greater responsibility to producers and creating adequate economic incentives to reduce waste generation; and to extend environment impact assessment (EIA) procedures to better integrate environmental concerns in sectorial projects and programme. Finally, we strongly believe that wider implementation of programme such as Eco-Labelling Scheme, MyHijau Label and GreenTAG could further promote the environmental friendly living culture and thus indirectly motivate greater commitment for businesses to go green.

CONCLUSION

This study aimed to identify the drivers and barriers for the business industry to implement green practices. It had implications for the academics, practitioners and policy makers. Firstly, it adds to the body of knowledge on green practices particularly within the Asian settings. Secondly, the results could be valuable to the managers by providing greater insights into green practices in Malaysian firms. The regulations, social responsibility, pro-environmental organizational culture and organizational supports were found to have significant impacts on the company's green initiatives. The environmental management standards of different organizations might vary in details and they are often subjected to the key elements of an environmental policy statement, objectives and targets, implementation procedures, internal monitoring, auditing and reporting. However, the adoption of *ISO 14001* Environmental Management System (Specifications with guidance for use) was found as one of the most obvious determinations on a firm's commitment towards adopting green efforts.

Thirdly, the results could also help the government to further plan and enhance current guidelines and policies. In this study, we had highlighted the key internal and external barriers for firms to adopt green initiatives. The regulatory pressure is said to be a major driver for their environmental performance as it pushes the companies to respond and react. We believe that a more stringent monitoring from the government on the firm's compliance to the environmental regulations. Effective law enforcement is equally important to ensure the adherence towards the environmental standards by businesses.

Date of submission: August 2014

Date of acceptance: December 2014

ACKNOWLEDGEMENT

The authors would like to thank the Institute Darul Ridzuan (IDR) for financially supporting this research under KRA Perak Amanjaya Project.

REFERENCES

Andic, E, Yurt, O & Baltacioglu, T 2012, 'Green supply chain: efforts and potential applications for the Turkish market', *Resources, Conservation and Recycling*, vol. 58, pp. 50–68.

Chen, CC, Shih, H-S, Shyur, H-J & Wu, K-S 2012, 'A business Strategy selection of green supply chain management via an analytic network process', *Computers and Mathematics with Applications,* vol. 64, pp. 2544–2557.

CCIP 2014, *Climate change performance index*, <https://germanwatch.org/en/download/ 8599.pdf>.

David, FS 2011, *Strategic management: concept and cases*, 14th edn, Pearson Prentice Hall International.

Diabat, A & Govindan, K 2011, 'An analysis of the drivers affecting the implementation of green supply chain management', *Resources, Conservation and Recycling,* vol. 55, pp. 659–667.

ElTayeb, TK, Zailani, S & Jayaraman, K 2010, 'The examination on the drivers for green purchasing adoption among *EMS 14001* certified companies in Malaysia', *Journal of Manufacturing Technology Management*, vol. 21, no. 2, pp. 206–225.

Esty, DC & Winston, AS 2009, *Green to gold: how smart companies use environmental strategy to innovate, create value and build competitive advantage*, John Wiley & Sons Inc.

Hair Jr. JF, Black, WC, Babin, BJ & Anderson, RE 2010, *Multivariate data analysis: a global perspective*, Pearson, London.

Hart, SL 2000, 'Beyond greening: strategies for a sustainable world', *Harvard Business Review*, vol. 72, no. 3, pp. 46–52.

Hong, P, Roh, JJ & Rawski, G 2012, 'Benchmarking sustainability practices: evidence from manufacturing firms', *Benchmarking: An International Journal*, vol. 19, nos. 4/5, pp. 634–648.

Kleindorfer, PR, Singhal, K & Van Wassenhove, LN 2005, 'Sustainable operations management', *Production and Operations Management*, vol. 14, pp. 482–492.

Loucks, ES, Martens, ML & Cho, CH 2010 'Engaging small- and medium-sized businesses in sustainability', *Sustainability Accounting, Management and Policy Journal*, vol. 1, no. 2, pp. 178–200.

Orsato, RJ 2006, 'Competitive environmental strategies: when does it pay to be green?', *California Management Review*, vol. 48, no. 2, pp. 27–144.

Perry, M & Singh, S 2001, 'Corporate environmental responsibility in Singapore and Malaysia: the potential and limits of voluntary initiatives', *Technology, Business and Society,* United Nations Research Institute for Social Development.

Porter & Van Der Linde 2000, 'Green and competitiveness: ending the stalement', *Harvard Business Review*, vol. 72, no. 3, pp. 131–167.

Raska, D & Shaw, D 2012, 'When is going green good for company image?', *Management Research Review*, vol. 35, nos. 3/4, pp. 326–347.

Sani, S 1999, 'Environmental Management Issues and Challenges in the Next Millennium in Malaysia', *Environmental Management Programme*, Universiti Kebangsaan Malaysia, Bangi, Malaysia.

ASEAN J. Sci. Technol. Dev., **31(2)**: 62 – 82

Generalized Fuzzy Filters in Ordered Ternary Semigroups

M. J. KHAN[1], A. KHAN[1*] AND N. H SARMIN[2]

In this paper, the concept of (α,β)-fuzzy generalized filters in an ordered ternary semigroup S is introduced, where $\alpha,\beta \in \{\in, q, \in \vee q, \in \wedge q\}$ with $\alpha \neq \in \wedge q$. We discussed some fundamental properties of $(\in, \in \vee q)$-fuzzy filters and introduced $(\overline{\in}, \overline{\in} \vee \overline{q})$-fuzzy filters. Some related properties of $(\overline{\in}, \overline{\in} \vee \overline{q})$-fuzzy filters were provided and the relation between ordinary fuzzy filters, $(\in, \in \vee q)$-fuzzy filters and $(\overline{\in}, \overline{\in} \vee \overline{q})$-fuzzy filters were also investigated.

Key words: Fuzzy filters; (α,β)-fuzzy filters; $(\in, \in \vee q)$-fuzzy filters; $(\overline{\in}, \overline{\in} \vee \overline{q})$-fuzzy filters

Lehmer (1932) introduced the concept of ternary semigroup. J. Los (1955) studied some properties of ternary semigroups and proved that every ternary semigroup can be embedded in a semigroup. Cayley and Sylsester along with several other mathematicians, in the 19th century considered ternary algebraic structures and cubic relations. Let S be a non-empty set, a fuzzy set, by definition, is an arbitrary mapping $f: S \longrightarrow [0,1]$ where $[0,1]$ is the usual interval of real numbers. The important concept of fuzzy set, introduced by Zadeh in 1965 (Yuen *et al*. 2003), has opened up keen insights and applications in wide range of scientific fields. Mordeson *et al*. (2003) gave an up-to-date account of fuzzy sub-semigroups and fuzzy ideals of a semigroup. It gives applications of fuzzy sub-semigroups in the field of fuzzy coding, fuzzy languages and fuzzy finite state machines. The notions of (α,β)-fuzzy subgroups was first introduced by Bhakat and Das (1996). They use the "belong to" relation $(\in)$ and "quasi coincidence" relation (q) to introduce the concept of $(\in, \in \vee q)$-fuzzy subgroup which is, in particular, an important and useful example of Rosenfeld's (1971) subgroup. Since then Kuroki introduced the notion of fuzzy bi-ideals in semigroups. Jun and Song (2006) introduce the general forms of fuzzy interior ideals in semigroup. Generalization of fuzzy bi-ideals in terms of $(\in, \in \vee q)$-fuzzy bi-ideals was given by Kazanchi and Yamak (2008). The generalization of fuzzy bi-ideals in semigroups was given by Jun *et al*. (2009). He gave characterizations of regular ordered semigroups in terms of fuzzy generalized fuzzy bi-ideals. The notion of fuzzy filter in an ordered semigroups was introduced by Kehaypulu and Tsingelis (2002). An ordered semigroup is a partially ordered set which is both left and right compatible with the semigroup operation. Applications of ordered semigroup are found in the theory of sequential machines, computer arithemetics, formal languages, error correcting codes and design of fast adders. An ordered ternary semigroup is an ordered semigroup with the property of associativity of its elements with respect to the ordered semigroup operation. In 2008, Shabir and Khan studied fuzzy filters in ordered semigroups (Shabir & Khan 2008. Davvaz and Khan (2013) gave

[1] Department of Mathematics, Abdul Wali Khan University, Mardan, KPK, Pakistan
[2] Department of Mathematical Sciences, Faculty of Science, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
* Corresponding author (e-mail: azhar4set@yahoo.com)

the concept of generalized fuzzy filters in ordered semigroup. They provide different characterizations of ordered semigroup by using (α,β)-fuzzy filters. In this work we will generalize (α,β)-fuzzy filters in ordered ternary semigroup. We will study $(\in,\in\vee q)$-fuzzy filters,$(\in,\in\vee q)$-fuzzy left (right, bi) filters and will give different characterizations of ordered ternary semigroup in terms of $(\in,\in\vee q)$-fuzzy filters and $(\in,\in\vee q)$-fuzzy left (right, bi) filters.

Preliminaries

A non-empty set T is called a *ternary semigroup* if there exists a ternary operation $T\times T\times T\rightarrow :(x_1,x_2,x_3)\longmapsto x_1x_2x_3$ satisfying the following property:

For all $x_1,x_2,x_3x_4,x_5\in T$, $[[x_1x_2x_3]x_4x_5]=[x_1[x_2x_3x_4]x_5]=[x_1x_2[x_3x_4x_5]]$. It is clear that every semigroup can be reduced to a ternary semigroup. However, Banach, showed that a ternary semigroup does not necessarily reduce to a semigroup by giving the following example.

Example 2.1 (Chinram & Saelee 2010)

$T=\{-i,0,i\}$ is a ternary semigroup but T is not a semigroup under the usual multiplication over complex numbers. The next example also shows that T is a ternary semigroup but is not a semigroup.

Example 2.2 (Chinram & Saelee 2010)

Z^- is a ternary semigroup but is not a semigroup under the multiplication over integers. Los (1955)showed that every ternary semigroup can be embedded into a semigroup. A partially ordered semigroup T is called an *ordered ternary semigroup* if for all $x_1,x_2,x_3x_4\in T$, $x_1\leq x_2\rightarrow x_1x_3x_4\leq x_2x_3x_4$, $x_3x_1x_4\leq x_3x_2x_4$, $x_3x_4x_1\leq x_3x_4x_2$.

Example 2.3 (Chinram & Saelee 2010)

$(Z^-,\cdot,\leq)$ is an ordered ternary semigroup. Throughout this paper T will denote ordered ternary semigroup, unless otherwise specified. Let A be a non-empty subset of T, we denote $(A]=\{x\in T : x\leq a$ for some $a\in A\}$. For non-empty subsets A,B,C, we denote $ABC=\{abc : a\in A, b\in B, c\in C\}$. A non-empty subset A of T is called a *ternary subsemigroup* T if $(A]\subseteq A$ and $AAA\subseteq A$.

Definition 2.4 (Chinram & Saelee 2010)

A non-empty subset F of T is called a *left filter* of T if it satisfies:

(1) $xyz\subseteq F$, for all $x,y,z\in F$.

(2) for all $x,y\in T$, $x\leq y$ and $x\in F\longrightarrow y\in F$,

(3) for all $x,y,z\in T$, $xyz\in F\longrightarrow z\in F$.

F is called a *right filter* of T if it satisfies conditions (1) and (2) of *Definition 2.4* and

(4) for all $x,y,z\in T$, $xyz\in F\longrightarrow y\in F$.

F is called *lateral filter T*, if it satisfies conditions (1) and (2) of *Definition 2.4* and

(5) for all $x,y,z \in T$, $xyz \in F \longrightarrow x \in F$

F is called a *filter* of T if it satisfies conditions (1) and (2) of *Definition 2.4* and

(6) for all $x,y,z \in T$, $xyz \in F \longrightarrow x,y,z \in F$.

Definition 2.5 (Chinram & Saelee 2010)

A fuzzy subset μ of T is called a *fuzzy left filter* (resp. *fuzzy right filter*) of T if for all $x,y,z \in T$ we have:

(1) $x \leq y \rightarrow \mu(x) \leq \mu(y)$,

(2) $\mu(xyz) \geq \min\{\mu(x), \mu(y), \mu(z)\}$,

(3) $\mu(xyz) \leq \mu(z)(resp.\ \mu(xyz) \leq \mu(x))$.

Let F be a non-empty subset of T. Then the characteristic function χ_F of F is defined by

$$\chi_F : T \rightarrow [0,1]$$
$$: x \mapsto \chi_F(x) = \begin{cases} 1 & \text{if } x \in F \\ 0 & \text{otherwise} \end{cases}$$

for all $x \in T$.

Obviously, a nonempty subset F of T is a filter if and only if the characteristic function χ_F of F is a fuzzy filter of T.

(α,β)-fuzzy Filters

Let T be an ordered ternary semigroup. A fuzzy subset μ of T defined by:

$$\mu : T \rightarrow [0,1],\ y \mapsto \mu(x) = \begin{cases} t & \text{if } y \leq x \\ 0 & \text{otherwise} \end{cases}$$

is called *an ordered fuzzy point with support* x and *value t* and is denoted by x_t. Pu and Liu (1980) gave the meaning of symbols $x_t \alpha \mu$ where $\alpha \in \{\in, q \in \vee q, \in \wedge q\}$. The symbol $x_t \in \mu$ (resp. $x_t q \mu$) means that $\mu(x) \geq t$ (resp. $\mu(x) + t > 1$) and say that the fuzzy subset x_t *belongs to* (resp. *quasi co-incident with*) μ. To say that $x_t \overline{\alpha} \mu$ means that the relation $x_t \alpha \mu$ does not hold. Let μ be a fuzzy subset of T, then for $t \in (0,1]$ the set $U(\mu;t) = \{x \in T : \mu(x) \geq t\}$ is called the *level subset* of μ.

Theorem 3.1 (Los 1955)
A fuzzy subset μ of T is a fuzzy filter of T if and only if the level subset $U(\mu;t)$ is a fuzzy filter of T.

Proof. Let $x,y \in T$, $x \leq y$ and $x \in U(\mu;t)$ for $t \in (0,1]$. Then $\mu(x) \geq t$. Since μ is fuzzy filter of T, we have $\mu(x) \leq \mu(y)$, $\mu(y) \geq t$ which implies that $y \in U(\mu;t)$. Let $t \in (0,1]$, $x,y,z \in U(\mu,t)$. Then $\mu(x) \geq t$, $\mu(y \geq t), \mu(z) \geq t$. Since μ is fuzzy filter of T, we have $\mu(xyz) \geq \min\{\mu(x),\mu(y),\mu(z)\} = t$, $xyz \in U(\mu;t)$. Let $x,y,z \in T$, $xyz \in U(\mu;t)$ for some $t \in (0,1]$. Then $\mu(xyz) \geq t$. Since μ is a fuzzy filter of T we have $\mu(xyz) \leq \min\{\mu(x),\mu(y),\mu(z)\}$, that is, $\mu(x) \geq t$, $\mu(y \geq t), \mu(z) \geq t$ which implies that $x,y,z \in U(\mu;t)$. Hence $U(\mu;t)$ is a fuzzy filter of T.

Conversely, assume that for a fuzzy subset μ of T and $t \in (0,1]$, the level subset $U(\mu;t)$ of μ is a filter of T. Let $x,y,z \in T$, $x \leq y$. If $\mu(x) = 0$ then $\mu(y) \geq 0 = \mu(x)$. If $\mu(x) = t(\neq o)$ then $x \in U(\mu;t)$. Since $U(\mu;t)$ is a filter of T, we have $y \in U(\mu;t)$, $\mu(y) \geq t = \mu(x)$. Let $x,y,z \in T$. Suppose that there exist $t \in (0,1]$ such that $\mu(xyz) \geq t > \min\{\mu(x),\mu(y),\mu(z)\}$. Then $xyz \in U(\mu;t)$ but $x,y,z \notin U(\mu;t)$ which is a contradiction to the fact that $U(\mu;t)$ is a filter of T. Hence $\mu(xyz) \leq \min\{\mu(x),\mu(y),\mu(z)\}$. Let $x,y,z \in T$. Let there exist $t \in (0,1]$ such that $\mu(xyz) < t \leq \min\{\mu(x),\mu(y),\mu(z)\}$. Then $x,y,z \in U(\mu;t)$ but $xyz \notin U(\mu;t)$ which is again a contradiction. Hence $\mu(xyz) \geq \min\{\mu(x),\mu(y),\mu(z)\}$. Thus μ is a fuzzy filter of T.

Example 3.2 (Davvas & Khan 2012)
Let $T = \{a,b,c,d,e,f\}$ be a set. Define a ternary operation $(\ \ )$ on T as $(abc) = a * b * c$, where the binary operation " $*$ " and order relation " $\leq$ " are defined as follows:

$*$	a	b	c	d	e	f
a	a	b	b	d	e	f
b	b	b	b	b	b	b
c	b	b	b	b	b	b
d	d	b	b	d	e	f
e	e	f	f	e	e	f
f	f	f	f	f	f	f

and

$$\leq : = \{(a,a),(b,b),(c,c),(d,d),(e,e),(f,f),(a,d),(a,e),(b,e),(d,e),(b,f),(c,f),(c,e),(f,e)\}.$$

Then $(T,(),\leq)$ is an ordered ternary semigroup. The subset $\{a,d,e\}$ and *T* are filters of *T*. Define a fuzzy subset μ of *T* as under:

$$\mu(e)=0.8,\ \mu(d)=0.7,\ \mu(a)=0.6,\ \mu(b)=0.4,\ \mu(c)=0.3,\ \mu(f)=0.5.$$

Then,

$$U(\mu;t)=\begin{cases} T & \text{if } 0<t\leq 0.3 \\ \{a,d,e\}, & \text{if } 0.5<t\leq 0.6 \\ \phi & \text{if } 0.8<t\leq 1 \end{cases}$$

Then by Theorem 3.1, μ is a fuzzy filter of *T*.

Theorem 3.3

Let μ be a fuzzy subset of *T*. Then $U(\mu;t)$ is a fuzzy filter of *T* for all $t\in(0,5,1]$ if and only μ satisfies the following conditions:

(1) $(\forall x,y\in T)(\max\{\mu(y),0.5\}\geq\mu(x)\text{with } x\leq y)$,

(2) $(\forall x,y,z\in T)(\max\{\mu(xyz),0.5\}\geq\min\{\mu(x),\mu(y),\mu(z)\})$,

(3) $(\forall x,y,z\in T)(\max\{\mu(x),\mu(y),\mu(z),0.5\}\geq\mu(xyz))$.

Proof. Suppose that $U(\mu;t)$ is a filter of *T* for all $t\in(0.5,1]$. Let us assume that there exist $x,y\in T$ with $x\leq y$ and $r\in(0,5,1]$ such that $\max\{\mu(y),0.5\}<\mu(x)=r$. Then $x\in U(\mu;r)$ but $y\notin U(\mu,r)$, a contradiction. Hence *Condition (1)* is true. Let there exist $x,y,z\in T$ and $s\in(0,5,1]$ such that $\max\{\mu(xyz),0.5\}<\min\{\mu(x),\mu(y),\mu(z)\}=s$. Then $x,y,z\in U(\mu;s)$ but $xyz\notin U(\mu;s)$, a contradiction. Hence *Condition (2)* is true. Now let us suppose that there $x,y,z\in T$ and $w\in(0,5,1]$ such that $\max\{\mu(x),\mu(y),\mu(z),0.5\}<\mu(xyz)=w$. Then $xyz\in U(\mu;w)$ but $x,y,z\notin U(\mu;w)$ which is a contradiction to the fact that $U(\mu;t)$ is a filter of *T* for all $t\in(0.5,1]$. Hence *Condition (3)* is true.

Conversely, assume that μ satisfies *Conditions (1)*, *(2)* and *(3)*. Let $x,y,z\in U(\mu;t)$. Then $\mu(x)\geq t$, $\mu(y)\geq t$ and $\mu(z)\geq t$. Now form *Condition (2)*, $\max\{\mu(xyz),0.5\}\geq\min\{\mu(x),\mu(y),\mu(z)\}=t>0.5$ which means that $\mu(xyz)\geq t$, so $xyz\in U(\mu;t)$. Let $x,y\in T$ with $x\leq y$ and $x\in U(\mu;t)$ then $\mu(x)\geq t$. Therefore from *Condition (1)* we have for some $t\in(0.5,1]$, $\max\{\mu(y),0.5\}\geq\mu(x)\geq t>0.5$ which means that $\mu(y)\geq t$, that is $y\in U(\mu;t)$. Let $x,y,z\in T$ such that $xyz\in U$. Then $\mu(xyz)\geq t$, we have from *Condition (3)*, $\max\{\mu(x),\mu(y),\mu(z),0.5\}\geq\mu(xyz)\geq t>0.5$ so that $\mu(x)\geq t$, $\mu(y)\geq t$, that is, $x,y,z\in U(\mu;t)$. Let $x,y,z\in T$ such that $x,y,z\in U(\mu;t)$. Then $\mu(x)\geq t$, $\mu(x)\geq t$ and $\mu(x)\geq t$.

Now from *Condition (2)*, we have, $\max\{\mu(xyz),0.5\} \geq \min\{\mu(x),\mu(y),\mu(z)\} = t > 0.5$ which implies that $\mu(xyz) \geq t$, that is, $xyz \in U(\mu;t)$. Hence $U(\mu;t)$ is a filter of *S*.

In view of *Definition 2.2*, we now give the following definition.

Definition 3.4

A fuzzy subset μ of an ordered ternary semigroup is called an $(\in,\in)$-*fuzzy filter* of *T* if it satisfies:

(1) $(\forall x,y \in S)(\forall t \in (0,1])(x \leq y, x_t \in \mu \to y_t \in \mu)$,

(2) $(\forall x,y,z \in S)(\forall t,r,s \in (0,1])\left(x_t,y_r,z_s \in \mu \to (x,y,z)_{mim\{t,r,s\}} \in \mu\right)$,

(3) $(\forall x,y \in S)(\forall t \in (0,1])((xyz)_t \in \mu \to x_t \in \mu, y_t \in \mu, z_t \in \mu)$.

In view of *Definition 3.4*, we have the following theorem.

Theorem 3.5

A fuzzy subset μ of *T* is a fuzzy filter of *T* if and only if it satisfies the *Conditions (1)*, *(2)* and *(3)* of *Definition 3.4*.

Proof. Using *Definition 2.5*, the proof is straight forward.

If μ is a fuzzy subset of *T* defined by $\mu(x) \leq 0.5$ for all $x \in T$, then the set $\{x_t : x_t \in \wedge q\mu\}$ is empty. So the case when $\alpha = \in \wedge q$ is excluded from the following definition.

Definition 3.6

A fuzzy subset μ of *T* is called an (α,β)-*fuzzy filter* of *T* where $\alpha \neq \in \wedge q$, if it satisfies the following conditions:

(1) $(\forall x,y \in T)(\forall t \in (0,1])(x \leq y, x_t\alpha\mu \to y_t\beta\mu)$,

(2) $(\forall x,y,z \in T)(\forall t,r,s \in (0,1])\left(x_t\alpha\mu, y_r\alpha\mu, z_s\alpha\mu \to (xyz)_{\min\{t,r,s\}}\beta\mu\right)$,

(3) $(\forall x,y \in T)(\forall t \in (0,1])((xyz)_t \in \mu \to x_t\beta\mu, y_t\beta\mu, z_t\beta\mu)$.

Theorem 3.7

Let μ be a non-zero (α,β)-fuzzy filter of *T*. Then the set $\mu_0 = \{x \in T : \mu(x) > 0\}$ is a filter of *S*.

Proof. Let $x,y,z \in \mu_0$. Then $\mu(x) > 0$, $\mu(y) > 0$, $\mu(z) > 0$. So $x_{\mu(x)} \in \mu$, $y_{\mu(y)} \in \mu$ and $z_{\mu(z)} \in \mu$. Since μ is an (α,β)-fuzzy filter of *T*, we have $(xyz)_{\min\{x_{\mu(x)},\, y_{\mu(y)},\, z_{\mu(z)}\}}\beta\mu$ for every $\beta \in \{\in, q, \in \vee q, \in \wedge q\}$. Thus $\mu(xyz) \geq \min\{x_{\mu(x)}, y_{\mu(y)}, z_{\mu(z)}\} > 0$ so that

$xyz \in \mu_0$. Let $x,y \in T$ such that $x \leq y$ and $x \in \mu_0$. Then $\mu(x) > 0$. Suppose that $x(y) = 0$. Then $x_{\mu(x)}\alpha\mu$ but $y_{\mu(y)}\overline{\beta}\mu$ for every $\alpha \in \{\in, q, \in \vee q\}$ and $\beta \in \{\in, q \in \vee q, \in \wedge q\}$, a contradiction. Note that $x_1 q\mu$ but $y_1\overline{\beta}\mu$ for every $\beta \in \{\in, q, \in \vee q, \in \wedge q\}$ a contradiction. Hence $\mu(y) > 0$, which implies that $y \in \mu_0$. Let $x,y,z \in T$ such that $x,y,z \in \mu_0$. Then $\mu(x) > 0$, $\mu(y) > 0$, $\mu(z) > 0$. Suppose that $\mu(xyz) = 0$. Then $x_{\mu(x)}\alpha\mu$, $y_{\mu(y)\alpha\mu}$, $z_{\mu(z)\alpha\mu}$ but $(xyz)_{\min\{x_{\mu(x)}, y_{\mu(y)}, z_{\mu(z)}\}}\overline{\beta}\mu$ for every $\alpha \in \{\in, q, \in \vee q\}$ and $\beta \in \{\in, q, \in \vee q, \in \wedge q\}$ a contradiction. Note that $x_1 q\mu$, $y_1 q\mu$, $z_1 q\mu$ but $(xyz)_{\min\{1,1,1\}} = (xyz)_{\{1\}}\overline{\beta}\mu$ for every $\beta \in \{\in, q, \in \vee q\}$ a contradiction. Hence $\mu(xyz) > 0$ so that $xyz \in \mu_0$. Let $x,y,z \in T$ such that $xyz \in \mu_0$. Then $\mu(xyz) > 0$. Suppose that $\mu(x) = 0$ or $\mu(y) = 0$ or $\mu(z) = 0$. Let $\alpha \in \{\in, q, \in \vee q\}$, then $xyz_{\mu(xyz)}\alpha\mu$ but $x_{\mu(x)}\overline{\beta}\mu$ or $z_{\mu(z)}\overline{\beta}\mu$ for every $\beta \in \{\in, q, \in \vee q, \in \wedge q\}$. Note that $(xyz)_1 q\mu$ but $x_1\overline{\beta}\mu$ or $y_1\overline{\beta}\mu$ or $z_1\overline{\beta}\mu$, for every $\beta \in \{\in, q, \in \vee q, \in \wedge q\}$ a contradiction. Thus $\mu(x) > 0$, $\mu(y) > 0$, $\mu(z) > 0$. Hence μ_0 is a filter of *T*.

$(\in, \in \vee q)$-fuzzy Filters

In this section, we introduce $\in, \in \vee q$-fuzzy filter in ordered ternary semigroup and will characterize ordered ternary semigroup in terms of $\in, \in \vee q$-fuzzy filters.

Definition 4.1

A fuzzy subset μ of *T* is called an $\in, \in \vee q$-*fuzzy filter* of *T* if it satisfies the following conditions:

(1) $(\forall x,y \in S)(\forall t \in (0,1])(x \leq y,\ x_t \in \mu \rightarrow y_t \in \vee q\mu)$,

(2) $(\forall x,y,z \in S)(\forall t,r,s \in (0,1])\left(x_t \in \mu,\ y_r \in \mu,\ z_s \in \mu \rightarrow (xyz)_{\min\{t,r,s\}} \in \vee q\mu\right)$,

(3) $(\forall x,y,z \in S)(\forall t \in (0,1])((xyz)_t \in \mu \rightarrow x_t \in \vee q\mu,\ y_t \in \mu \vee q,\ z_t \in \vee q\mu)$.

Example 4.2

Consider the ordered semigroup as given in *Example 3.2*, and define a fuzzy subset μ by:

$\mu(e) = 0.8$, $\mu(d) = 0.7$, $\mu(a) = 0.6$, $\mu(c) = 0.4$, $\mu(b) = 0.3$, $\mu(f) = 0.45$ then μ is an $\in, \in \vee q$-fuzzy filter of *T*.

(i) μ is not $(\in, \in)$-fuzzy filter of *T*, since $d_{0.68} \in \mu$, $c_{0.38} \in \mu$ and $f_{0.4} \in \mu$ but $(dcf)_{\min\{0.68, 0.38, 0.4\}} = b_{0.38} \notin \mu$.

(ii) μ is not $(q, \in)$-fuzzy filter of *T*, since $c_{0.7} q\mu$, $d_{0.68} q\mu$ and $f_{0.78} q\mu$ but $(cdf)_{\min\{0.7, 0.68, 0.78\}} = b_{0.68} \notin \mu$.

(iii) μ is not $(\in, q)$-fuzzy filter of *T*, since $a_{0.58} \in \mu$, $b_{0.3} \in \mu$ and $c_{0.38} \in \mu$ but $(abc)_{\min\{0.58, 0.3, 0.38\}} = b_{0.3} \overline{q} \mu$.

Theorem 4.3

A fuzzy subset μ of T is an $(\in, \in \vee q)$-fuzzy filter of T if and only if it satisfies the following conditions:

(1) $(\forall x,y \in T)(x \leq y,\ \mu(y) \geq \min\{\mu(x), 0.5\})$,

(2) $(\forall x,y,z \in T)(\mu(xyz) \geq \min\{\mu(x), \mu(y), \mu(z), 0.5\})$,

(3) $(\forall x,y,z \in T)(\min\{\mu(x), \mu(y), \mu(z)\} \geq \min\{\mu(xyz), 0.5\})$.

Proof. Suppose that μ is an $\in, \in \vee q$-fuzzy filter of T. Let $x,y \in T$ such that $x \leq y$. If $\mu(x) = 0$, then $\mu(y) = \mu(x)$. Let $\mu(x) \neq 0$ and assume that there exists some $t \in (0,1]$ such that $\mu(y) < t \leq \min\{\mu(x), 0.5\}$. If $\mu(x) < 0.5$ then $\mu(y) < t \leq \mu(x)$ which implies that $x_t \in \mu$ but $y_t \notin \mu$, a contradiction. If $0.5 \leq \mu(x)$, then $\mu(y) < 0.5 \leq \mu(x)$, that is $x_{0.5} \in \mu$ but $y_{0.5} \notin \mu$, again a contradiction. Hence $\mu(y) \geq \min\{\mu(x), 0.5\}$. Let $x,y,z \in T$. Let us assume that $\mu(x) = 0$, or $\mu(y) = 0$, $\mu(z) = 0$, then $\mu(xyz) \geq \min\{\mu(x), \mu(y), \mu(z), 0.5\}$. Suppose that $\mu(x) \neq 0$, $\mu(y) \neq 0$ and $\mu(z) \neq 0$ and assume on contrary that there exist $x,y,z \in T$ and $s \in (0,1]$ such that $\mu(xyz) < s \leq \min\{\mu(x), \mu(y), \mu(z), 0.5\}$. If $\min\{\mu(x), \mu(y), \mu(z) < 0.5$, then $\mu(xyz) < s \leq \min\{\mu(x), \mu(y), \mu(z)\}$ which implies that $x_s, y_s, z_s \in \mu$ but $(xyz)_s \notin \mu$ a contradiction. If $0.5 \leq \min\{\mu(x), \mu(y), \mu(z)\}$ then $\mu(xyz) < s \leq 0.5 \leq \min\{\mu(x), \mu(y), \mu(z)\}$ which implies that $x_{0.5}, y_{0.5}, z_{0.5} \in \mu$ but $(xyz)_{0.5} \notin \mu$, again a contradiction. Hence $\mu(xyz) \geq \min\{\mu(x), \mu(y), \mu(z), 0.5\}$ for all $x,y,z \in T$. Let $x,y,z \in T$. If $\mu(xyz) = 0$. Then $\min\{\mu(x), \mu(y), \mu(z), 0.5\} \geq \min\{\mu(xyz), 0.5\}$. Let $\mu(xyz) \neq 0$ and assume that there exist $x,y,z \in T$ and $r \in (0,1]$ such that $\min\{\mu(x), \mu(y), \mu(z), 0.5\} < r \leq \min\{\mu(xyz), 0.5\}$. If $\mu(xyz) < 0.5$, then $\min\{\mu(x), \mu(y), \mu(z), 0.5\} < r \leq \mu(xyz)$ which implies that $(xyz)_r \in \mu$ but $x_r, y_r, z_r \notin \mu$, a contradiction. If $0.5 \leq \mu(xyz)$, then $\min\{\mu(x), \mu(y), \mu(z), 0.5\} < r \leq 0.5 \leq \mu(xyz)$ which implies that $(xyz)_{0.5} \in \mu$ but $x_{0.5}, y_{0.5}, z_{0.5} \notin \mu$ again a contradiction. Hence $\min\{\mu(x), \mu(y), \mu(z)\} \geq \min\{\mu(xyz), 0.5\}$ for all $x,y,z \in T$.

Conversely, assume that for a fuzzy subset μ of T, *Conditions (1)*, *(2)*, and *(3)* hold. Let $x,y \in T$ such that $x \leq y$ and $x_t \in \mu$ for some $t \in (0,1]$. Then $\mu(x) \geq t$. Then by *Condition (1)*, we have, $\mu(y) \geq \mu(x)$, that is $y_t \in \mu$. Hence $y_t \in \vee q\mu$. Let $x, y, z \in T$ and $t, r, s \in (0,1]$ such that $x_t, y_r, z_s \in \mu$. Then $\mu(x) \geq t$, $\mu(y) \geq r$ and $\mu(z) \geq s$. By *Condition (2)* of the hypothesis, we have, $\mu(xyz) \geq \min\{\mu(x), \mu(y), \mu(z), 0.5\} \geq \min\{t, r, s, 0.5\}$. If $\min\{t, r, s, 0.5\} \leq 0.5$, then $\mu(xyz) \geq \min\{t, r, s\}$ then $(xyz)_{\min\{t,r,s\}} \in \mu$. If $\min\{t, r, s\} > 0.5$, then $\mu(xyz) + \min\{t, r, s\} > 0.5 + 0.5 = 1$ which implies that $(xyz)_{\min\{t,r,s\}} \in \mu$. Hence $(xyz)_{\min\{t,r,s\}} \in \vee q\mu$. Let $x, y, z \in T$ such that $(xyz)_t \in \mu$ for all $t \in (0,1]$. Then $\mu(xyz) \geq t$.

By *condition (3)*, we have $\min\{\mu(x),\mu(y),\mu(z)\}\geq\min\{\mu(xyz),0.5\}\geq\min\{t,0.5\}$. If $t\leq 0.5$ then $\min\{\mu(x),\mu(y),\mu(z)\}\geq t$ which implies that $x_t, y_t, z_t\in\mu$. If $t>0.5$, then $\min\{\mu(x),\mu(y),\mu(z)\}+t>0.5+0.5=1$, that is, $\mu(x)+t>1$, $\mu(y)+1$, $\mu(z)+t>1$. Thus $x_t\mathrm{q}\mu$, $y_t\mathrm{q}\mu$, $z_t\mathrm{q}\mu$. Hence $x_t\in\vee\mathrm{q}\mu$, $y_t\in\vee\mathrm{q}\mu$, $z_t\in\vee\mathrm{q}\mu$. Consequently μ is an $(\in,\in\vee\mathrm{q})$-fuzzy filter of *T*.

Remark 4.4

A fuzzy subset of an ordered ternary semigroup is an $(\in,\in\vee\mathrm{q})$-fuzzy filter of T if and only if it satisfies *Conditions (1)*, *(2)* and *(3)* of **Theorem 4.3**.

Remark 4.5

By the above remark every fuzzy filter of *T* is an $(\in,\in\vee\mathrm{q})$-fuzzy filter of *T*. However the converse is not true in general.

Example 4.6

Consider the ordered ternary semigroup as given in **Example 3.2**, and define a fuzzy subset μ of *T* as follows:

$\mu(e)=0.8$, $\mu(d)=0.7$, $\mu(a)=0.6$, $\mu(c)=0.4$, $\mu(b)=0.3$, $\mu(f)=0.45$, then μ is an $(\in,\in\vee\mathrm{q})$-fuzzy filter of *S*. But μ is not an (α,β)-fuzzy filter of *S*, where $\alpha\in\{\in,\mathrm{q},\in\vee\mathrm{q}\}$ and $\beta\in\{\in,\mathrm{q},\in\vee\mathrm{q},\in\wedge\mathrm{q}\}$ as shown in **Example 4.2**.

Using **Theorem 4.3**, we have the following characterization of fuzzy filters of ordered ternary semigroups. The proof of **Theorem 4.7** is easy and is therefore omitted.

Theorem 4.7

Let $T,\cdot,\leq$ be an ordered ternary semigroup and $\phi\neq F\subseteq T$. Then *F* is a filter of *T* if and only if the characteristic function χ_F of F is an $(\in,\in\vee\mathrm{q})$-fuzzy filter of *T*.

Theorem 4.8

Let *F* be a filter of *T* and μ a fuzzy subset of *S* such that

$$\mu(x):=\begin{cases}\geq 0.5 & \text{if } x\in F\\ 0 & \text{if } x\in T\setminus F\end{cases}$$

Then,

(a) μ is a $(\mathrm{q},\in\vee\mathrm{q})$-fuzzy filter of *T*,

(b) μ is an $(\in,\in\vee\mathrm{q})$-fuzzy filter of *T*.

Proof. (a) Let $x,y\in S$, $x\leq y$ and $t\in(0,1]$ such that $x_t q\mu$, then $x\in F$. Since $x\leq y$, we have, $y\in F$. If $t\leq 0.5$ then $\mu(y)=0.5\geq t$ implies that $y_t\in\mu$. If $t>0.5$ then

$\mu(y)+t > 0.5+0.5 = 1$ implies that $y_t q\mu$. Hence $y_t \in\vee q\mu$. Let $x, y, z \in T$ and $t, r, s \in (0,1]$ such that $x_t q\mu$, $y_r q\mu$ and $z_s q\mu$. Then $x, y, z \in F$ implies that $xyz \in F$. If $\min\{t,r,s\} \le 0.5$ then $\mu(xyz) \ge 0.5 \ge \min\{t,r,s\}$ implies that $(xyz)_{\min\{t,r,s\}} \in \mu$. If $\min\{t,r,s\} > 0.5$ then $\mu(xyz)+\min\{t,r,s\} > 0.5+0.5 = 1$ implies that $(xyz)_{\min\{t,r,s\}} q\mu$. Hence $(xyz)_{\min\{t,r,s\}} \in \vee q\mu$. Let $x, y, z \in T$ such that $(xyz)_t q\mu$ where $t \in (0,1]$, we have $xyz \in F$ then $x, y, z \in F$. If $t \le 0.5$ then $\min\{\mu(x), \mu(x), \mu(x)\} \ge 0.5 \ge t$ and we have $\mu(x) \ge t$, $\mu(y) \ge t$, $\mu(z) \ge t$. Hence $x_t, y_t, z_t \in \mu$. If $t \le 0.5$ then we have $\min\{\mu(x), \mu(x), \mu(x)\}+t > 0.5+0.5 = 1$ that is $\mu(x)+t > 1$, $\mu(y)+t > 1$, and $\mu(z)+t > 1$, it follows that $x_t q t$, $y_t q t$ and $z_t q t$. Hence $x_t \in\vee q t$, $y_t \in\vee q t$ and $z_t \in\vee q t$.

Proof. (b) Let $x,y \in S$, $x \le y$ and $t \in (0,1]$ such that $x_t \in \mu$, then $x \in F$. Since $x \le y$, we have, $y \in F$. If $t \le 0.5$ then $\mu(y) = 0.5 \ge t$ implies $y_t \in \mu$. If $t \le 0.5$ then $\mu(y)+t > 0.5+0.5 = 1$ implies $y_t q\mu$. Hence $y_t \in\vee q\mu$. Let $x,y,z \in T$ and $t, r, s \in (0,1]$ such that $x_t \in \mu$, $y_r \in \mu$ and $z_s \in \mu$. Then $x, y, z \in F$ implies $xyz \in F$. If $\min\{t,r,s\} \le 0.5$ then $\mu(xyz) \ge 0.5 \ge \min\{t,r,s\}$ implies $(xyz)_{\min\{t,r,s\}} \in \mu$. If $\min\{t,r,s\} > 0.5$ then $\mu(xyz)+\min\{t,r,s\} > 0.5+0.5 = 1$ implies $(xyz)_{\min\{t,r,s\}} q\mu$. Hence $(xyz)_{\min\{t,r,s\}} \in \vee q\mu$. Let $x, y, z \in T$ such that $(xyz)_t \in \mu$ where $t \in (0,1]$, we have $xyz \in F$ then $x, y, z \in F$. If $t \le 0.5$ then $\min\{\mu(x), \mu(x), \mu(x)\} \ge 0.5 \ge t$ and we have $\mu(x) \ge t$, $\mu(y) \ge t$, $\mu(z) \ge t$. Hence $x_t, y_t, z_t \in \mu$. If $t > 0.5$ then we have $\min\{\mu(x), \mu(x), \mu(x)\}+t > 0.5+0.5 = 1$ that is $\mu(x)+t > 1$, $\mu(y)+t > 1$ and $\mu(z)+t > 1$, it follows that $x_t q t$, $y_t q t$ and $z_t q t$. Hence $x_t q t$, $y_t \in\vee q t$ and $z_t \in\vee q t$.

It is important to note that in **Theorem 4.8** we impose a condition on the fuzzy subset μ of *T*. Without the condition,

$$\mu(x) := \begin{cases} \ge 0.5 & \text{if } x \in F \\ 0 & \text{if } x \in T \setminus F \end{cases}$$

μ may not be a $(q, \in \vee q)$-fuzzy filter of *T* as shown in **Example 4.2(ii)**.

In the following theorem we give the condition an $(\in, \in \vee q)$-fuzzy filter to be an $(\in, \in)$-fuzzy filter of *T*.

Theorem 4.9

Let μ be an $(\in, \in \vee q)$-fuzzy filter of *T* such that $\mu(x) < 0.5$ for all $x \in T$. Then μ is an $(\in, \in)$-fuzzy filter of *T*.

Proof. Assume that μ is an $(\in, \in \vee q)$-fuzzy filter of *T* such that $\mu(x) < 0.5$ for all $x \in T$. Let $x, y \in T$ with $x \le y$ and $x_t \in \mu$ for some *t*. Then $\mu(x) \ge t$. Since μ is an $(\in, \in \vee q)$-fuzzy filter of *T*, using **Theorem 4.3**, we have $\mu(y) \ge \min\{\mu(x), 0.5\} = \mu(x) \ge t$. Hence $y_t \in \mu$. Let

$x, y, z \in T$ such that $x_t \in \mu$, $y_r \in \mu$, $z_r \in \mu$ for some $t, r, s \in (0,1]$. Then $\mu(x) \geq t$, $\mu(y) \geq r$ and $\mu(x) \geq s$ and so by hypothesis $\mu(xyz) \geq \min\{\mu(x), \mu(y), \mu(x), 0.5\} \geq \min\{t, r, s\}$. Hence $(xyz)_{\min\{t,r,s\}} \in \mu$. Let $x, y, z \in T$ such that $(xyz)_t \in \mu$ then $\mu(xyz) \geq t$ so $\min\{\mu(x), \mu(y), \mu(x)\} \geq \min\{\mu(xyz), 0.5\} = \mu(xyz) \geq t$. Hence $x_t \in \mu$, $y_t \in \mu$, $z_t \in \mu$. Consequently μ is an $(\in,\in)$-fuzzy filter of *T*.

Theorem 4.10

A fuzzy subset μ of T is an $(\in,\in \vee \mathrm{q})$-fuzzy filter of T if and only if the set $U(\mu;t) := \{x \in T \mid \mu(x) \geq t\}$ is a filter of *T* for all $t \in (0, 0.5]$.

Proof. Suppose that μ is an $(\in,\in \vee \mathrm{q})$-fuzzy filter of *T*. Let $x, y \in U(\mu;t)$ with $x \leq y$ and $x \in U(\mu;t)$ where $t \in (0,0.5]$. Then $\mu(x) \geq t$ and it follows from **Theorem 4.3(1)** that $\mu(y) \geq \min\{\mu(x), 0.5\} \geq \min\{t, 0.5\} = t$ and so $y \in U(\mu;t)$. Let $x, y, z \in U(\mu;t)$ for some $t \in (0, 0.5]$. Then $\mu(x) \geq t$, $\mu(y) \geq t$, $\mu(z) \geq t$. It follows from **Theorem 4.3(2)** that $\mu(xyz) \geq \min\{\mu(x), \mu(y), \mu(z), 0.5\} \geq \min\{t, 0.5\} = t$ and so $xyz \in U(\mu;t)$. Now let $xyz \in U(\mu;t)$ for some $t \in (0, 0.5]$. Then $\mu(xyz) \geq t$ and it follows from **Theorem 4.3(3)** that $\min\{\mu(x), \mu(y), \mu(z)\} \geq \min\{\mu(xyz), 0.5\} \geq \min\{t, 0.5\} = t$ and so $\mu(x) \geq t$, $\mu(y) \geq t$, $\mu(z) \geq t$. Hence $x, y, z \in U(\mu;t)$.

Conversely, assume that for a fuzzy subset μ of *T* and for all $t \in (0, 0.5]$ the set $U(\mu;t) := \{x \in T | \mu(x) \geq t\}$ is a filter of *T*. Let there exist $x, y \in T$ with $x \leq y$ such that $\mu(y) < \min\{\mu(x), 0.5\}$, then we can choose $t \in (0, 0.5]$ such that $\mu(y) < t \leq \min\{\mu(x), 0.5\}$, then $x_t \in \mu$ but $y_t \notin \mu$, a contradiction. Hence $\mu(y) \geq \min\{\mu(x), 0.5\}$ for all $x, y \in T$ with $x \leq y$. If there exist $x, y, z \in T$ such that $\mu(xyz) < \min\{\mu(x), \mu(y), \mu(z), 0.5\}$, then we can choose $r \in (0, 0.5]$ such that $\mu(xyz) < r \leq \min\{\mu(x), \mu(y), \mu(z), 0.5\}$. Then $x, y, z \in U(\mu;r)$ but $xyz \notin U(\mu;r)$, a contradiction. Hence $\mu(xyz) \geq \min\{\mu(x), \mu(y), \mu(z), 0.5\}$. Finally let there exist $x, y, z \in T$ such that $\min\{\mu(x), \mu(y), \mu(z)\} < s \leq \min\{\mu(xyz), 0.5\}$, then we can choose $s \in (0, 0.5]$ such that $\min\{\mu(x), \mu(y), \mu(z)\} < s \leq \min\{\mu(xyz), 0.5\}$. Then $xyz \in U(\mu;s)$ but $x, y, z \notin U(\mu;s)$, again a contradiction. Hence $\min\{\mu(x), \mu(y), \mu(z)\} \geq \min\{\mu(xyz), 0.5\}$ for all $x, y, z \in T$ and $t \in (0, 0.5]$. Consequently μ is an $(\in,\in \vee \mathrm{q})$-fuzzy filter of *T*.

For any fuzzy set μ of *T* and for any $t \in (0, 0.5]$, we denote

$$Q[\mu;t] = \{x \in T \mid x_t \mathrm{q} \mu\} \text{ and } [\mu]_t = \{x \in T \mid x_t \in \vee \mathrm{q} \mu\}.$$

It is obvious that $[\mu_t] = U(\mu;t) \cup \mathrm{q}[\mu;t]$.

Theorem 4.11

A fuzzy subset μ of T is an $(\in,\in\vee \mathrm{q})$-fuzzy filter of T if and only if for all $t\in(0,1]$, $[\mu]_t(\neq 0)$ is a filter of T.

Proof. Assume that μ is an $(\in,\in\vee \mathrm{q})$-fuzzy filter of T. Let $t\in(0,1]$ be such that $[\mu]_t(\neq 0)$ and $x,y\in T$, $x\le y$, $x\in[\mu]_t$. Then $\mu(x)\ge t$ or $\mu(x)+t>1$. Since μ is an $(\in,\in\vee \mathrm{q})$-fuzzy filter of T and $x\le y$, we have $\mu(y)\ge \min\{\mu(x),0.5\}$. We consider the following cases:

(1) $\mu(x)\ge t$,

(2) $\mu(x)+t>1$.

(1) If $t>0.5$, then $\mu(y)\ge\min\{\mu(x),0.5\}\ge\min\{t,0.5\}=0.5$ and $\mu(y)+t>0.5+0.5=1$ implies $y_t\mathrm{q}\mu$. Hence $y\in q(\mu;t)\subseteq[\mu]_t$. If $t\le 0.5$ then $\mu(y)\ge\min\{\mu(x),0.5\}\ge\min\{t,0.5\}=t$ implies $y_t\in\mu$, i.e., $y\in U(\mu;t)\subseteq[\mu]_t$.

(2) If $t>0.5$, then $\mu(y)\ge\min\{\mu(x),0.5\}\ge\min\{1-t,0.5\}=1-t$, that is, $\mu(y)+t>1$ and so $y_t\mathrm{q}\mu$, i.e., $y\in \mathrm{q}(\mu;t)\subseteq[\mu]_t$, hence $y\in[\mu]_t$. If $t\le 0.5$, then $\mu(y)\ge\min\{\mu(x),0.5\}\ge\min\{1-t,0.5\}=0.5\ge t$, that is, $y_t\in\mu$ and so $y\in U(\mu;t)\subseteq[\mu]_t$, hence $y\in[\mu]_t$. Thus in both cases we have $y_t\in\mu$. Let $x,y,z\in[\mu]_t$. Then $\mu(x)\ge t$, or $\mu(x)+t>1$, $\mu(y)\ge t$ or $\mu(y)+>1$, $\mu(z)\ge t$ or $\mu(z)+t>1$. We consider the following cases:

(1) $\mu(x)\ge t$, $\mu(y)\ge t$ and $\mu(z)\ge t$,

(2) $\mu(x)\ge t$, $\mu(y)\ge t$ and $\mu(z)+t>1$,

(3) $\mu(x)\ge t$, $\mu(y)+t>1$, and $\mu(z)\ge t$,

(4) $\mu(x)+t>1$, $\mu(y)\ge t$ and $\mu(z)\ge t$,

(5) $\mu(x)+t>1$, $\mu(y)+t>1$ and $\mu(z)\ge t$,

(6) $\mu(x)+t>1$, $\mu(y)+t>1$ and $\mu(z)+t>1$.

(1) If $\mu(x)\ge t$, $\mu(y)\ge t$ and $\mu(z)\ge t$. Then since μ is an $\in,\in\vee \mathrm{q}\mu$-fuzzy filter of T, we have from **Theorem 4.3(2)**,

$$\mu(xyz)\ge\min\{\mu(x),\mu(y),\mu(z),0.5\}\ge\min\{t,0.5\}=\begin{cases}0.5 & \text{if } t>0.5\\ t & \text{if } t\le 0.5\end{cases}$$

and so $(xyz)_t\mathrm{q}\mu$ or $(xyz)_t\in\mu$ i.e., $xyz\in \mathrm{q}(\mu;t)\cup U(\mu;t)=[\mu]_t$.

(2) If $\mu(x) \geq t$, $\mu(y) \geq t$ and $\mu(z) \geq t$. Then from **Theorem 4.3(2)**,

$$\mu(xyz) \geq \min\{\mu(x), \mu(y), \mu(z), 0.5\} > \min\{t, t, 1-t, 0.5\} = \begin{cases} 1-t & \text{if } t > 0.5 \\ t & \text{if } t \leq 0.5 \end{cases}$$

and so $(xyz)_t q\mu$ or $(xyz)_t \in \mu$ i.e., $xyz \in \mathrm{q}(\mu;t) \cup U(\mu;t) = [\mu]_t$.

(3) If $\mu(x) \geq t$, $\mu(y) + t > 1$ and $\mu(z) \geq t$. Then using **Theorem 4.3(2)**, we have

$$\mu(xyz) \geq \min\{\mu(x), \mu(y), \mu(z), 0.5\} > \min\{t, 1-t, t, 0.5\} = \begin{cases} 1-t & \text{if } t > 0.5 \\ t & \text{if } t \leq 0.5 \end{cases}$$

and so $(xyz)_t q\mu$ or $(xyz)_t \in \mu$ i.e., $xyz \in \mathrm{q}(\mu;t) \cup U(\mu;t) = [\mu]_t$.

(4) $\mu(x) + t > 1$, $\mu(y) \geq t$ and $\mu(z) \geq t$. Then we have

$$\mu(xyz) \geq \min\{\mu(x), \mu(y), \mu(z), 0.5\} > \min\{1-t, t, t, 0.5\} = \begin{cases} 1-t & \text{if } t > 0.5 \\ t & \text{if } t \leq 0.5 \end{cases}$$

Hence $(xyz)_t q\mu$ or $(xyz)_t \in \mu$ i.e., $xyz \in \mathrm{q}(\mu;t) \cup U(\mu;t) = [\mu]_t$.

(5) If $\mu(x) + t > 1$, $\mu(y) + t > 1$ and $\mu(z) \geq t$ then we have from **Theorem 4.3(2)**,

$$\mu(xyz) \geq \min\{\mu(x), \mu(y), \mu(z), 0.5\} > \min\{1-t, 1-t, t, 0.5\} = \begin{cases} 1-t & \text{if } t > 0.5 \\ t & \text{if } t \leq 0.5 \end{cases}$$

and we have $(xyz)_t q\mu$ or $(xyz)_t \in \mu$ i.e., $xyz \in \mathrm{q}(\mu;t) \cup U(\mu;t) = [\mu]_t$.

(6) If $\mu(x) + t > 1$, $\mu(y) + t > 1$ and $\mu(z) + t > 1$. Then

$$\mu(xyz) \geq \min\{\mu(x), \mu(y), \mu(z), 0.5\} > \min\{1-t, 1-t, 1-t, 0.5\} = \begin{cases} 1-t & \text{if } t > 0.5 \\ 0.5 & \text{if } t \leq 0.5 \end{cases}$$

and thus we have $\mu(xyz) > 1-t$ or $\mu(xyz) > 0.5 \geq t$, i.e. $(xyz)_t q\mu$ or $(xyz)_t \in \mu$ and hence $xyz \in \mathrm{q}(\mu;t) \cup U(\mu;t) = [\mu]_t$.

Let $x, y, z \in [\mu]_t$ then $\mu(xyz) \geq t$ or $\mu(xyz) + t > 1$. Assume that $\mu(xyz) \geq t$ then since μ is an $(\in, \in \vee \mathrm{q})$-fuzzy filter of *T*, we have by **Theorem 4.3(3)**,

$$\min\{\mu(x), \mu(y), \mu(z)\} \geq \min\{\mu(xyz), 0.5\} \geq \min\{t, 0.5\} = \begin{cases} t & \text{if } \quad t \leq 0.5 \\ 0.5 > 1-t & \text{if } \quad t > 0.5 \end{cases}$$

so that $x, y, z \in U(\mu;t) \cup \mathrm{q}(\mu;t) = [\mu]_t$. Suppose that $\mu(xyz) + t > 1$, then we have

$$\min\{\mu(x), \mu(y), \mu(z)\} \geq \min\{\mu(xyz), 0.5\} \geq \min\{1 - t, 0.5\} = \begin{cases} 0.5 & \text{if} \quad t < 0.5 \\ 1 - t & \text{if} \quad t \geq 0.5 \end{cases}$$

and thus $xyz \in \mathrm{q}(\mu;t) \cup U(\mu;t) = [\mu]_t$. Consequently $[\mu]_t$ is a filter of *T*.

Conversely, assume that for all $t \in (0,1]$, the set $[\mu]_t (\neq 0)$ is a filter of *T*. If there exist $x_0, y_0 \in T$ with $x_0 \leq y_0$ such that $\mu(y_0) < \min\{\mu(x_0), 0.5\}$ then we can choose $t_0 \in (0, 0.5]$ such that $\mu(y_0) < t_0 \leq \min\{\mu(x_0, 0.5)\}$. It follows that $x_0 \in U(\mu;t_0) \subseteq [\mu]_{t_0}$ and so $x_0 \in [\mu]_{t_0}$. Thus $\mu(x_0) \geq t_0$ or $\mu(x_0) + t_0 > 1$. Since $x_0 \leq y_0$, $x_0 \in [\mu]_{t_0}$ and $[\mu]_{t_0}$ is a filter of *T*, it follows that $y_0 \in [\mu]_{t_0}$, i.e. $\mu(y_0) \geq t_0$ or $\mu(y_0) + t_0 > 1$, a contradiction. Hence $\mu(y) \geq \min\{\mu(x), 0.5\}$ for all $x, y \in T$ with $x \leq y$. If There exist $a, b, c \in T$ such that $\mu(abc) < \min\{\mu(a), \mu(b), \mu(c), 0.5\}$ then $\mu(abc) < t_1 \leq \min\{\mu(a), \mu(b), \mu(c), 0.5\}$ for some $t_1 \in (0, 0.5]$. Hence $a, b, c \in U(\mu;t_1) \subseteq [\mu]_{t_1}$ and so $abc \in [\mu]_{t_1}$. Thus $\mu(abc) \geq t_1$ or $\mu(abc) + t_1 > 1$, a contradiction. Hence $\mu(xyz) \geq \min\{\mu(x), \mu(y), \mu(z), 0.5\}$ for all $x, y, z \in T$. Now if there exist $d, e, f \in T$ such that $\min\{\mu(d), \mu(e), \mu(f)\} \leq \min\{\mu(def), 0.5\}$, then $\{\mu(d), \mu(e), \mu(f)\} < t_2 \leq \min\{\mu(def), 0.5\}$ for some $t_2 \in (0, 0.5]$. Then $def \in U(\mu;t_2) \subseteq [\mu]_{t_2}$ and so $d, e, f \in [\mu]_{t_2}$. Thus $\mu(d) \geq t_2$ or $\mu(d) + t_2 > 1$, $\mu(e) \geq t_2$ or $\mu(e) + t_2 > 1$ and $\mu(f) \geq t_2$ or $\mu(e) + t_2 > 1$, a contradiction. Hence $\min\{\mu(x), \mu(y), \mu(z)\} \geq \min\{\mu(xyz), 0.5\}$ for all $x, y, z \in T$. Consequently μ is a fuzzy filter of *T*.

Let μ be a fuzzy subset of *T* and $J = \{t | t \in (0,1]$ and $\mu_t (\neq 0)$ is a filter of $T\}$. When $J = (0,1]$, μ is an ordinary filter of *T* (**Theorem 3.1**). When $J = (0, 0.5]$, μ is an $(\in, \in \vee \mathrm{q})$-fuzzy filter of *T* (**Theorem 4.10**). Consider $J = \{t | t \in (0,1]$ and $\mu_t (\neq 0)$ is a filter of $T\}$. In the next topic we will answer the following questions:

(1) If $J = (0, 0.5]$, what kind of fuzzy filters of *T* will be μ?

(2) If $J(r,s]$, $(r,s \in (0,1])$ will μ be a kind of fuzzy filter of *T* or not?

Definition 4.12

A fuzzy subset μ of *T* is called an $(\overline{\in}, \overline{\in} \vee \overline{q})$-fuzzy filter of *T* if it satisfies the following conditions:

(F1) $(\forall x, y \in T)(\forall t \in (0,1])(x \leq y,\ x_t \,\overline{\in}\, \mu \longrightarrow y_t \,\overline{\in} \vee \overline{q}\, \mu)$,

(F2) $(\forall x, y, z \in T)(\forall t, r, s \in (0,1])\big((xyz)_{\min\{t,r,s\}} \,\overline{\in}\, \mu \longrightarrow x_t \,\overline{\in} \vee \overline{q}\, \mu,\ y_r \,\overline{\in} \vee \overline{q}\, \mu,\ z_s \,\overline{\in} \vee \overline{q}\, \mu\big)$,

(F3) $(\forall x, y, z \in T)(\forall t \in (0,1])(x_t \,\overline{\in}\, \mu,\ y_t \,\overline{\in}\, \mu,\ z_t \,\overline{\in}\, \mu \longrightarrow (xyz)_t \,\overline{\in} \vee \overline{q}\, \mu)$.

Example 4.13 (Davvaz & Khan 2012)

Consider the ordered ternary semigroup T as given in **Example 3.2** and define the fuzzy subset μ of T as follows:

$$\mu(e) = 0.6,\ \mu(d) = 0.5,\ \mu(a) = 0.4,\ \mu(b) = 0.2,\ \mu(c) = 0.3,\ \mu(f) = 0.0.35$$

Then,

$$U(\mu;t) = \begin{cases} T & if \quad 0 < t \leq 0.2 \\ \{a,d,e\} & if \quad 0.35 < t \leq 0.4 \\ \phi & if \quad 0.6 < t \end{cases}$$

Then μ is an $(\overline{\in}, \overline{\in} \vee \overline{q})$-fuzzy filter of T.

Theorem 4.14

A fuzzy subset μ of T is an $(\overline{\in}, \overline{\in} \vee \overline{q})$-fuzzy filter of T if and only if it satisfies the following conditions:

(F4) $(\forall x, y \in T)(\max\{\mu(y), 0.5\} \geq \mu(x))$,

(F5) $(\forall x, y, z \in T)(\max\{\mu(xyz), 0.5\} \geq \min\{\mu(x), \mu(y), \mu(z)\})$,

(F6) $(\forall x, y, z \in T)(\min\{\mu(x), \mu(y), \mu(z), 0.5\} \geq \mu(xyz))$.

Proof: (F1) $\longrightarrow$ (F4). Let $x, y \in T$, $x \leq y$ such that $\max\{\mu(y), 0.5\} < \mu(x) = t$. Then $t \in (0.5, 1]$, $y_t \overline{\in} \mu$ but $x_t \in \mu$. By (F1), we have $x_t \overline{q}\, \mu$. Then $t \leq \mu(x)$ and $\mu(x) + t \leq 1$ which implies that $t \leq 0.5$, a contradiction. Hence (F4) is true.

(F4) $\longrightarrow$ (F1). Let $x, y \in T$, $t \in (0,1]$ such that $y_t \overline{\in} \mu$ then $\mu(y) < t$. (i) If $\mu(y) \geq \mu(x)$ then $\mu(x) < t$ and so $x_t \in \mu$. Hence $x_t \overline{\in} \vee \overline{q}\, \mu$ (ii) If $\mu(y) < \mu(x)$ then by (F4) we have $\mu(x) \leq 0.5$. If $x_t \in \mu$ then $t \leq \mu(x) \leq 0.5$ which implies that $x_t \overline{q}\, \mu$. Hence, $x_t \overline{\in} \vee \overline{q}\, \mu$.

(F2) $\longrightarrow$ (F5). If there exist $x, y, z \in T$ such that $\max\{\mu(xyz), 0.5\} < \min\{\mu(x), \mu(y), \mu(z)\} = s$. Then $s \in (0.5, 1]$, $(xyz)_s \overline{\in} \mu$ but $x_s \in \mu$, $y_s \in \mu$, $z_s \in \mu$. By (F2), we have $x_s \overline{q}\, \mu$, $y_s \overline{q}\, \mu$, $z_s \overline{q}\, \mu$. Then $(s \leq \mu(x)$ and $\mu(x) + s \leq 1)$, $(s \leq \mu(y)$ and $\mu(y) + s \leq 1)$ and $(s \leq \mu(x)$ and $\mu(x) + s \leq 1)$ which implies that $s \leq 0.5$, a contradiction. Hence (F5) is valid.

(F5) $\longrightarrow$ (F2). Let $(xyz)_{\min\{t,r,s\}} \overline{\in} \mu$ then $\mu(xyz) < \min\{t, r, s\}$. (i) If $\mu(xyz) \geq \min\{\mu(x), \mu(y), \mu(z)\}$ then $\min\{\mu(x), \mu(y), \mu(z)\} < \min\{t, r, s\}$ and so $\mu(x) < t$, $\mu(y) < r$, $\mu(z) < s$. It follows that $x_t \overline{\in} \mu$, $y_r \overline{\in} \mu$, $z_s \overline{\in} \mu$. Thus $x_t \overline{\in} \vee \overline{q}\, \mu$, $y_r \overline{\in} \vee \overline{q}\, \mu$. (ii) If $\mu(xyz) < \min\{\mu(x), \mu(y), \mu(z)\}$, then by (F5), we have $0.5 \geq \min\{\mu(x), \mu(y), \mu(z)\}$. If $x_t \in \mu$ or $y_r \in \mu$ or $z_s \in \mu$, then $t \leq \mu(x) \leq 0.5$, $r \leq \mu(y) \leq 0.5$, $s \leq \mu(x) \leq 0.5$ which implies that $x_t \overline{q}\, \mu$, $y_r \overline{q}\, \mu$, $z_s \overline{q}\, \mu$. Thus $x_t \overline{\in} \vee \overline{q}\, \mu$, $y_r \overline{\in} \vee \overline{q}\, \mu$, $z_s \overline{\in} \vee \overline{q}\, \mu$.

(F3) $\longrightarrow$ (F6). If there exist $x, y, z \in T$ such that $\min\{\mu(x), \mu(y), \mu(z), 0.5\} < \mu(xyz) = r$ then $r \in (0.5, 1]$, $x_r \overline{\in} \mu$, $y_r \overline{\in} \mu$ and $z_r \overline{\in} \mu$ but $(xyz)_r \in \mu$. By (F3), we have $(xyz)_r \overline{q} \mu$. Then $r \leq \mu(xyz)$ and $\mu(xyz) + r \leq 1$. Which implies that $r \leq 0.5$, a contradiction. Hence, (F6) is valid.

(F6) $\longrightarrow$ (F3). Let $x_t \overline{\in} \mu$, $y_t \overline{\in} \mu$ and $z_t \overline{\in} \mu$. Then $\mu(x) < t$, $\mu(y) < t$ and $\mu(z) < t$, that is $\min\{\mu(x), \mu(y), \mu(z)\} < t$. (i) If $\min\{\mu(x), \mu(y), \mu(z)\} \geq \mu(xyz)$, then $\mu(xyz) < t$ and so $(xyz)_t \in \mu$. It follows that $(xyz)_t \overline{\in} \vee \overline{q} \mu$ (ii) If $\min\{\mu(x), \mu(y), \mu(z)\} < \mu(xyz)$ then we have from (F6), $0.5 \geq \mu(xyz)$. If $(xyz)_t \in \mu$, then $t \leq \mu(xyz) \leq 0.5$ which implies that $(xyz)_t \overline{q} \mu$. Thus $(xyz)_t \overline{\in} \vee \overline{q} \mu$.

Lemma 4.15

Let μ be a fuzzy subset of *S*. Then $U(\mu; t)(\neq 0)$ is a filter of *T* if and only if it satisfies the conditions (F4) and (F6) of **Theorem 4.14**.

Theorem 4.16

A fuzzy subset μ of *T* is an $(\overline{\in}, \overline{\in} \vee \overline{q})$-fuzzy filter of *T* if and only if $U(\mu; t)(\neq 0)$ is a filter of *T* for all $t \in (0.5, 1]$.

Proof. Follows from **Theorem 4.14** and **Lemma 4.15**.

Based on Shabir and khan (2008), in next definition we give the concept of fuzzy filters with the tresholds. Yuan, Zhang and Ren gave the definition of a fuzzy subgroup with tresholds in Shabir and khan (2008), which is a generalization of Rosenfeld's (1971) subgroup, and Bahakat and Das's fuzzy subgroup.

Definition 4.17

Let $r, s \in (0, 1]$ and $r \leq s$. Let μ be a fuzzy subset of an ordered ternary semigroup *T*. Then μ is called a *fuzzy filter with threshold (r,s)* of *T*. If it satisfies the following conditions:

(1) $(\forall x, y \in T)(x \leq y, \max\{\mu(y, r)\} \geq \min\{\mu(x), s\})$,

(2) $(\forall x, y, z \in T)(\max\{\mu(xyz), r\} \geq \min\{\mu(x), \mu(y), \mu(z), s\})$,

(3) $(\forall x, y, z \in T)(\max\{\mu(x), \mu(y), \mu(z), r\} \geq \min\{\mu(xyz), s\})$.

If μ is a fuzzy filter with thresholds (r,s) of *T*, then μ is an ordinary fuzzy filter of *T* if $r = 0$, $s = 1$ and μ is an $(\in, \in \vee \mathrm{q})$-fuzzy filter of *T* if $r = 0$ and $s = 0.5$. In the next theorem, we characterize fuzzy filters with thresholds $(r, s]$ of *T*, by their level filters.

Theorem 4.18

A fuzzy subset μ of an ordered ternary semigroup *T* is a fuzzy filter with thresholds (r,s) of *T* if and only if $\mu_t(\neq 0)$ is a filter of *T* for all $t \in (r,s]$.

Proof. Suppose that μ be a fuzzy filter with thresholds (r,s) of *T*. Let $x,y \in T$ with $x \leq y$ and $x \in \mu_t$ then $\mu(x) \geq t$ and from (1) of **Definition 4.17**, we have $\max\{\mu(y),r\} \geq \min\{\mu(x),s\} \geq \min\{t,s\} \geq t > r$ so that $\mu(y) \geq t$ and hence $y \in \mu_t$. Let $x,y,z \in \mu_t$, then $\mu(x) \geq t$, $\mu(y) \geq t$, $\mu(z) \geq t$ then by (2) of **Definition 2.17(2)**, we have, $\max\{\mu(xyz),r\} \geq \min\{\mu(x),\mu(y),\mu(z),s\} \geq \min\{t,s\} = t > r$ and so $\mu(xyz) \geq t$ implies that $xyz \in \mu_t$. Let $xyz \in \mu_t$. Then $\mu(xyz) \geq t$ and we have from Definition **4.17(3)**, $\min\{\mu(x),\mu(y),\mu(z),r\} \geq \min\{\mu(xyz),s\} \geq \{t,s\} = t > r$ which implies that $\mu(x) \geq t$, $\mu(y) \geq t$, $\mu(z) \geq t$, so that $x,y,z \in \mu_t$.

Conversely, assume that μ be a fuzzy subset of *T* such that $\mu_t(\neq 0)$ is a filter of *T* for all $t \in (r,s]$. Let $x,y \in T$ with $x \leq y$ such that $\max\{\mu(y),r\} < \min\{\mu(x),s\} = t$ then $t \in (r,s]$, $\mu(y) < t$ and $x \in \mu_t$. Since $x \leq y$ and μ_t is a filter of *T*, we have $y \in \mu_t$ implies that $\mu(y) \geq t$, a contradiction. Hence $\{\mu(y),r\} \geq \min\{\mu(x),s\}$ for all $x,y \in T$ with $x \leq y$. Let there exist $x,y,z \in T$ such that $\max\{\mu(xyz),r\} < \min\{\mu(x),\mu(y),\mu(z),s\} = t$ then $t \in (r,s]$, $\mu(xyz) < t$, $x \in \mu_t$, $y \in \mu_t$, $z \in \mu_t$. Since μ_t is a filter of *T*, we have $xyz \in \mu_t$ which implies that $\mu(xyz) \geq t$, a contradiction. Hence $\max\{\mu(xyz),r\} \geq \min\{\mu(x),\mu(y),\mu(z),s\}$ for all $x,y,z \in T$. Finally let us suppose that there exist $x,y,z \in T$ such that $\max\{\mu(x),\mu(y),\mu(z),r\} < \min\{\mu(xyz),s\} = t$ then $t \in (r,s]$, $\mu(x) < t$, $\mu(y) < t$, $\mu(z) < t$ and $xyz \in \mu_t$. Then since μ_t is a filter of *T*, we have, $x,y,z \in \mu_t$ which implies that $\mu(x) \geq t$, $\mu(y) \geq t$, $\mu(z) \geq t$ which is a contradiction. Hence $\max\{\mu(x),\mu(y),\mu(z),r\} \geq \min\{\mu(xyz),s\}$ for all $x,y,z \in T$. Consequently μ is a fuzzy filter of *T*.

Remark 4.19

(1) By *Definition 4.17*, we have the following conclusion: If μ is a fuzzy filter of *T* with thresholds $(r,s]$, then we have:

(i) μ is an ordinary fuzzy filter when $r = 0$ and $s = 1$,

(ii) μ is an $(\in,\in \vee \mathrm{q})$-fuzzy filter when $r = 0$ and $s = 0.5$,

(iii) μ is an $(\overline{\in},\overline{\in} \vee \overline{q})$-fuzzy filter when $r = 0$ and $s = 1$.

(2) By *Definition 4.17*, we can define other types of fuzzy filters of an ordered ternary semigroup *T* such as fuzzy filter with thresholds $(0.5, 0.6]$ of *T*, fuzzy filter with thresholds $(0.4, 0.8]$ of *T*, etc.

(3) However, the fuzzy filter with thresholds of T may not be an ordinary fuzzy filter, may not be an $(\in, \in \vee \mathrm{q})$-fuzzy filter, and may not be an $(\overline{\in}, \overline{\in} \vee \overline{q})$-fuzzy filter. This is shown in the following example.

Example 4.20 (Davvaz & Khan 2012)

Consider the ordered semigroup as given in **Example 3.2** and define a fuzzy subset μ of T as follows:

$$\mu(e) = 0.8,\ \mu(d) = 0.7,\ \mu(a) = 0.6,\ \mu(b) = 0.4,\ \mu(c) = 0.3,\ \mu(f) = 0.5$$

Then,

$$U(\mu;t) = \begin{cases} T & \text{if} \quad 0 < t \leq 0 \\ \{a,d,e\} & \text{if} \quad 0.5 < t \leq 0.6 \\ \{a,d,e,f\} & \text{if} \quad 0.4 < t \leq 0.5 \\ \{a,d,e,f,b\} & \text{if} \quad 0.3 < t \leq 0.4 \\ \phi & \text{if} \quad 0.8 < t \end{cases}$$

Thus, μ is a fuzzy filter with thresholds $(0.5, 0.6]$ of T. But neither μ is a fuzzy filter of T and $(\in, \in \vee \mathrm{q})$-fuzzy filter of T nor an $(\overline{\in}, \overline{\in} \vee \overline{q})$-fuzzy filter of T.

$(\in, \in \vee \mathbf{q})$-fuzzy left(right) filters

Definition 5.1

A fuzzy subset μ of T is called an $(\in, \in \vee \mathrm{q})$-fuzzy left (resp. fuzzy right) filter of T if it satisfies:

(1) $(\forall x, y \in T)(\forall t \in (0,1])(x \leq y, x_t \in \mu \longrightarrow y_t \in \mu)$,

(2) $(\forall x, y, z \in T)(\forall t, r, s \in (0,1])\left(x_t \in \mu, y_r \in \mu, z_s \in \mu \longrightarrow (xyz)_{\min\{t,r,s\}} \in \mu\right)$

(3) $(\forall x, y, z \in T)(\forall t \in (0,1])(x_t \in \mu \longrightarrow (xyz)_t \in \mu(\text{resp.}\,(zyx)_t \in \mu))$

Example 5.2 (Davvaz & Khan 2012)

Let $T = \{a,b,c,d,e,f\}$ be a set. Define a ternary operation $(\ \ )$ on T as $(abc) = a * b * c$, where the binary operation $" * "$ and order relation $" \leq "$ are defined as follows:

$*$	a	b	c	d	e	f
a	b	c	d	d	d	d
b	c	d	d	d	d	d
c	d	d	d	d	d	d
d	d	d	d	d	d	d
e	e	e	e	e	e	e
f	f	f	f	f	f	f

and,

$$\leq := \{(a,a),(b,b),(c,c),(d,d),(e,e),(f,f),(a,d),(b,d),\\ (c,d),(d,e),(d,f),(a,e),(b,e),(c,e),(a,f),(b,f),(c,f),\}$$

Then, $(T,\cdot,\leq)$ is an ordered ternary semigroup. Left filter of T are $\{e,f\}$ and T. Define a fuzzy subset μ of T as follows:

$$\mu(a)=\mu(b)=\mu(c)=\mu(d)=0.3, \mu(e)0.7=, \mu(f)=0.5$$

Then,

$$U(\mu;t)=\begin{cases} T & \text{if} \quad 0 < t \leq 0.3 \\ \{e,f\} & \text{if} \quad 0.3 < t \leq 0.5 \\ \phi & \text{if} \quad 0.7 < t \leq 1 \end{cases}$$

Then, μ is an $(\overline{\in},\overline{\in}\vee\overline{q})$-fuzzy filter of T.

Theorem 5.3

For a fuzzy subset μ of T the **Conditions (1) – (3)** respectively, of **Definition 5.1**, are equivalent to the following conditions:

(i) $(\forall x,y \in T)(\mu(y) \geq \min\{\mu(x),0.5\})$,

(ii) $(\forall x,y,z \in T)(\mu(xyz) \geq \min\{\mu(x),\mu(z),0.5\})$,

(iii) $(\forall x,y,z \in T)(\mu(xyz) \geq \min\{\mu(x),0.5\}(\text{resp. } \mu(xyz) \geq \min\{\mu(z),0.5\}))$

Proof. (1) ⇒ (i) Suppose that (1) is true. Let there exists $a,b \in T$, $t_0 \in (0,1]$, such that $\mu(b) < t_0 \leq \min\{\mu(a),0.5\}$, then $a_{t_0} \in \mu$ but $b_{t_0} \overline{\in} \mu$, a contradiction. Hence $\mu(y) \geq \min\{\mu(x),0.5\}$ for all $x,y \in T$.

(i) ⇒ (1) Assume that (i) is true. Let $a,b \in T$, $a \leq b$, $t \in (0,1]$ such that $x_t \in \mu$, then $\mu(x) \geq t$, by hypothesis, we have $\mu(y) \geq \min\{\mu(x),0.5\} \geq \min\{t,0.5\}$. If $t \leq 0.5$, then $\mu(y) \geq t$ implies $y_t \in \mu$. If $t > 0.5$, then $\mu(y) \geq 0.5$ so that $\mu(y)+t > 0.5+0.5 = 1$ implies that $y_t q \mu$. Hence $y_t \in\vee q \mu$.

(2) ⇒ (ii) Suppose that (2) is true. If $\mu(x)=\mu(y)=\mu(z)=0$, then $\mu(xyz) \geq \min\{\mu(x),\mu(y),\mu(z),0.5\}$. Let $\mu(x) \neq 0$, $\mu(y) \neq 0$, $\mu(x) \neq 0$ and on contrary suppose that there exists $a,b,c \in T$, $t_1 \in (0,1]$ such that $\mu(abc) < t_1 \leq \min\{\mu(a),\mu(b),\mu(c),0.5\}$ which implies that $a_{t_1} \in \mu$, $b_{t_1} \in \mu$, $c_{t_1} \in \mu$ but $(abc)_{t_1} \overline{\in} \mu$, a contradiction. Hence $\mu(xyz) \geq \min\{\mu(x),\mu(y),\mu(z),0.5\}$ for all $z,y,z \in T$.

(ii) ⇒ (2) Assume that (i) is true and let $x, y, z \in T$ and $t, r, s \in (0,1]$, such that $x_t, y_r, z_s \in \mu$. Then $\mu(x) \geq t$, $\mu(y) \geq r$, $\mu(z) \geq s$. By hypothesis, we have $\mu(xyz) \geq \min\{t, r, s, 0.5\}$. If $\min\{t, r, s\} > 0.5$, then $\mu(xyz) \geq \min\{t, r, s\}$ implies that $(xyz)_{\min\{t,r,s\}} \in \mu$. If $\min\{t, r, s\} > 0.5$. Then $\mu(xyz) \geq 0.5$, so that $\mu(xyz) + \min\{t, r, s\} > 0.5 + 0.5 = 1$ implies $(xyz)_{\min\{t,r,s\}} q \mu$. Hence $(xyz)_{\min\{t,r,s\}} \in \vee q \mu$.

(3) ⇒ (iii) Suppose that (3) is true. If there exists $a, b, c \in \mu$ and $t_2 \in (0,1]$ such that $\mu(abc) < t_2 \leq \min\{\mu(a), 0.5\}$. Then $a_{t_2} \in \mu$ but $(abc)_{t_2} \notin \mu$ a contradiction. So $\mu(xyz) \geq \min\{\mu(x), 0.5\}$ for all $x, y, z \in \mu$.

(iii) ⇒ (3) Assume that (3) is true. Let $x, y, z \in T$ and $t \in (0,1]$ such that $x_t \in \mu$. Then $\mu(x) \geq t$. By hypothesis we have, $\mu(xyz) \geq \min\{\mu(x), 0.5\} \geq \min\{t, 0.5\}$. If $t \leq 0.5$, then $\mu(xyz) \geq t$ implies that $(xyz)_t \in \mu$. If $t > 0.5$. Then $\mu(xyz) \geq 0.5$. So that $\mu(xyz) + t > 0.5 + 0.5 = 1$ implies $(xyz)_t q \mu$. Hence $(xyz)_t \in \vee q \mu$.

Definition 5.4

Let $r,s \in (0,1]$ and $r < s$. Let *m* be a fuzzy subset of an ordered ternary semigroup *T*. Then μ is called *a fuzzy left (*resp. *right) filter with thresholds (r,s) of T* if it satisfies the following conditions:

(1) $(\forall x,y \in T)(x \leq y, \max\{\mu(y),r\} \geq \min\{\mu(x)s\})$

(2) $(\forall x,y \in T)(\max\{\mu(xyz),r\}) \geq \min\{\mu(x),\mu(y),\mu(z),s\}$

(3) $(\forall x,y \in T)(\max\{\mu(xyz),r\}) \geq \min\{\mu(x),s\}$ $(resp. \max\{\mu(xyz),r\} \geq \min\{\mu(z),s\})$.

If μ is a fuzzy filter with thresholds (r,s) of *T*. Then *m* is an $(\in, \in\vee q)$-fuzzy left (resp. right) filter of *T* if *r* = 0 and *S* = 0.5. Now we characterize fuzzy left (right) filters with thresholds (r,s) of *T* by their level left (right) filters.

Theorem 5.5

A fuzzy subset μ of an ordered ternary semigroup *T* is a fuzzy left (resp. right) filter with thresholds (r,s) of *T* if and only if $\mu_t(\pi,0)$ is a left (right) filter of *T* for all $t \in (r,s]$.

Proof. The proof follows from **Theorem 4.18**.

Date of submission: September 2014

Date of acceptance: December 2014

REFERENCES

Bhakat, SK & Das, P 1996, '$(\in,\in\vee q)$-fuzzy subgroups', *Fuzzy Sets and Systems*, vol. 80, pp. 359–368.

Bhakat, SK & Das, P 1996, 'Fuzzy subrings and ideals redefined', *Fuzzy Sets and Systems*, vol. 81, pp. 383–393.

Davvaz, B 2006, '$(\in,\in\vee q)$-fuzzy subnear-rings and ideals', *Soft Computing*, vol. 10, pp. 206–211.

Davvaz, B & Corsini, P 2008, 'On (α,β)-fuzzy H_v-ideals of H_v-rings', *Iran. J. Fuzzy Syst.*, vol. 5, pp. 35–47.

Davvaz, B, Zhan, J & Shum, KP 2008, 'Generalized fuzzy polygroups endowed with interval valued membership functions', *Journal of Intelligent and Fuzzy Systems*, vol. 19, pp. 181–188.

Davvaz, B 2008, 'Fuzzy *R*-subgroups with thresholds of near-rings and implication operators', *Soft Computing*, vol. 12, pp. 875–879.

Davvaz, B, Kazanci, O & Yamak, S 2009, 'Generalized fuzzy n-ary subpolygroups endowed with interval valued membership functions', *Journal Intelligent and Fuzzy Systems*, vol. 20, pp. 159–168.

Davvaz, B & Mozafar, Z 2009, '$(\in,\in\vee q)$-fuzzy Lie subalgebra and ideals', *International Journal of Fuzzy Systems*', vol. 11, no. 2, pp. 123–129.

Davvaz, B & Khan, A 2012, 'Generalized fuzzy filters in ordered semigroups', *Iranian Journal of Science & Technology*, vol. A1, pp. 77–86.

Davvaz, B, Khan, A, Sarmin, N & Hidayatulla, K, 2013, 'More general forms of interval valued fuzzy filters of ordered semigroup', *Iranian Journal of Fuzzy System*, vol. 15, no. 2, pp. 110–126.

Jun, YB & Song, SZ 2006, 'Generalized fuzzy interior ideals in semigroups', *Information Sciences*, vol. 176, pp. 3079–3093.

Jun, YB, Khan, A & Shabir, M 2009, 'Ordered semigroups characterized by their $(\in,\in\vee q)$-fuzzy biideals', *Bull. Malays. Math. Sci. Soc.*, vol. 32, no. 2, pp. 391–408.

Kuroki, N 1981, 'On fuzzy ideals and fuzzy biideals in semigroups', *Fuzzy Sets and Systems*, vol. 5, pp. 203–215.

Khan, A & Shabir, M 2009, '(α,β)-fuzzy interior ideals in ordered semigroups', *Lobachevskii Journal of Mathematics*, vol. 30, pp. 30–39.

Kazanci, O & Yamak, S 2008, 'Generalized fuzzy bi-ideals of semigroup', *Soft Computing*, vol. 12, pp. 1119–1124.

Kazanci, O & Davvaz, B 2009, 'Fuzzy n-ary polygroups related to fuzzy points', *Computers & Mathematics with Applications*, vol. 58, pp. 1466–1474.

Kehayopulu, N & Tsingelis, M 2002, 'Fuzzy sets in ordered groupoids', *Semigroup Forum*, vol. 65, 128–132.

Lehmer, DH 1932, 'A ternary analoue of abelian groups', *Amer. J. Math.*, vol. 59, pp. 329–338.

Los, J 1955, 'On the extending of model', *Fundamenta Mathematicae*, vol. 42, pp. 38–54.

Liu, L & Li, K 2005, 'Fuzzy implicative and Boolean filters of R_0-algebras', *Information Sciences*, vol. 171, pp. 61–71.

Lee, SK & Park, KY 2003, 'On right (left) duo po-semigroups', *Kangweon-Kyungki Math. Jour.*, vol. 11, pp. 147–153.

Mordeson, JN, Malik, DS & Kuroki, N 2003, '*Fuzzy semigroups, studies in fuzziness and soft computing'*, vol. 131, Berlin, Springer-Verlag.

Ma, X, Zhan, J & Jun, YB 2009, 'On $(\in,\in\vee q)$-fuzzy filters of R_0-algebras', *Math. Log. Quart.*, vol. 55, pp. 493–508.

Pu, PM & Liu, YM 1980, 'Fuzzy topology I, neighborhood structure of a fuzzy point and Moore-Smith convergence', *J. Math. Anal. Appl.*, vol. 76, pp. 571–599.

Rosenfeld, A 1971, 'Fuzzy groups', *J. Math. Anal. Appl.*, vol. 35, pp. 512–517.

Shabir, M & Khan, A 2008, 'Characterizations of ordered semigroups by the properties of their fuzzy generalized bi-ideals', *New Mathematics and Natural Computation*, vol. 4, pp. 237–250.

Shabir, M & Khan, A 2008, 'Fuzzy filters in ordered semigroups', *Lobachevskii J. Math.*, vol. 29, pp. 82–89.

Chinram, R & Saelee, S 2010, 'Fuzzy ideals and fuzzy filters of ordered ternary semigroups', *Journal of Mathematics Research*, vol. 2, pp. 93–97.

Yuan, X, Zhang, C & Ren, Y 2003, 'Generalized fuzzy groups and many-valued implications', *Fuzzy Sets and Systems*, vol. 138, pp. 205–211.

Zadeh, LA 1965, 'Fuzzy sets', *Inf. Cont.*, vol. 8, pp. 338–353.

ASEAN J. Sci. Technol. Dev., **31(2)**: 83 – 89

Effects of Oil Palm (*Elais guineensis*) Fruit Extracts on Glucose Uptake Activity of Muscle, Adipose and Liver Cells

S. FAEZ[1*], H. MUHAJIR[2], I. AMIN[3] AND A. ZAINAH[4]

The effect of oil palm (*Elaeis guineensis*) fruit aqueous extract (OPF) on glucose uptake activity of three different cell lines was investigated. The cell lines were incubated with different concentrations of OPF to evaluate the stimulatory effect of OPF towards glucose uptake activity of L6 myotubes, 3T3F442A adipocytes and Chang liver cell line. The glucose uptake activities of all tested cells were enhanced in the presence of OPF extract (basal condition). Nevertheless in combination of OPF extract and 100 nM insulin, the glucose uptake activity was only significantly enhanced in L6 myotubes and 3T3F442A adipocytes cell lines. The extracts enhanced the glucose uptake into cells through either insulin-mimetic or insulin-sensitizing property or combination of these two properties. It can be suggested that the OPF extract exerts its antihyperglycemic action partly by mediated glucose uptake into the glucose-responsive disposal cells, muscle, adipose and liver.

Hyperglycaemia in diabetic patients is reduced in a number of ways. One known mechanism to reduce hyperglycaemia is by glucose uptake into peripheral cells (muscle, adipocytes and liver) (Patel & Mishra 2008). Glucose is taken into the cells through glucose transpoter (GLUTS). In the liver glucose, it is taken up through GLUT2 while GLUT4 play its role to take up glucose in adipocyte and muscle cells (Troy & Glenn 2009). Insulin sensitizers like thiazolidinediones and metformin have been reported to improve insulin-mediated glucose uptake into peripheral cells (Zangeneh *et al*. 2003). They are oral antidiabetic drugs that usually prescribed to diabetic patients. However the drugs exert some adverse effect where those drugs were reported to cause gastrointestinal problems, peripheral edema and can cause weight gain (Arner 2003; Zangeneh *et al*. 2003). Thus these limitations have fuelled the search for alternative therapeutic agents for the treatment of diabetes mellitus.

Several plants have been identified to improve glucose uptake into peripheral cells. The antihyperglycemic properties of plants were reported to be associated with the polyphenolic and flavonoid content which can be found in various plants. Plants like *Amomi semen* (Kang & Kim 2004) and *Cortex Phellodendri* (Ko *et al*. 2005) have been reported to enhance insulin-mediated glucose uptake activity into adipocytes cells. On the other hand *Pterocarpus marsupium* had been reported to enhance glucose uptake into L6 myotubes (Anandharajan *et al*. 2006). Those plants are believed to

[1] Department of Biotechnology, Kulliyah of Sciences, International Islamic University Malaysia, 25200 Indera Mahkota, Kuantan, Pahang, Malaysia
[2] Department of Microbiology, Faculty of Biotechnology and Biomolecular Sciences, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[3] Department of Nutrition and Dietetics, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, 43400 Serdang, Selangor Malaysia
[4] Medical Technology Division, Malaysian Nuclear Agency, Bangi 43000 Kajang, Selangor, Malaysia
* Corresponding author (e-mail: faezsharif@gmail.com)

enhance glucose uptake into peripheral cells through either mimicking or sensitizing insulin action (Jung *et al*. 2007). Plants with high phenolic antioxidant compounds exert high potential as supplements for improving blood glucose control and preventing long-term complications among diabetics (Gallegher *et al*. 2003).

The oil palm fruit is planted abundantly throughout Malaysia. The fruit has been extensively researched for its health and nutritional properties, including antioxidant activities, cholesterol lowering, anticancer effects and protection against cardiovascular diseases (Sundram *et al*. 2003). The fruits are also reported to contain a significant degree of antioxidant polyphenolic compounds (Sundram *et al*. 2003; Neo *et al*. 2010). Nevertheless the antidiabetic effects of oil palm fruits on stimulating glucose uptake activity are yet to be known. Therefore in the present study the ability of oil palm fruit extracts (OPF) to stimulate glucose uptake into peripheral (muscle, adipose and liver) cells were evaluated. The L6 myotubes, 3T3F442A adipocytes and Chang liver cell line was used as the model of the system.

MATERIALS AND METHODS

Sampling and Sample Preparation

The oil palm fruit, *E. guineensis*, was collected from the Universiti Putra Malaysia Agriculture Park. Ripe oil palm fruits were harvested from trees and used as the fresh sample. The fresh oil palm fruits were scraped into thin flakes and dried in oven overnight at 40°C. The dried fruits then were ground into small particles and the oil was removed with hexane (Merck, Germany) by using the Soxhlet method (45°C, 8 h). Following removal of oil, the OPF was extracted according to the method described by Wang and Halliwell (2001). Briefly 1g of dried de-oiled oil palm mesocarp was mixed with 40 ml of 60% aqueous ethanol (Merck, Germany). Subsequently, 5 ml of 6 M HCl (Merck, Germany) was added into the mixture prior to reflux. After refluxing for 2 h, the extract was cooled, filtered, and standardized to 50 ml with 60% ethanol. Then the solvent was removed using a rotary evaporator. Finally the OPF was preserved by freeze drying.

Cell Line Maintenance

In the evaluation of glucose uptake activity, three cell lines were used (L6 myotubes, 3T3F442A adipocytes and Chang liver cells) as the model of the glucose uptake system. L6 myotubes and 3T3F442A adipocytes were maintained in Dulbecco's Modified Eagle Medium (DMEM) while Chang liver cells were maintained in medium Roswell Park Memorial Institute (RPMI). The complete culture medium was done by addition of 10% (v/v) fetal bovine serum (FBS) and 1% (v/v) antibiotic solution. The cell lines were incubated and humidified with 5% CO_2 at 37°C condition. Following sub-confluences (70%–80%) cultures were split using 0.25% Trypsin to 1:3. After that the cells were centrifuged for 5 min at 10 000 r.p.m. and the pellets were suspended again into culture medium until reaching confluency. The L6 myoblasts were induced to differentiate into myotubes by reducing the FBS in the complete culture medium from 10% to 2% (Ziyou *et al*. 2009). The cells were maintained with this medium for 4–6 days post-confluence. Along the period the cells were observed and the extent of differentiation was established by observing multinucleation of cells. The 3T3F442A fibroblast-like cells were spontaneously differentiated into adipocytes upon reaching confluency. The presence of viscous media in each well confirmed the extent of differentiation as free fatty acids were produced by the cells and secreted into the media.

Evaluation of Glucose Uptake Activity of OPF Extract

The cells were seeded into 12-well plate at the concentration of 2×10^5 cells per well. The cells then were left overnight to allow attachment. After the cells were attached on the following day, they were washed with serum-free medium thrice. Then the cells were incubated with the same medium for two hours. After the starvation period, the cells were then washed with Kreb's-Ringer bicarbonate buffer (KRB) thrice. Then the cells were pre-incubated for 30 min with various concentration of OPF extract. Metformin and rosiglitazone maleate were used as positive control. After 30 min of incubation, 500 µl of 2-deoxy-[^{3}H]-glucose 1 µCi/ml diluted 0.1 mM glucose was added to each well except the blanks to initiate the glucose uptake reaction. The reaction was allowed to occur for 60 min. Subsequently the cells were washed trice with ice-cold KRB buffer. Then 0.1% sodium dodecyl sulphate dissolved in 0.1M phosphate buffer pH 7.4 was added to solubilize the cells. Then the mixture of each well was transferred into the scintillated cocktail and 15 ml of scintillated cocktail, Ultima Gold™ was added. Finally the radioactivities incorporated into the L6 myotubes which indicated the glucose uptake activity were measured using Liquid Scintillation Counter (Hewlett Packard, USA).

Statistical Analysis

Data were expressed as mean ± standard deviation. One-way ANOVA (GraphPad Prism 5) were used for analysis and groups were considered significantly different at the 5% significance level ($p<0.05$). Dunnet post-hoc test was done if a significant value was obtained for ANOVA.

RESULTS AND DISCUSSIONS

Cell lines are homogenous culture of cells. Due to their homogeneity, the cell lines become the best choice to study the effects of an agent on insulin activity compared to isolated cells or tissues which are mixed in nature. Furthermore, cell lines are more stable and have longer lifespan compared to the isolated cells (Parthasarathy *et al*. 2009). In the present study, three cell lines were used to study the effects of OPF extract on glucose uptake activity. The cell lines used include L6 myotubes, 3T3F442A adipocytes and Chang liver cells. A previous report has found that L6 myotube was the best-characterized cellular model of skeletal muscle to study the glucose uptake activity by GLUT4 translocation (Patel & Mishra 2008). The 3T3F442A adipocyte on the other hand has been widely used to study the effects of an insulinotropic agent on glucose uptake activity into adipocytes (Sakurai *et al*., 2004). Meanwhile the Chang liver cell is one of the models used widely to study the glucose transports in the liver besides HepG2 and H4IIE (Rengarajan *et al*. 2007). All models of cell lines used in this study showed the ability to enhance glucose uptake activity when treated with OPF extract at particular concentrations (*Figures 1–3*). This observation indicated that there was a possibility that the antidiabetic compounds were present in the OPF extract. The compounds might have the potential to regulate hyperglycaemia through the enhancement of glucose disposal into muscle, adipose and liver cells. However purification of the compounds was not conducted in the present study. Therefore further experimentations are needed to be carried out to evaluate the exact compounds which may be responsible to regulate the mechanism by which this disposal is mediated.

Plant extracts may potentiate the glucose uptake into cells through insulin-mimetic or insulin sensitizing properties. These properties of plants were reported to be associated with the flavonoids content which can be found in various plants. For example, a flavonoids found in grapefruit namely naringenin, has been shown to increase basal glucose uptake in L6 myotubes which is comparable to 100 nM insulin (Zygmunt *et al*. 2010). On the other hand, the grape seed contains procyanidins which is reported to have insulin-mimetic effect during stimulating glucose uptake into 3T3L1 adipocytes cells (Pinent *et al*. 2004). Glucose is taken into the cells through glucose transpoter (GLUTS). In the liver glucose it is taken up through GLUT2 while GLUT4 plays its role to take up glucose in adipocyte and muscle cells (Troy & Glenn 2009). The GLUT4 is located inside the cells and its translocation to cell membrane to facilitate glucose transport into the cells are sensitize with the presence of insulin. In contrast GLUT2 is located in the cell membrane and facilitate glucose transport into cells without the need of insulin. GLUT2 can sensor the presence of glucose independently since they have high capacity and low affinity (high K_m value, 15 mM–20 mM) for glucose. The high K_m value allows for glucose sensing where the rate of glucose uptake is proportional to blood glucose level (Li *et al*. 2007). Nevertheless according to the previous report the presence of insulin can also enhance the glucose uptake activity in Chang liver cells (Satake *et al*. 2002). Our present data are in accordance with the previous reports where insulin 100 nM alone significantly enhanced glucose uptake activity in all types of cells evaluated (*Figures 1–3*). The same concentration of insulin was used to mediate the glucose uptake activity of OPF extract in L6 myotubes, 3T3F442A adipocytes and Chang liver cells. Furthermore according to the previous report, the 100 nM of insulin concentration has also been widely used to mediate the glucose disposals into cells (Sakurai *et al*. 2004). Nevertheless in the treatment using combination of OPF and 100 nM insulin, only the L6 myotubes and 3T3F4424A adipocytes showed a significant enhancement in the glucose uptake activity. The glucose uptake activity of Chang liver cell was not significantly enhanced in the presence of both OPF and 100 nM insulin (*Figure 3*). The Chang liver cell mediated the glucose uptake through GLUT2 where insulin was not the core factors in their mechanism to mediate glucose uptake compared to GLUT4 which required insulin to promote glucose transportation into the muscle and adipose cells. Therefore the difference of functional GLUT protein involved in the translocation of glucose into the liver cells might explain the results obtained in the previous study (Li *et al*. 2007).

The mechanisms underlie the insulin-mimetic and insulin-sensitizing property of the OPF extract was not elucidated in the presence study. However the insulin-like or insulin-mimetic activity of a plant has been

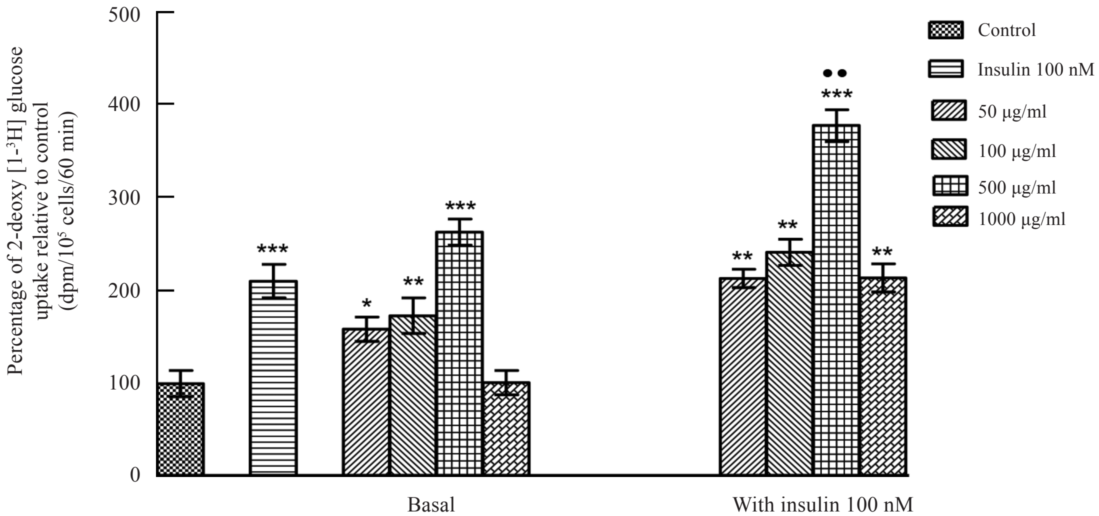

*Figure 1. Effect of OPF extract on basal and insulin-mediated glucose uptake activity of L6 myotubes. Values represent the means ±S.D. *p<0.05, **p<0.01 and ***p<0.001 compared with control. ●●p<0.01 compared to 100 nM insulin alone.*

evaluated previously in several plants. An example is the fanugreek seed. The fenugreek seed extract has been reported to mediate the glucose uptake activity into liver and adipocytes through the activation of tyrosine phosphorylation of ß-subunit of insulin receptor. This activation subsequently enhanced tyrosine phosphorylation of insulin receptor substrate-1 (IRS-1) and p85 subunit of phosphatidylinositol-3-kinase (PI3-kinase) which leads to glucose uptake by these cells (Vijayakumar *et al*. 2005). The insulin sensitizing activity has

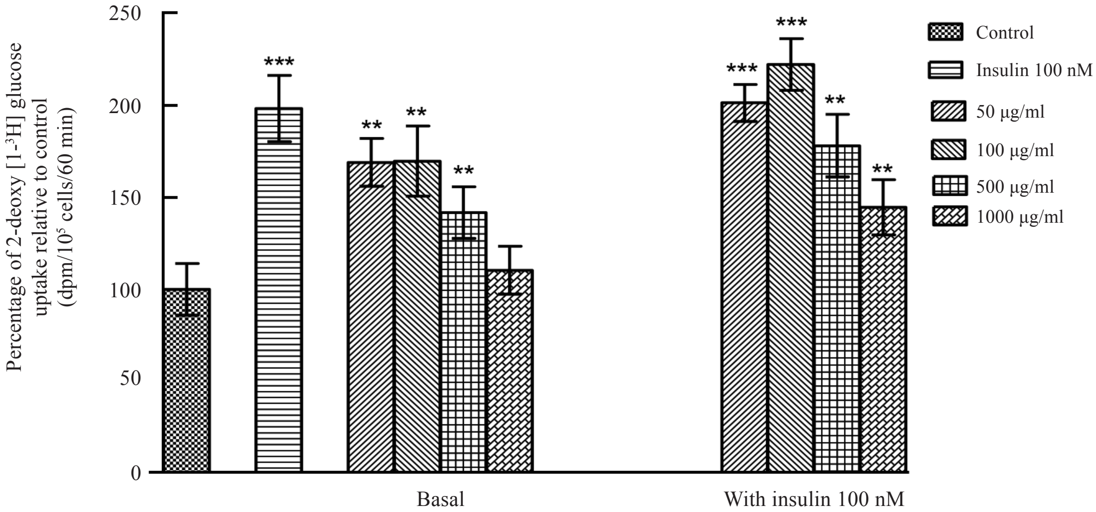

*Figure 2. Effect of OPF extract on basal and insulin-mediated glucose uptake activity of 3T3F442A adipocytes. Values represent the means ±S.D. **p<0.01 and ***p<0.001 compared with control.*

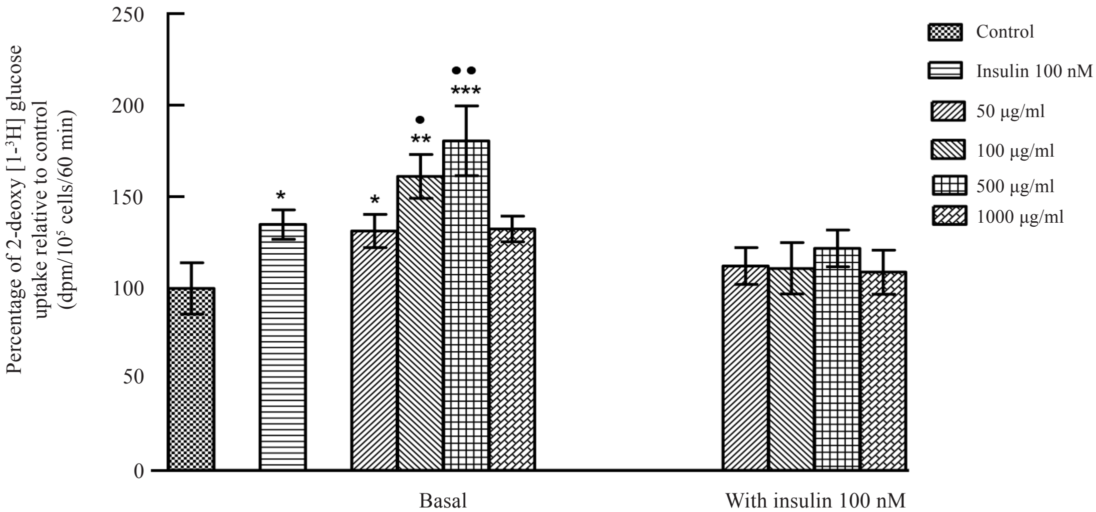

*Figure 3. Effect of OPF extract on basal and insulin-mediated glucose uptake activity of Chang liver cells. Values represent the means ±S.D. *p<0.05, **p<0.01 and ***p<0.001 compared with control. ●p<0.05 and ●●p<0.01 compared to 100 nM insulin alone.*

been previously reported in several plants like *Campsis grandiflora* (Jung *et al*. 2007) and *miltiorrihiza* Bunge. They were reported to enhance the tyrosine phosphorylation of insulin receptor and activation of downstream kinase. Therefore there are possibilities that OPF extract exert the insulin-mimetic and insulin-sensitizing properties through the mentioned mechanisms. However further evaluation are needed to be carried out to confirm this suggestion.

Date of submission: September 2014

Date of acceptance: November 2014

REFERENCES

Anandharajan, R, Pathmanathana, K, Shankernarayanan, NP, Vishwakarmab, RA & Balakrishna, A 2005, 'Upregulation of GLUT4 and PPARγ by an isoflavone from *Pterocarpus marsupium* on L6myotubes: A possible mechanism of action', *Journal of Ethnopharmacology,* vol. 97, pp. 253−260.

Arner, P 2003, 'The adipocyte in insulin resistance: key molecules and the impact of the Thiazolidinediones', *Trends in Endocrinology and Metabolism*, vol. 14, no. 3, pp. 137−144.

Gallagher, AM, Flatt, PR, Duffy, G & Abdel-Wahab, YHA 2003, 'The effects of tradisional antidiabetic plants *in vitro* glucose diffusion', *Nutrition Research,* vol. 23, pp. 413−424.

Jung, SH, Ha, YJ, Shim, E K, Choi, SY, Jin, JL, Yun-Choi, HS & Lee, JR 2007, ' Insulin mimetic and insulin sensitizing activities of tanshinones, diterpine compounds of the root of *Salvia miltiorrhiza* Bunge, *Phytomedicine*, vol. 16, pp. 327−335.

Kang, Y & Kim, YH 2004, 'Glucose uptake-stimulatory activity of *Amomi semen* in 3T3-L1 adipocytes', *Journal of Ethnopharmacology*, vol. 92, pp. 103−105.

Ko, BS, Choi, SB, Park, SK, Jang, JS, Kim, YE & Park, S 2005, 'Insulin-sensitizing and insulinotropic action of Berberin from *Cortidis Rizhoma, Biological & Pharmaceutical Bulletin,* vol. 28, no. 8, pp. 1431−1437.

Li, R, Thorens, B & Loeken, MR 2007, ' Expression on the gene encoding the high Km glucose transporter 2 by the early post-implantation mouse embryo is essential for neural tube defects associated with diabetic embryopathy', *Diabetologia,* vol. 503, pp. 682−689.

Neo, YP, Aziz, A, Tan, C P & Tan, YA 2010, 'Phenolic acid analysis and antioxidant activity assessment of oil palm *E. Guineensis* fruit extracts', *Food Chemistry*, vol. 122, pp. 353−359.

Parthasarathy, C, Renuka, VN & Balasubramaniam, K 2009, 'Sex steroids enhance insulin receptors and glucose oxidation in Chang liver cells', *Clinica Chimica Acta, vol.* 399, vols. 1−2, pp. 49−53.

Patel, MB & Mishra, SH 2008, 'Cell line in diabetic research: a review', *Pharmacognosy Review*, vol. 2, no. 4, pp. 188−205.

Pinent, M, Blay, M, Blade, MC, Salvado, MJ, Arola, L & Ardevol, A 2004, 'Grape seed derived procyanidins have an antihyperglycemic effect in streptozotocin-induced diabetic rats and insulinomimetic activity in insulin sensitive cell lines', *Endocrinology,* vol. 145, no. 11, pp. 4985−4990.

Rengarajan, S, Parthasarathy, C, Anitha, M & Balasubramaniam, K 2007, 'Diethyl phthalate impairs insulin binding and glucose oxidation in Chang liver cells', *Toxicology in Vitro,* vol. 21, pp. 99−102.

Sakurai, K, Kawazuma, M, Adachi, T, Harigaya, T, Saito, Y, Hashimoto, N & Mori, C 2004, 'Bisphenol A affects glucose transport in mouse 3T3F442A adipocytes', *British Journal of Pharmacology*, vol. 141, no. 2, pp. 209−214.

Satake, S, Moore, MC, Igawa, K, Converse, M, Farmer, B, Neal, DW & Cherrington, AD 2002, 'Direct and indirect effects of insulin on glucose uptake and storage by the liver', *Diabetes*, vol. 51, no. 6, pp. 1663−1671.

Sundram, K, Sambarthamurti, R & Tan, YA 2003, 'Palm fruit chemistry and nutrition', *Asia Pacific J. Clin. Nutr.*, vol. 12, no. 3, pp. 355−362.

Troy, LM & Glenn, KM 2009, 'Skeletal muscle glucose uptake during excercise: a focus on reactive oxygen species and nitric oxide signalling', *Life*, vol. 615, pp. 479-484.

Vijayakumar, MV, Singh, S, Chhipa, RR & Bhat, MK 2005, 'The hypoglycaemic activity of fenugreek seed extract is mediated through the stimulation of an insulin signalling pathway', *British Journal of Pharmacology*, vol. 146, pp. 41−48.

Wang, H & Helliwell, K 2001 Determination of flavonols in green and black tea leaves and green tea infusion by high performance liquid chromatography', *Food Research International*, vol. 34, pp. 223–227.

Zangeneh, F, Kudva, YC & Basu, A 2003, 'Insulin sensitizers', *Mayo Clinic Proceedings,* vol. 784, pp. 471−479.

Ziyou, C, Xiulan, C, Bingwen, L, Sung, KP, Tao, X, Zhensheng, X, Peng, X, Junjie, H, Haiying, H, John, RY & Fuquan, Y 2009 'Preliminary quantitative profile of differential expression between rat L6 myoblast and myotubes by stable isotope labelling by amino acids in cell culture', *Proteomics*, vol. 95, pp. 1274−1292.

Zygmunt, K, Faubert, B, MacNeil, J & Tsiani, E 2010, 'Naringenin, a citrus flavonoid, increases muscle cell glucose uptake via AMPK, '*Biochemical and Biophysical Research Communications,* vol. 398, no. 2, pp. 178−183.

ASEAN J. Sci. Technol. Dev., **31(2)**: 90 – 100

Biodiesel Production from Castor Oil and Its Application in Diesel Engine

S. ISMAIL[1], S. A. ABU*, R. REZAUR[3] AND H. SININ[4]

In this study, the optimum biodiesel conversion from crude castor oil to castor biodiesel (CB) through transesterification method was investigated. The base catalyzed transesterification under different reactant proportion such as the molar ratio of alcohol to oil and mass ratio of catalyst to oil was studied for optimum production of castor biodiesel. The optimum condition for base catalyzed transesterification of castor oil was determined to be 1:4.5 of oil to methanol ratio and 0.005:1 of potassium hydroxide to oil ratio. The fuel properties of the produced CB such as the calorific value, flash point and density were analyzed and compared to conventional diesel. Diesel engine performance and emission test on different CB blends proved that CB was suitable to be used as diesel blends. CB was also proved to have lower emission compared to conventional diesel.

Key words: biodiesel, transesterification, castor oil, diesel engine, emission; conversion

Petroleum fuels play a very important role in the development of various industries, transportations, agriculture sector and to meet many other basic human needs in modern civilization. These fuels are limited and depleting day by day as the consumption increase very rapidly. Moreover, the use of petroleum fuel has caused a lot of environmental problems by the high emission of harmful gases. A global movement towards generation of environmentally friendly yet renewable fuel is therefore under way to help meet the increased energy demands. Biofuel had become one of the most promising alternatives for petroleum fuels.

Biodiesel is the potential biofuel that can easily being produced from vegetable oil. Biodiesel has become an interesting alternative fuel over conventional diesel for decades. Biodiesel is suitable to be used in diesel engine due to the similar properties to conventional diesel in terms of power and torque and none or very minor engine modification is required (Mushtaq *et al*. 2011). Moreover, biodiesel is biodegradable which will results in less environmental impact upon accidental release to the environment (Janaun & Ellis 2010).

Biodiesel has many important technical advantages over conventional diesel such as inherent lubricity, low toxicity, derivation from a renewable and domestic feedstock, superior flash point, negligible sulphur content and lower exhaust emissions (Moser 2009). Biodiesel had been used widely as a blend with diesel. The

[1] Department of Chemical Engineering, Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia
[2] Department of Mechanical Engineering, Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia.
[3] Department of Chemical Engineering, Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia.
[4] Pusat Pengajian Pra-Universiti, Universiti Malaysia Sarawak, 94300 Kota Samarahan,Sarawak. Malaysia
* Corresponding author (e-mail: aasaleh@feng.unimas.my)

use of biodiesel as diesel blends will promote cleaner emission with less soot particles and whiter smoke. It also helps in reducing engine wear by lubrication and produces less sulphur emission. A biodiesel lifecycle study in 1998 which was jointly sponsored by the U.S. Department of Energy and the U.S. Department of Agriculture concluded biodiesel reduces carbon dioxide emissions by 78 percent compared to petroleum diesel. The CO_2 released into the atmosphere when biodiesel burned is recycled by plants, which produce more oxygen (Petracek 2014).

Among the common vegetable oils used as feedstock for the production of biodiesel are soybean, rapeseed, castor, jatropha and palm oil. Castor oil is one of the promising feedstock for biodiesel production. Castor oil is produced by means of extraction from castor bean. Castor oil is distinguished by its high content (over 85%) of ricinoleic acid. No other vegetable oil contains so high a proportion of fatty hydroxyacids. Castor oils have high molecular weight (298), low melting point (5˚C) and very low solidification point (–12˚C to –18˚C) that make it industrially useful, most of all it is has the highest and most stable viscosity of any vegetable oil (Shrirame *et al*. 2011).

The chemical structure of castor oil is of great interest because of the wide range of reactions it affords to the oleochemical industry and the unique chemicals that can be derived from it. These derivatives are considerably superior to petrochemical products since they are from renewable sources, bio-degradable and eco-friendly (Nielsen *et al*. 2011). Recent research had concerns in the using of castor oil as a feedstock for biodiesel production. As castor oil is non-edible, there is no issue of competition with the food market and it can be the promising source of feedstock for biodiesel production.

In this study, the acid-based catalyzed transesterification of castor oil was carried out to determine the optimum reaction condition for the production of castor biodiesel. Then, the fuel properties such as density, flash point and calorific value was analyzed and compared to conventional diesel. Engine performance and emission of castor biodiesel was also tested using various biodiesel blends and compared to the conventional diesel.

METHODOLOGY AND MATERIALS

In this study, crude castor oil was extracted from castor bean by using mechanical and solvent extraction. The castor beans used was obtained from a local company. The acid value of the crude castor oil was determined by titrimetry. The castor oil was converted into biodiesel by using two-step transesterification processes. In this process, the first step is acid-catalyzed esterification used to convert free fatty acids (FFA) in castor oil to methyl ester, followed by base-catalyzed transesterification using potassium hydroxide as a catalyst with methanol.

In the second step, potassium hydroxide was dissolved in methanol and the mixture is then heated up to 60°C to react accordingly to form methoxide. On the other hand, the pre-treated oil in step 1 was then heated up to 60°C. The heated oil was mixed with the methoxide and the solution was shaken at 250 r.p.m. for 2 h by using orbital shaker. The volume ratio of methanol to oil used was 1:4.0, 1:4.5 and 1:5.0 while the volume ratio of potassium hydroxide catalyst to oil used was 0.0025:1, 0.0050:1 and 0.0075:1. The volume ratio of alcohol to oil was kept constant when the catalyst amounts were being manipulated. The volume ratio of catalyst to oil was kept constant when the amount of alcohol was being manipulated. After completing the process, the mixture was allowed to settle for 8 h and then the mixture was poured into separatory funnels.

The lower layer of glycerol, extra methanol, catalyst and other byproducts were removed.

The upper layer of methyl ester or biodiesel was washed several times with de-sterilized water until the washing water become neutral. The biodiesel layer was filtered to remove impurities and then the biodiesel was heated up to 100°C to remove any remaining water. The biodiesel was the tightly sealed and kept for storage.

Biodiesel testing was carried out to compare the properties and performances of castor biodiesel and conventional diesel. The density, flash point and calorific value are measured respectively using density meter, multi-flash flash point tester and bomb calorimeter. Emission analyses were carried out using Flue Gas Analyzer. Castor biodiesel and conventional diesel were tested using FT-IR Shimadzu Iraffinity-1 Spectrophotometer for component analysis.

Diesel engine test was performed using Techno-mate, TNM-TDE-700 machine. The diesel engine testing was done three times with each blend of biodiesel. The blending percentage of biodiesel with diesel was set to 0%, 10%, 20%, 30%, 40%, 50% and they are mentioned as B10, B20, B30, B40, B50. Important values such as motor speed, output voltage, output current and time for 20 ml fuel flow were recorded. The brake load for the diesel engine testing was fixed at 120 N and the radius of brake arm was set to 0.5 m .

RESULTS AND DISCUSSIONS

Measurement of Free Fatty Acid (FFA) in Crude Castor Oil

Measurement of FFA in crude castor oil is essential for the decision of the method of transesterification for biodiesel production. From the titration method, the acid value of FFA in crude castor oil was determined to be between 20% to 23%, which is higher than 4%. The best conversion method for oil with free fatty acid higher than 4% was two-steps transesterification where FFA value is reduced at the first step (acid esterification) before proceeding to the second step (base transesterification) .

Optimization of Biodiesel Production by Manipulation of Catalyst and Alcohol Amount

For the first set of experiment, the amount of catalyst was set as the manipulated variable while the amount of methanol was set as the constant variable. From *Table 1*, it is observed that the highest yield of biodiesel was achieved with potassium to oil ratio of 0.0050:1. However, the biodiesel yield before and after the optimal amount of catalyst was noted to be lower. In the case of the catalyst shortage (0.0025:1 ratio), the biodiesel yield percentage was 60% as catalyst was exhausted before all the crude oil was converted to biodiesel while in the case of excess catalyst (0.0075:1 ratio), the yield percentage was at 55% as excess catalyst attributed to soap formation which decreased the production of biodiesel.

For the second set of experiment, the amount of methanol was set as the manipulated variable while the amount of catalyst was set as the constant variable. From *Table 2*, it is observed that the highest yield of biodiesel was achieved with the 1:4.5 of oil-to-methanol ratio. The biodiesel yield was also affected by the amount of methanol used. The shortage

Table 1. Biodiesel Yield Percentage for Different Amount of KOH (catalyst).

KOH to oil ratio (v/v)	Castor biodiesel produced (ml)	Biodiesel yield (%)
0.0025:1	12	60
0.005:1	13	65
0.0075:1	11	55

of methanol used will decrease the yield of biodiesel significantly. Excess methanol (1:5.0 ratio) contributed to methanol wastage and difficulty in the end product purification. Excess methanol increased the solubility of glycerol which was the by-product formed in biodiesel transesterification thus, it caused difficulty in the purification of biodiesel. Shortage of methanol (1:4.0 ratio) attributed to the lack of solution for the reaction to take place. Thus, it could be concluded that the optimal reactant proportion used to achieve the highest yield of biodiesel produced by base-catalysed transesterification was 0.0050:1 KOH to oil ratio with 1:4.5 of oil to methanol ratio.

FTIR Analysis

Based on the infrared spectrum of castor biodiesel and conventional diesel *Figures 1* and *2*, both castor biodiesel and conventional diesel showed the alkane C–H bond which lies on the wave numbers from 2800 cm^{-1} to 3000 cm^{-1} and alkene C–H bond at 1400 cm^{-1} to 1500 cm^{-1} .Thus, it could be confirmed that both conventional diesel and castor biodiesel had the same functional group of C–H. However, the conventional diesel had no oxygen group, whereas castor biodiesel showed oxygen functional group of ester C–O bond at 1000 cm^{-1} to 1300 cm^{-1} and ester C=O bond at 1735 cm^{-1} to 1750 $cm^{-1.}$ The presence

Table 2. Biodiesel Yield Percentage for Different Amount of Methanol.

Oil to methanol ratio (v/v)	Castor biodiesel produced (ml)	Biodiesel yield (%)
1:4.0	9.5	47.5
1:4.5	10.5	52.5
1:5.0	7.0	35.0

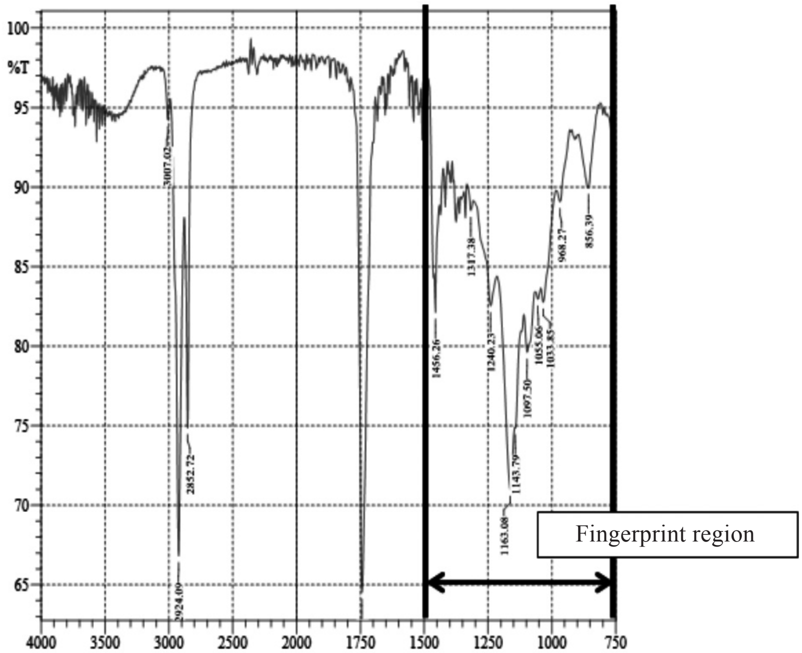

Figure 1. FTIR spectrum of castor biodiesel.

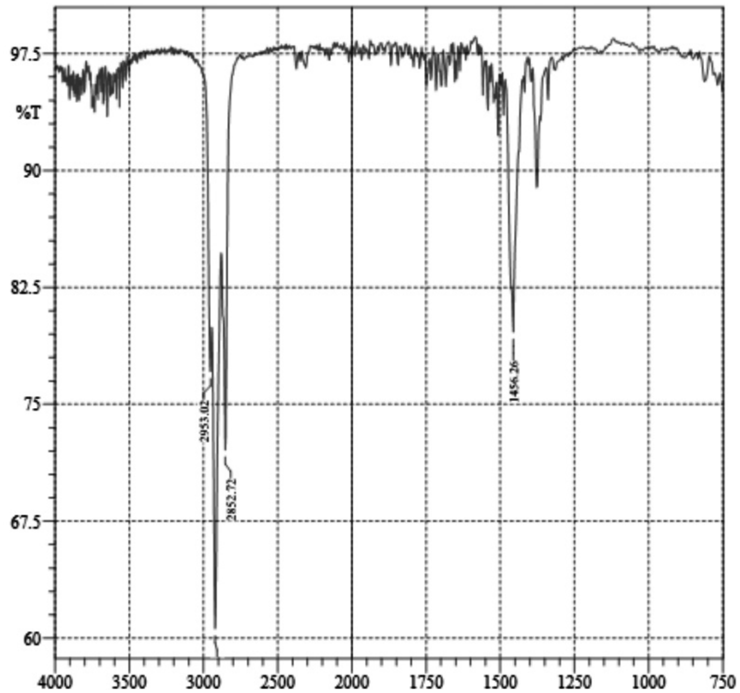

Figure 2. FTIR spectrum of conventional diesel.

of oxygen in biodiesel promotes cleaner and complete combustion. On the other hand, the conventional diesel without any oxygen component produced more black smoke and incomplete combustion during burning .

Fuel Property Analysis of Castor Biodiesel

Density

Density value must be maintained within tolerable limits to allow optimal air to fuel ratios for complete combustion in diesel engine (Ibeto *et al*. 2012). For diesel, the standard range for density value is 848 kg/m^3. For biodiesel, the standard for density value is in the range of 870 kg/m^3– 900 kg/m^3. For crude castor oil, the density value is in the range of 956 kg/m^3 – 963 kg/m^3. As observed from *Table 3*, the density for conventional diesel, castor biodiesel and crude castor oil are 841 kg/m^3, 921 kg/m^3 and 950 kg/m^3, respectively. It is observed that in comparison to ASTM standards, conventional diesel and crude castor oil conforms to the range while castor biodiesel is sighted to be slightly higher than that of the standard. Higher density value of biodiesel is contributed by the high viscosity of castor oil. The lack of double bond in triglyceride molecule plus long hydrocarbon tail on fatty acid molecule contribute to high viscosity of castor oil (Okullo *et al*. 2012). High-density biodiesel is not favourable as it can lead to incomplete combustion and particulate matter emissions (Galadima *et al*. 2008). However, this problem could be solved by blending biodiesel with conventional diesel.

Table 3. The density value for crude castor oil, castor biodiesel and conventional diesel.

Sample	Density value (kg/m^3)
Conventional diesel	841
Castor biodiesel	921
Crude castor oil	950

Calorific value. From *Table 4*, it was observed that conventional diesel had the highest calorific value followed by crude castor oil and castor biodiesel with the calorific value of 44.803 MJ/kg, 38.130 MJ/kg and 37.908 MJ/kg. The calorific value for castor biodiesel was slightly lower than that of the conventional diesel, where more amounts of biodiesel was needed to produce the same thermal energy as conventional diesel. Biodiesel has lower calorific value as its composition comprised of additional oxygen functional group and relatively lower hydrocarbon content compared to that of conventional diesel (Mathiyazhagan & Ganapathi 2011).

Table 4. The calorific value of crude castor oil, castor biodiesel and conventional diesel.

Sample	Calorific value (MJ/kg)
Conventional diesel	44.803
Castor biodiesel	37.908
Crude castor oil	38.13

Flash point. Flash point is the temperature that indicates the overall flammability hazards in the presence of air; higher flash point makes for safe handling and storage of biodiesel (Mushtaq *et al*. 2011). The flash point values for conventional diesel, castor biodiesel and crude castor oil are 75.0°C, 130.0°C and 230.0°C, respectively. From *Table 5*, it was observed that crude castor oil had the highest value of flash point followed by castor biodiesel and conventional diesel. Castor biodiesel hadhigher flash point value over conventional diesel as biodiesel was more viscous compared to conventional diesel. Flash point was positively correlated with the viscosity of diesel. The higher the viscosity, the higher the boiling point and thus caused higher flash point. Other than that, diesel has branches and lower molecular weight components which lead to a reduction of flash point (Knothe 2010). The high flash points of biodiesel make it suitable to be used as alternative to conventional diesel.

Table 5. The flash point for crude castor oil, castor biodiesel and conventional diesel.

Sample	Flash point (°C)
Conventional diesel	75
Castor biodiesel	130
Crude castor oil	230

Engine Performance

Data collected from diesel engine testing were calculated and presented as shown in *Table 6*. From the results shown, it was observed that the brake horsepower, engine power output and mechanical efficiency were decreasing while the biodiesel blend ratio was increasing. However, the specific fuel consumption increased with the increase of biodiesel blend ratio.

Table 6. Engine performance of various castor biodiesel blends.

Castor biodiesel blends	Fuel consumption rate (ml/s)	Brake horse power, BHP (kW)	Engine power output (kW)	Specific fuel consumption, SFC (ml/kW)	Mechanical efficiency, η (%)
B0	0.25	7.527	1.201	16.653	13.022
B10	0.247	7.521	1.187	16.849	13.012
B20	0.241	7.521	1.165	17.167	13.012
B30	0.241	7.515	1.165	17.167	13.002
B40	0.241	7.515	1.142	17.513	13.002
B50	0.238	7.508	1.142	17.513	12.99

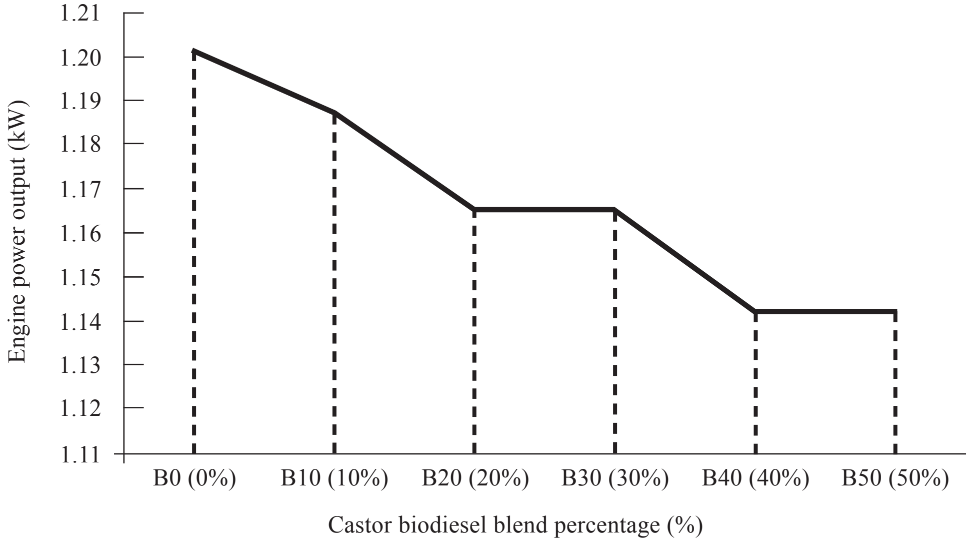

Figure 3. The graph of engine power output versus castor biodiesel blends.

The decrement percentage of the decrease of engine power output for B10, B20, B30, B40 and B50 relative to B0 (conventional diesel) were 1.17%, 3.00%, 3.00%,4.91% and 4.91%, respectively. The decrement of engine power output were due to lower energy content per volume of castor biodiesel compared to conventional diesel. However the power output decrement was less than 5% although 50% blends of biodiesel were used. This showed that biodiesel was suitable to be used as diesel blends.

From *Figure 4*, the increment of specific fuel consumption were observed when the blending percentage of biodiesel increased. The increment percentage for for B10, B20, B30, B40 and B50 relative to B0 (conventional diesel) were 1.18%, 3.09%, 3.09%, 5.16%, 5.16% respectively. The higher specific fuel consumption of those higher percentage blends ratio was due to the fact that biodiesel had lower calorific value than the conventional diesel. More fuel was consumed to produce 1 kW of power compared to conventional diesel. Furthermore, higher containment of oxygen in biodiesel was also the cause of the lower calorific value. Despite the better combustion of biodiesel compared to the conventional diesel, the oxygen in biodiesel took up space in the blend and slightly increased the fuel consumption rate. Thus, higher oxygen content in biodiesel leads to the low calorific value of Biodiesel (Islam *et al*. 2014).

Based on *Figure 5*, the mechanical efficiency decreased slightly with the increase of blending percentage of biodiesel. The decrement noted for B10, B20, B30, B40 and B50 were 0.08%, 0.08%, 0.15%, 0.15%, 0.25%, respectively. The decrement was however, insignificant as it was less than 1%. The lower mechanical efficiency of biodiesel is mainly due to the low volatility and high density of ester which affects the automization of the fuel and thus leads to poor combustion (Islam *et al*. 2014).

Emission Analysis

From *Table 7*, it was observed that castor biodiesel had lower emission of carbon monoxide (CO), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) compared to conventional diesel. Lower emission of CO and SO_2 for biodiesel were due to the additional

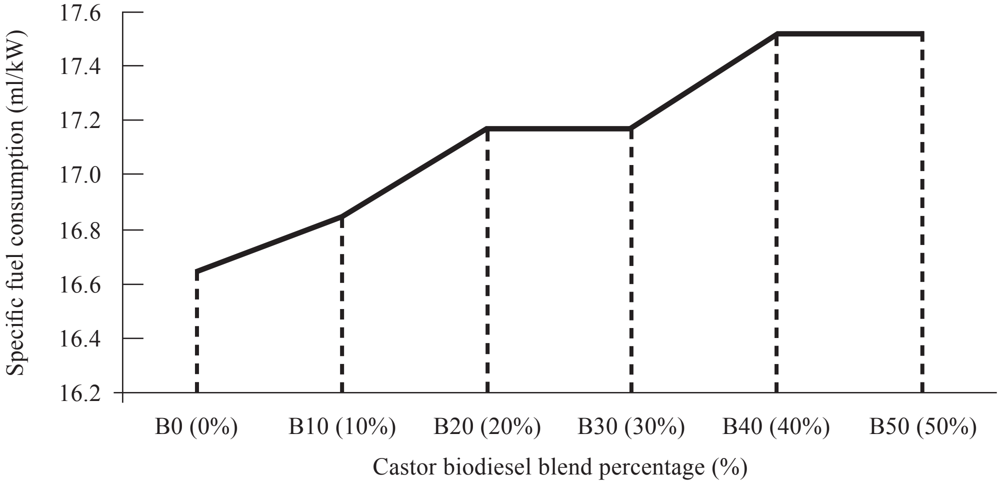

Figure 4. The graph of specific fuel consumption versus castor biodiesel blends.

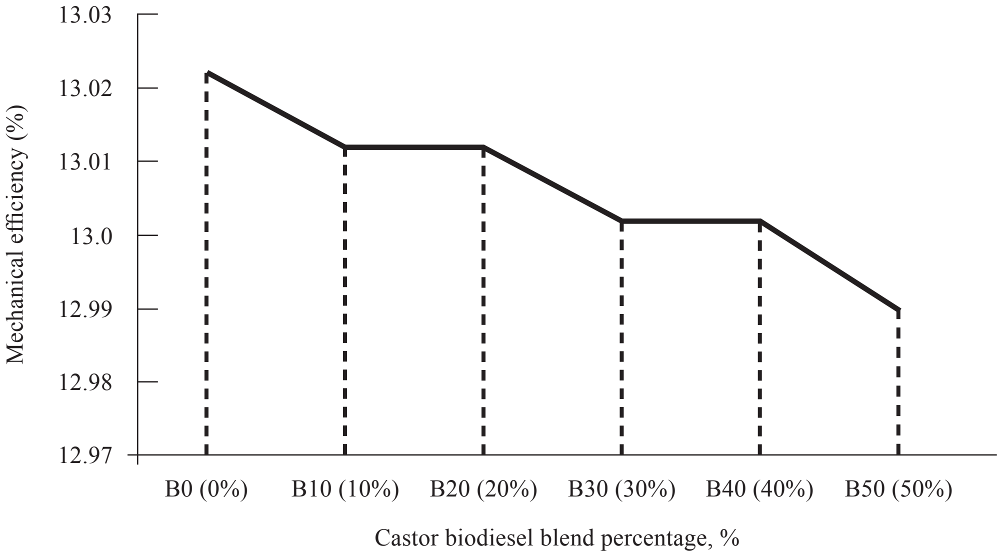

Figure 5. The graph of mechanical efficiency versus castor biodiesel blends.

Table 7. The emission analysis for conventional diesel and castor biodiesel.

Sample	CO (p.p.m.)	SO_2 (p.p.m.)	NO_2 (p.p.m.)	NO_x (p.p.m.)
Conventional diesel	79	3	0.4	2
Castor biodiesel	60	2	0.2	3

oxygen content in biodiesel, which improved the combustion in the cylinders of diesel engine. Higher nitrogen oxide (NO_x) emission for biodiesel is due to the oxygen concentration in biodiesel causing the formation of NO_x in the emission gas (Christopher *et al*. 2001). NO_x emission is primarily a function of total oxygen inside the combustion chamber, temperature, pressure, compressibility, and velocity of sound. Furthermore, the increase of NO_x emission is due to the higher cetane number of biodiesel which will reduce the ignition delay (Fazal *et al*. 2011). The increase of NO_x emission is a result of the reduced ignition delay. However, the NO_x emissions can be reduced through engine tuning or using exhaust catalytic converter (Leung 2001; Enweremadu & Mbarawa 2009). Moreover, the use of exhaust gas recirculation (EGR) can reduce the NO_x emission too where the temperature of exhaust gas is reduced when passing through the combustion chamber. In overall, castor biodiesel emitted cleaner gas emissions than conventional diesel and the combustion is more complete. These properties make biodiesel suitable to be used as an alternative to conventional diesel or as a blend to lower the emission of conventional diesel.

CONCLUSION

The optimum reactant proportion for base catalyzed transesterification of castor oil was determined to be 1:4.5 of oil to methanol ratio, and 0.005:1 of potassium hydroxide to oil ratio. The additional content of oxygen in castor biodiesel promoted complete combustion in diesel engine thus, it led to lower emissions. The high flash point of castor biodiesel made it safe for handling and storage. Reduction of mechanical efficiency and power output of castor biodiesel compared to conventional diesel was minor and tolerable. Lower emission of castor biodiesel compared to conventional diesel proved it as a green fuel. Castor biodiesel was a suitable fuel to be used as diesel blends.

ACKNOWNLEDGEMENT

This study was supported by the Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, University Malaysia Sarawak, Malaysia.

Date of submission: *September 2014*

Date of acceptance: November 2014

REFERENCES

Christopher, C, Enweremadu, Rutto, HL & Peleowo, N 2001, 'Performance evaluation of a diesel engine fueled with methyl ester of shea butter', *World Academy of Science, Engineering and Technology*, vol. 5.

Enweremadu, CC & Mbarawa, MM 2009 'Technical aspects of production and analysis of biodiesel from used cooking oil—a review', *Renewable and Sustainable Energy Reviews*, vol. 13, pp. 2205–2224.

Fazal, MA, Asma, H & Masjuki, HH 2011, 'Biodiesel feasibility study: an evaluation of material compatibility, performance, emission and engine durability', *Renewable and Sustainable Energy Reviews*, vol. 15, pp. 1314–1324.

Galadima, A, Garba, ZN & Ibrahim, BM 2008, 'Homogeneous and heterogeneous transesterification of groundnut oil for synthesizing methyl biodiesel', *International Journal of Pure and Applied Sciences*, vol. 2, pp. 138–144.

Ibeto, CN, Okoye, COB & Ofoefule, AU 2012, 'Comparative study of physicochemical characterization of some oils as potential feedstock for biodiesel production', *Renewable Energy*, vol. 3.

Islam, MS, Ahmed, AS, Islam, A, Aziz, SA, Xian, LC & Mridha, M 2014, 'Study on emission and performance of diesel engine using castor biodiesel', *Journal of Chemistry*, vol. 8.

Janaun, J & Ellis N 2010, 'Perspectives on biodiesel as a suitable fuel', *Renewable and Sustainable Energy Reviews*, vol. 14, pp. 1312–1320.

Knothe, G 2010, 'Biodiesel and renewable diesel', *Progress in Energy and Combustion Science*, vol. 36, pp. 364–373.

Leung, DYC 2001, 'Development of a clean biodiesel fuel in Hong Kong using recycled oil', *Water, Air, and Soil Pollution*, vol. 130, pp. 277–282.

Mathiyazhagan, M & Ganapathi, A 2011, Factors Affecting Biodiesel Production', *Plant Biology*, vol. 1, pp. 1–5.

Moser, BR 2009, 'Biodiesel production, properties and feedstocks', In Vitro *Cell Dev. Biology, Plant*, vol. 45, pp. 229–266.

Mushtaq, A, Ajab, KM, Muhammad, Z & Shazia, S 2011, 'Biodiesel from non edible oil seeds: a renewable source of bioenergy', in *Economics of Effects of Bio Fuel Production,* ed MADS Bernades, InTech Europe.

Nielsen, F, Jongh, BHJD & Arrakis 2011, 'Potential of castor for bio-fuel production', Available: www.fact-foundation.com.

Okullo, A, Temu, AK, Ogwok, P & Ntalikwa, JW 2012, 'Physico-chemical properties of biodiesel from jatropha and castor oils, *International Jornal of Renewable Energy Research,* vol. 2, pp. 47–52.

Petracek, R 2014, 'The advantages of using biodiesel blends', viewed 24 July 2014, <http://www.streetdirectory.com/travel_guide/49884/mileage_and_fuel/the_advantages_of_using_biodiesel_blends.html>.

Shrirame, HY, Panwar NL & Bamniya, BR 2011, 'Bio diesel from castor oil — a green energy option', *Low Carbon Economy*, vol. 2, pp. 1–6.

APPENDIX

Calculation for Engine Power Output

$$\text{Engine power output (kW)} = \frac{V \times I}{1000}$$

Where, V is the output voltage
I is the output current.

Calculation for Specific Fuel Consumption (SFC)

$$\text{SFC (ml/kW)} = \frac{20}{\text{Engine power output}}$$

Calculation for Mechanical Efficiency

$$\text{Mechanical efficiency, } \eta = \frac{\text{Bhp}}{1\,\text{hp}} \times 100\%$$

$$\text{Brake Horse Power, Bhp (kW)} = \frac{2 \times \pi \times \hat{n} \times T}{60 \times 10^3}$$

Where, $\hat{n}$ is the speed in r.p.m.

Torque, $T = W \times r$

Where, W is the brake load in N;
R is the radius of the brake arm in m.

Indicated Horse Power, 1 hp (kW) $= \dfrac{N \times \rho \times l \times a \times \eta}{1000}$

Where, *N* is the number of strokes;
ρ is the mean indicated pressure in the cylinders;
l is the length of stroke;
a is the cross-section area of the cylinder; and
n is the number of working strokes per mm.

ASEAN J. Sci. Technol. Dev., **31(2)**: 101 – 111

Development of Suspended Particulate Matter Empirical Equation for Tropics Estuary from Landsat ETM+ Data

Z. RAZAK[1], A. ZUHAIRI[2*], S. SHAHBUDIN[3] AND Y. ROSNAN[4]

Suspended Particulate Matter (SPM) essentially related to the total scattering of particles in the water column. It plays the role as a transport medium for pollutants, total load of organic and inorganic substance in the water phase. In this study, we have developed empirical relationship based on a strong relationship between Landsat near infrared (NIR) band and archived SPM data. The following were the power equations:

$$SPM\ NE\ (\text{mg/l}) = 11.68x^{0.666}$$
$$SPM\ SW\ (\text{mg/l}) = 18.61x^{0.493}$$

where, x (TM4) is radiance of ETM+ NIR band 4 was developed under tropical atmospheric conditions. Using the above equation, the SPM concentration for Northeast and Southwest monsoon in the Pahang River estuary as a case study was determined. The mean SPM concentration and mean reflectance value during Northeast monsoon were 131.69 mg/l and 0.135 mg/l. The mean SPM concentration value and reflectance were 95.94 mg/l and 0.078 mg/l during the Southwest monsoon. Generally, from remote sensing archive data and above equations, the SPM concentrations of Pahang River were successfully determined from 1999 to 2012.

Key words: Suspended particulate matter; Pahang River estuary; Landsat ETM+; historical data; water quality

Suspended sediment particulate plays an important role in estuary ecology, as it is one of the major features affecting sedimentation and accretion. Conventional field methods for monitoring SPM are time consuming and expensive. One of the alternative methods is using remote sensing techniques to retrieve SPM concentrations from satellite image. Regression analysis is a significant representative of SPM concentrations and spectral reflectance relationship, which exclusively allow remotely sensed data to be used for monitoring sediments. Such efforts for empirical regression equations development were conducted by Milan and Pavla (2008), Kloiber *et al*. (2002), Wang *et al*. (2004), and Giardino *et al*. (2001).

Suspended particulate matter data derived from satellite sensors can be obtained based on reflectance from backscattering effect in the

[1] Faculty of Maritime and Marine Science, University Malaysia Terengganu, 21300, Kuala Terengganu, Terengganu, Malaysia.
[2] Marine Science Department, Kulliyyah of Science, International Islamic University Malaysia, Jalan Istana, Bandar Indera Mahkota, 25200, Kuantan, Pahang, Malaysia.
[3] Institute of Oceanography and Maritime Studies (INOCEM), Kulliyyah of Science, International Islamic University Malaysia, Jalan Istana, Bandar Indera Mahkota, 25200, Kuantan, Pahang, Malaysia.
[4] Faculty of Maritime and Marine Science, University Malaysia Terengganu, 21300, Kuala Terengganu, Terengganu, Malaysia.
* Corresponding author (e-mail: zuhairiahmad@iium.edu.my)

visible and near infrared of spectrum regions. Mostly, high reflectance value will reflect high sediment suspension (Collen & Tamlin, 2013). Nonetheless, the exact relationship of suspended SPM and reflectance also depends on the sediment characteristics, climate, atmospheric conditions and anthropogenic activities. These factors were highly variable in natural environment at different area under several circumstances. Therefore, most studies developed unique relationships in a particular area by relating *in-situ* SPM data and reflectance data from satellite imagery.

Several studies have been widely utilized Landsat 7 ETM+ (Enhanced Thematic Mapper Plus) for this purpose. It is often practical for Landsat 7 ETM+ data to be used for SPM monitoring despite its low spectral and radiometric resolution (Min *et al*. 2012; Kabbara *et al*. 2008; Islam *et al*. 2001). Surface SPM envisioned as natural tracer by Landsat 7 ETM+ bands two through four, which are sensitive reflective bands (Milan & Pavla, 2008). Having the status of better than 5% data calibration, Landsat 7 ETM+ served as an on-orbit standard for cross-calibration of other Earth remote sensing missions. The image also acquired systematically to periodically refresh a global archive of sun-lit and substantially cloud-free images, thus optimizing the data acquisition strategy. There was a probability of recent data existing, hence it could be quickly retrieved to compare with newly acquired data. These features have proved the Landsat 7 data was important for a wide and diverse remote sensing applications including suspended sediment monitoring.

Thus, this application could be adapted to certain areas where the sedimentation problems occurred; either potentially or continuously with unpredicted monsoon factors such in Pahang River Estuary, Pahang. For the past ten years, sedimentation and erosion problems have occurred in Pahang River estuary, emerging sand banks and tidal shoals. It becomes a major defect especially to the local villagers as most of them are fisherman. Primary sources of the sediments were highly likely from the catchment areas upstream. Concerns have arisen on the river capacity as upstream areas are often faced with flooding during heavy rains. Numerous sand dredging sites also can be found in the Pahang River estuary. To date, more than ten different sites have been identified including sand dredging operations using vessels. During operational time, high suspended sediment concentrations were observed around the area which resulted for the poor water quality.

This study described the remote sensing analysis and calibration using archived satellite data and historical *in-situ* data to obtain suitable suspended particulate matter (SPM) equations based on previous studies, using the Pahang River estuary as a case study.

Study Area

The Pahang River estuary is in the east coast of Pahang, facing the South China Sea (*Figure 1*). The estuary received tidal flow from Kuala Pahang inlet and Tanjung Agas inlet, while freshwater from upstream. The Pahang River stretched for almost 440 km long and drained an area of 29071.32 km^2 (*Figure 2*). The Pahang River is divided into the Tembeling and Jelai River, and meets at a confluence at Kuala Tembeling. The river meanders through Jerantut, Temerloh, Maran, Bera and Pekan. Annual rainfall in the catchment area ranged from 1609 mm to 2132.36 mm (Pan *et al*. 2011). The estuary also faced bimodal pattern of two-monsoon period.

In Malaysia, Northeast monsoon starts around October to March, and Peninsular Malaysia is expected to be wetter than normal. This pattern is linked to a continuation of enhanced low-level easterly trade winds and anomalous upper-level westerly winds over western and central equatorial pacific (MET 2010). Thus, with a huge catchment area, the freshwater inflows are persistently larger during the Northeast monsoon. The atmospheric conditions are relatively stable during the Southwest monsoon. This situation starts around June to September due to the weakened La Niña phenomenon. The Southwest monsoon is generally found to be drier than the inter-monsoon periods, reflected by slower vertical mixing which reduces the strong convection process. Most of the areas in Peninsular Malaysia will have more days without rain (MET 2011). This resulted in the less freshwater inflow during the Southwest monsoon towards the Pahang River estuary.

MATERIALS AND METHODS

Satellite Data and SPM Data

Efficient and accurate retrieval of suspended particulate matter versus water surface reflectance relations for the study area requires two types of data: *in-situ* suspended particulate matter data and Landsat 7 ETM+ images. Eighteen scenes of Landsat 7 ETM images were acquired from Earth Resources Observation and Science (EROS) Center, United States Geological Survey (USGS). Scenes from path/row 126/57 and 126/58 were selected because of the image data extent. It covered several Malaysian Department of Irrigation and Drainage (DID) suspended sediment gauge stations.

The images extent several DID suspended sediment gauge stations. Scene 126/57 covered suspended sediment gauge stations of Kampung Merting and Sungai Yap. Scene 126/58 covered Lubuk Paku, Temerloh and Sungai Teriang stations. Scene 127/57 covered Jeram Bungor, Sungai Perting and Kampung Batu Buaya stations.

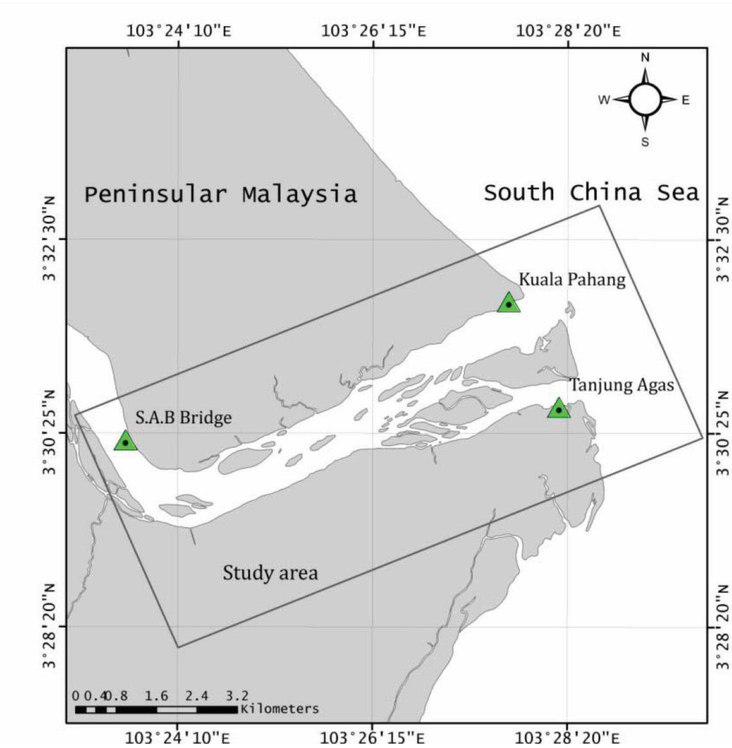

Figure 1. Study Area.

Figure 2. Boundary of the Pahang River catchment area.

The availability of both ETM+ images and suspended sediment data is a constraint for this study. It was difficult to obtain the satellite images and simultaneous suspended sediment data at the gauging stations. In certain image acquired date, only a few of the suspended data existed at DID gauging stations. Thus, archived suspended sediment data were obtained (as many as possible) from the gauging stations, which measured data on the same dates as these ETM+ images. In this study, 72 data information and images were compared between DID stations records and image reflectance/radiance. The gauging station recorded suspended sediment data in tonnes/day and flow, in m^3/s. These units need to be converted into mg/l or g/l for regression correlation with data from satellite images. Derived correlation equations were used to analyze SPM concentration from Landsat 7 ETM+ image of Pahang river estuary during the Northeast and Southwest monsoon period using ENVI 4.5 band maths expression.

Calibration and Image Processing

Each ETM+ image used was referenced to Rectified Skewed Orthomorphic (RSO) Malaysia projection. The Modified Everest and Kertau 1948 were applied to the projection spheroid and datum. The false Easting and Northing of the projection was 804671.29977 and 0. The 1:50000 scale topographic map series L7070 edition 1-PPNM of Kuantan (Sheet 4360), Kuala Pahang (Sheet 4359) and Pekan (Sheet 4359) prepared by Department of Survey and Mapping Malaysia (JUPEM) were used. Image to map rectification were applied using 50 well distributed ground control points (GCPs) in the reference process. The root mean square error (RMSE) error was ±0.22 (±5.5m for ETM+ data images).

The satellite-generated digital numbers (DN) were converted to spectral radiance by removing the gain and offset effects introduced by the satellite system. The equation to convert DN to radiance (Wm^2 sr^1 μm^1) using gain and bias method (**Equation 1**) is as following:

$$L\lambda = \text{Gain} \times DN + \text{Bias} \quad \text{...............1}$$

where, $L\lambda$ is pixel value as radiance, DN is digital number, Gain is gain value for specific band and Bias is bias value for specific band. The radiance pixels were converted to top of atmosphere reflectance using the following equation (*Equation 2*):

$$\rho\lambda = \frac{\pi \times L\lambda \times d^2}{\text{ESUN}\lambda \times \sin\theta} \qquad (2)$$

where, $\rho\lambda$ is unit less planetary reflectance, $L\lambda$ is radiance, d is Earth-Sun distance in astronomical units, ESUNλ is the mean solar exo-atmospheric irradiance and θ is sin sun elevation (cos solar zenith = sin sun elevation) (Chander *et al*. 2009).

Fast Line-of-sight Atmospheric Analysis of Spectral Hypercube (FLAASH) is MODTRAN4 based model which were used to analyze each image using multiple parameter input: scene acquisition information, sensor information, aerosol model and retrieval methods, cloud cover, reflectance factor data, and multispectral settings. It is to reduce the surface reflectance signals which constrain the reliability of the satellite image analysis due to scattering and absorption effects of water vapor and aerosols in the atmosphere (Matthew *et al*. 2000).

The images (path: 126 row: 58; dated 11/12/2010 and 23/7/2011) which had undergone geometric, radiometric and atmospheric corrections were subset for the extended study area. The output subset image were geo-referenced as the parent image. The subset procedures were carried out using AOI tools in ENVI 4.5. Mosaicking procedures were applied to the subset images to remove the clouds, cloud shadows and lands. The classifications were performed using Nearest Neighbour configuration and the output were exported in raster format for analysis.

RESULTS

Based on the power regression analysis, the relationship between SPM from DID station and images during the Northeast and Southwest monsoon is show in *Figure 3* and *Figure 4*. The relationship results between similar parameters including the Inter-monsoon period is show in *Figure 5*.

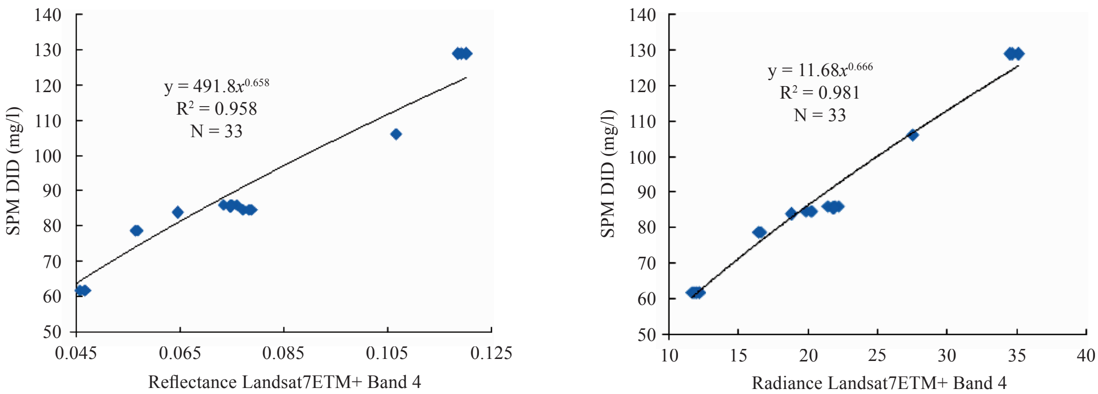

Figure 3. Regression analysis between SPM from ETM+ and SPM from DID station during the Northeast monsoon period (Left: SPM DID vs Reflectance; Right: SPM DID vs Radiance).

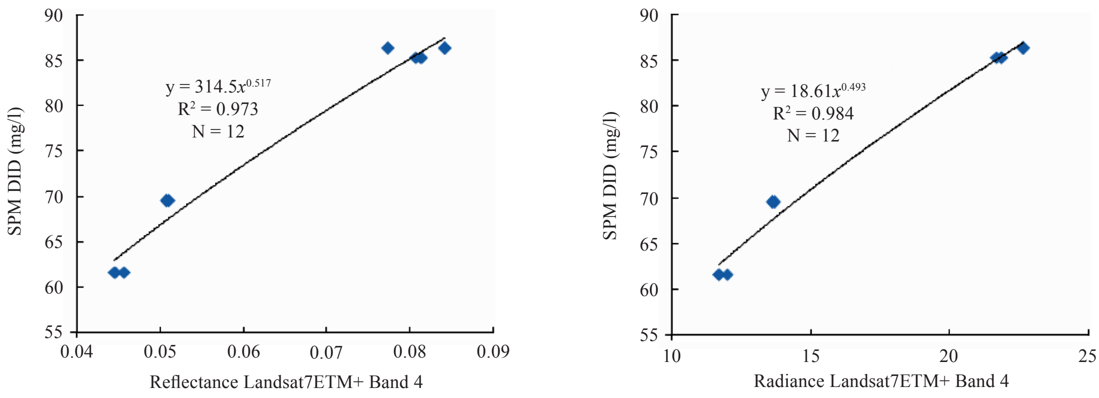

Figure 4. Regression analysis between SPM from ETM+ and SPM from DID station during the Southwest monsoon period (Left: SPM DID vs Reflectance*; Right:* SPM DID vs Radiance*).*

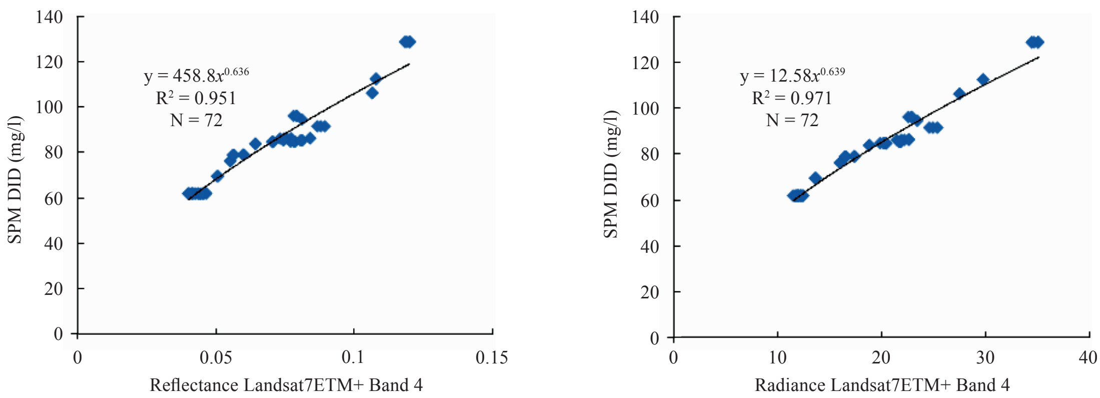

Figure 5: Regression analysis between total samples of SPM from ETM+ and SPM from DID station including intermonsoon (Left: SPM DID vs Reflectance*; Right:* SPM DID vs Radiance*).*

The relationship between images reflectance and radiance and SPM from DID was highly significant at 95% confidence level for both monsoons. Based on the higher significant R^2 between the SPM from DID station and radiance, the relationship equations were thus selected. These new SPM equations had good predictive power for SPM retrieval in this study.

Based on the *F*-test, the *F* calculated for all relationship were smaller than *F* distributed. Therefore, the differences in variances between the datasets were statistically significant. Using *t*-test assuming unequal variances, the values of *t*-calculated for all relationships were smaller than *t*-critical two tail and means are not statistically different. The P values were computed using R^2 and degree of freedom (Df) with $p<0.0001$ and considered to be extremely, statistically significant. In addition, the intercepts did not significantly differ from zero. The R^2 values for relationship between SPM from DID station and radiance (L) was 0.981 for Northeast monsoon and 0.984 for Southwest monsoon. The standard errors for these equations were 0.878 for Northeast monsoon, and 0.717 for Southwest monsoon.

Therefore, the following power was considered for power (*Equation 3* and *Equation 4*):

$$\text{SPM NE (mg/l)} = 11.68x^{0.666} \quad (3)$$

$$\text{SPM SW (mg/l)} = 18.61x^{0.493} \quad (4)$$

where, x (TM4) is radiance (*L*) of ETM NIR band 4 was developed under tropical atmospheric conditions and could be used for monitoring SPM concentration in tropical areas especially for the Pahang River. These equations were applied to the subset image of the Pahang River estuary and the following images are shown in *Figure 6* and *Figure 7*.

In 2010, during the Northeast monsoon with specific date and time of 11/12/2010, 11:15:24 AM indicated the maximum SPM concentration of 145.63 mg/l and minimum SPM concentration value of 126.24 mg/l. The mean SPM concentration value was 131.69 mg/l. Results from image analysis showed maximum reflectance value (factor between 0 to 1) of captured image as 0.157. The minimum reflectance value was 0.126 and the mean reflectance value was 0.135.

In 2011, during the Southwest monsoon with specific date and time of 23/07/2011, 11:15:54 AM indicated the maximum SPM concentration of 149.41 mg/l and minimum SPM concentration value of 81.45 mg/l. The mean SPM concentration value was 95.94 mg/l. Results from image analysis showed maximum reflectance value (factor between 0 to 1) of captured image as 0.237. The minimum reflectance value was 0.074 and the mean reflectance value was 0.078.

Power regression was used for validations of derived equations; retrieved using SPM from image and SPM from proxies extracted from validated sediment transport models (Razak *et al*. 2013). The power regression analysis for Northeast monsoon in *Figure 8* (left) show high significant at 95% confidence level (n = 100, $R^2 = 0.907$). The multiple R value was 0.952 and the adjusted R^2 value was 0.906. The value of standard error was 0.755 with maximum standard error percentage was 1.25%. Validation for Southwest monsoon in *Figure 8* (right) show high significance at 95% confidence level

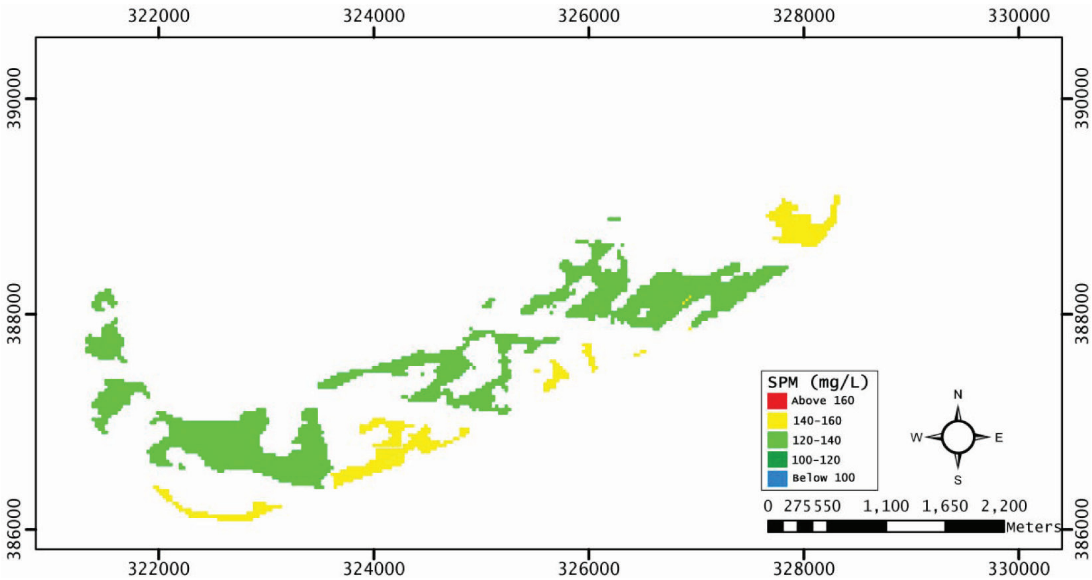

Figure 6. SPM concentration during Northeast Monsoon using Equation 3.

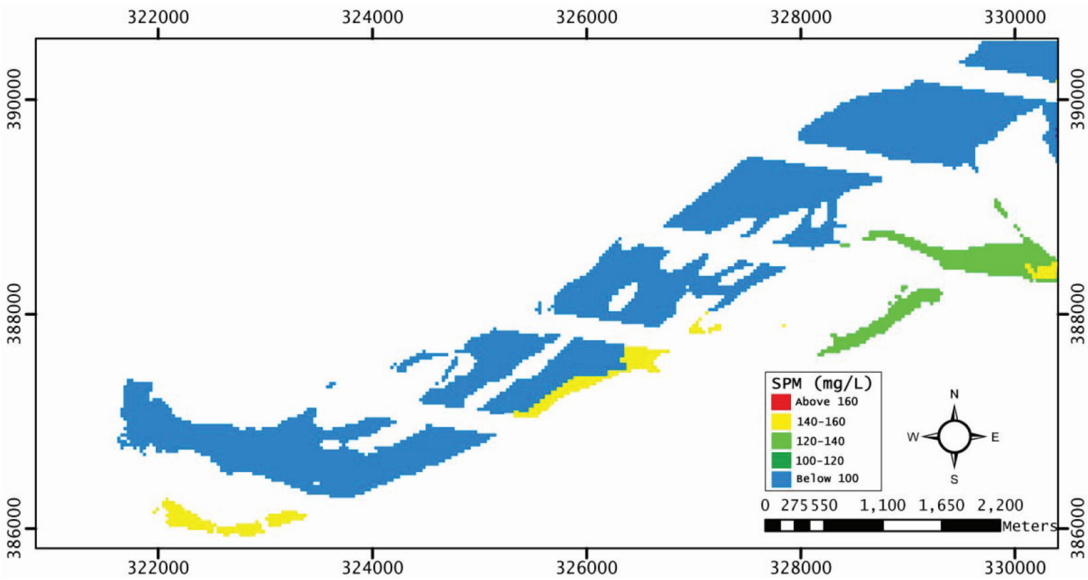

Figure 7. SPM concentration during Southwest monsoon using Equation 4.

(n = 100, R^2 = 0.934). The multiple R value was 0.967 and the adjusted R^2 value was 0.934. The value of standard error was 1.991 and the maximum standard error percentage was 2.37%. Generally, from remote sensing archive data, the SPM concentrations of Pahang River were successfully determined from 1999 to 2012 as shown in *Figure 9*.

DISCUSSIONS AND CONCLUSIONS

The analyzed Landsat images provided SPM data for the surface water. High concentrations of suspended sediment were observed during Northeast monsoon from the analyzed images showing spatial distribution of SPM. The SPM concentration was higher than >120 mg/l, and in shallow channel of Tanjung

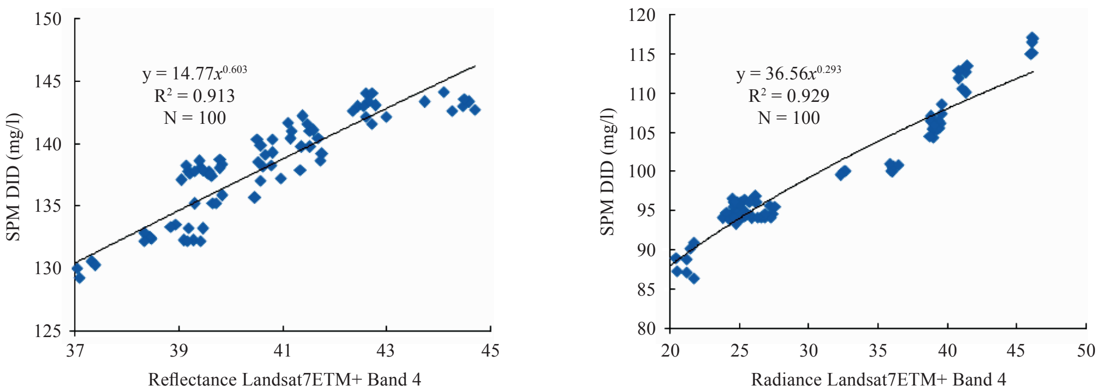

Figure 8. Validation using power regression analysis between SPM from ETM+ and SPM from proxies data of validated sediment transport model (Razak et al. *2013) during Northeast monsoon (left) and Southwest monsoon (right).*

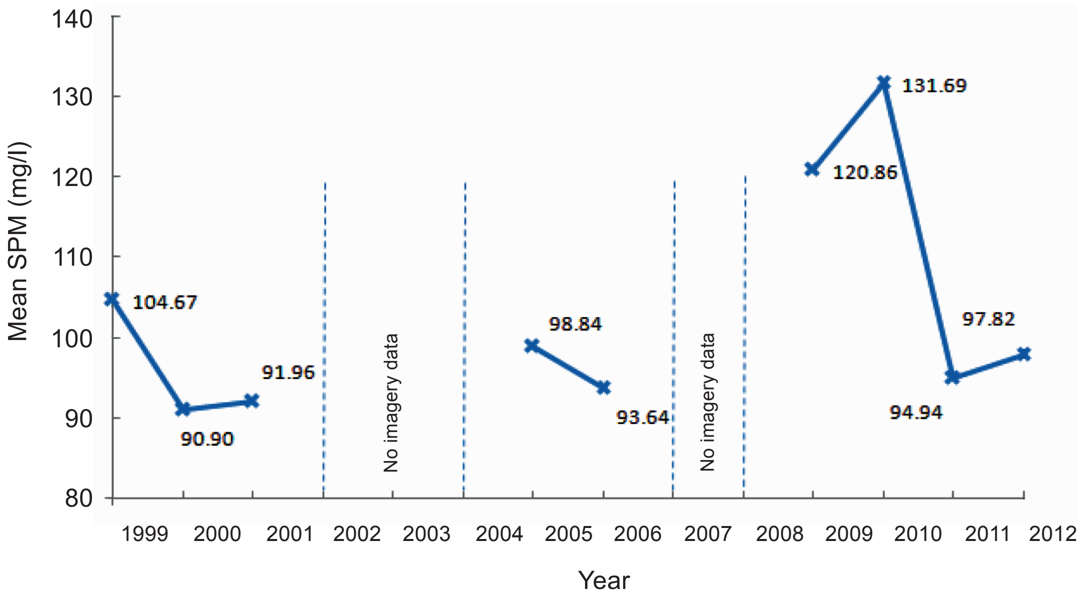

Figure 9. SPM concentrations of Pahang river estuary from archive images.

Agas, the concentration was between 140 mg/l to 160 mg/l. By contrast, relatively lower concentration in the deeper channel of Kuala Pahang was observed. The main transport pathway of the SPM is the deeper channel of Kuala Pahang, relating to the factors of channel size and discharge amount. It was observed that the smaller channel of Tanjung Agas retained more SPM, which induced sediment settlement. This condition also occured during Southwest monsoon with SPM in the deeper channel was less than <100 mg/l. The pattern of shallow channel retaining the SPM was similar, as the concentration in Tanjung Agas channel was between 140 mg/l to 160 mg/l.

The reflectance representing SPM concentrations in Northeast monsoon were of higher value than Southwest monsoon, neglecting bottom reflectance. The factors associates with Northeast monsoon season were, high amount of discharge from upstream, also the turbulence of inflow and outflow water resulted from wave and discharge influences (Razak *et al*. 2013). Using remote sensing, the concentration of SPM could be retrieved from the satellite imagery. Yet, the exact condition of SPM concerning its transport could not be interpreted from spatially acquisition data as it only gave a one-time SPM concentration condition.

It was also found that equations that used SPM produced significant results compared to that of SSC. The satellite image mainly provided suspended sediment reflectance information as total bodies, not fractions of inorganic and organic materials. Generally, the equation correlation R^2 depended on several factors: SSC limits, regional and specific additional reflectance data. Equations with high SSC limits were not suitable to be used in the Pahang river estuary based on the correlations. Some of the studies also focused on coastal areas that neglected the estuary properties such as freshwater discharges, thus it was inappropriate to represent Pahang river estuary. Morever, the significant reflectance data that used for each different study sites increased the responsive factors towards various changing on different regions. Although the study reliability might increase, it could not be adapted to other areas.

Still, in studies related to suspended sediment concentration retrieval, both SSC and SPM values were needed as it described the sediment transport properties in the system.

Application of *Equations 3* and *4* towards archive image of the Pahang river estuary showed decreasing pattern of SPM concentration in the earliest estimation year (1999) and slightly increased by year 2000 to 2001. With no imagery data to support the whole pattern of view, the SPM concentration decreased from 2004 to 2006. Yet, the pattern increased from year 2009 to 2010, and dropped in year 2011. These data are significantly important in order to obtain historical view on the SPM distribution in the Pahang river estuary.

Although good correlations were produced, development of the equation for determining SPM as in *Equations 3* and *4* required more extensive spatial data of SPM. Developed equation used image reflectance and radiance for comparisons with SPM. It is the fact that the atmospheric Rayleigh and aerosol scattering, which provide image additive effects, mainly influence the visible bands. Furthermore, near infrared and middle infrared wavelengths are affected by atmospheric absorption while the influence of air molecules and aerosol particle scattering are negligible in these ranges. It could be concluded that an application of atmospheric correction had a more significant effect on the maximum and minimum values than the effect on their average values.

ACKNOWLEDGMENT

This research has been funded by the International Islamic University Malaysia Research Grant (Ref: IIUM/202/C/1/1/AT107) and Fundamental Research Grant Scheme Vote 59247 from Ministry of Higher Education, Malaysia.

Date of submission: October2014

Date of acceptance: January 2015

REFERENCES

ATSM 2010, 'Standard test method for filterable matter (total dissolved solids) and non-filterable matter (total suspended solids) in water,' *ATSM*, DOI, pp. 10.1520/D5907-10.

Colleen, ML & Tamlin, MP 2013, 'Remote sensing of suspended sediment concentration and hydrologic connectivity in a complex wetland environment', *Remote Sens. Environ*., vol. 129, pp. 197−209.

Dekker, AG, Vos, RJ & Peters, SWM 2001, 'Comparison of remote sensing data, model results and *in situ* data for total suspended matter (TSM) in the southern Frisian Lakes', *Sci. Total Environ.,* vol. 268, pp. 97−214.

Doxaran, D, Froidefond, JM & Castaing, P 2003, 'Remote-sensing reflectance of turbid sediment-dominated waters, reduction of sediment type variations and changing illumination conditions effects by use of reflectance ratios', *Applied Optics*, vol. 42, pp. 2623−2634.

Giardino, C, Pepe, M, Brivio, P, Ghezzi, P & Zilioni, E 2001, 'Detecting chlorophyll, Secchi disk depth and surface temperature in sub-alpine lake using Landsat imagery', *Sci. Total Environ.*, vol. 268, pp. 19−29.

Gyanesh, C, Brian, LM & Dennis, LH 2009, 'Summary of current radiometric calibration coefficients for Landsat MSS TM, ETM+, and EO-1 ALI sensors', *Remote Sens. Environ.,* vol. 113, pp. 893−903.

Islam, MR, Yamaguchi, Y & Ogawa, K 2001, 'Suspended sediment in the Ganges and Brahmaputra Rivers in Bangladesh, observation from TM and AVHRR data', *Hydrol. Processes,* vol. 15, pp. 493−509.

Kabbara, N, Benkhelil, J, Awad, M & Barale, V 2008, 'Monitoring water quality in the coastal area of Tripoli (Lebanon) using high-resolution satellite data', *ISPRS. Photogramm Remote Sens.,* vol. 63, pp. 488−495.

Keiner, LE & Yan, XH 1998, 'A neural network model for estimating Sea surface chlorophyll and sediments from thematic mapper imagery,' *Remote Sens. Environ*., vol. 66, pp. 153−165.

Kloiber, S, Brezonik, P & Olmanson, L 2002, 'Bauer M, 'A procedure for regional lake water quality assessment using Landsat multispectral data,' *Remote Sens. Environ*., vol. 82, pp. 38−47.

Matthew, MW, Adler-Golden, SM, Berk, A & Richtsmeier, SC, Levine, RY, Bernstein, LS, Acharya, PK, Anderson, GP, Felde, GW, Hoke, MP, Ratkowski, A, Burke, HH, Kaiser, RD & Miller, DP 2000, 'Status of Atmospheric Correction Using a MODTRAN4-based Algorithm', in *SPIE Proceedings Algorithms for Multispectral*, *Hyperspectral, and Ultraspectral Imagery VI,* vol. 4049, pp. 199–207.

MET 2010, 'Northeast monsoon report,' Malaysian Meteorological Department, Malaysia.

MET 2011,'Southwest monsoon report,' Malaysian Meteorological Department, Malaysia.

Milan, O & Pavla, P 2008, 'Retrieval of suspended particulate matter concentrations in the Danube River from Landsat ETM data', *Sci. Total Environ*., vol. 397, pp. 238–243.

Min, JE, Ryu, JH, Lee, S & Son, SH 2012, 'Monitoring of suspended sediment variation using Landsat and MODIS in the Saemangeum coastal area of Korea', *Marine Pollution Bulletin,* vol. 64, pp. 382–390.

Pan, IL, Barzani, MG, khwan, MT, Sahibin, AR & Khairul, AK 2001, 'Hydrological pattern of Pahang River basin and their relation to flood historical event', *E-Bangi J*., vol. 4, pp. 29–37.

Razak, Z, Zuhairi, A, Shahbudin, S & Rosnan, Y 2013, 'Modelling suspended sediment transport in monsoon seasons: a case study of Pahang river estuary, Pahang, Malaysia', *EGU General Assembly* , vol. 15, pp. 2592.

Ritchie, JC & Cooper, CM 1991, 'An algorithm for estimating surface suspended sediment concentrations with Landsat MSS digital data', *JAWRA*, vol. 27, pp. 373–379.

Topliss, BJ, Almos, CL & Hill, PR 1990, 'Algorithms for remote sensing of high concentration, inorganic suspended sediment', *Int. J. Remote Sens*., vol. 11, pp. 947–966.

CONTRIBUTIONS TO THE JOURNAL

Contributions from academics, policy makers, research personnel and managers in public institutions as well as those in private organizations and industry are welcome. However, it is required that manuscripts submitted to the Journal should not have been published and will not be simultaneously submitted or published elsewhere. Research papers must also be factual and original.

Contributions to the Journal will normally include original research work, papers on science and technology policy, and technical notes and communications. As the Journal is a prime source in information on science and technology for development, contributions that fall within the following areas are particularly welcome:

- Science and technology policy
- Original research work; and
- Technical notes and communications.

MANUSCRIPT PREPARATION

Manuscripts should be prepared in Microsoft Word 6.0 and above. Two copies of the manuscripts on A4-size paper and a soft copy on cd should be provided. The manuscript should not exceed 5000 words and specialist terminology and footnotes should be avoided. Each paper should be provided with an abstract of about 150 words, reporting concisely on the purpose and result of the paper. All papers will be published in English. The names(s) of the authors(s) should only appear on the title page which will be detached from the paper before the referees comments are invited.

Mathematical analysis and statistical data should be placed in appendices whenever possible. Numbered tables, figures and illustrations should have their intended position in the printed text clearly indicated. Photographs in black and white should be printed on glossy paper or scanned into text at the intended position. For illustrations, the original and one copy should be provided, if the illustration is not scanned into the text. Similarly, line drawings should either be provided in soft copy or be in a form suitable for reproduction, in Indian ink, with lettering, etc., completed.

References, or citing, should follow the Harvard author-date system. The in-text reference should contain: the author's or editor's family name (or organization responsible); year of publication; page number if appropriate and where available. The bibliography at the end of the article should be arranged alphabetically. Authors are responsible for checking and accuracy of all references.

The Editor-in-Chief reserves the right to adjust the style to certain standards of uniformity. All articles should be directed to:

Prof Emeritus Dr Md Ikram Mohd Said
Editor-in-Chief
School of Chemical Sciences and Food Technology
Faculty of Science and Technology, Universiti Kebangsaan Malaysia
43600 UKM Bangi, Selangor D.E.
(e-mail:kiamco65@gmail.com; kiam@ukm.edu.my)

Manuscripts are accepted for publication on the understanding that the copyright is assigned to the Journal. The completed copyright transfer form should be submitted together with the manuscript to the Editor. We regret that manuscripts without the copyright transfer from will not be considered for publication.

TRANSFER OF COPYRIGHT AGREEMENT

The author(s) agree that upon acceptance for publication, copyright (including the right to authorise photocopying and reproduction in all media, whether separately or as a part of a journal issue or otherwise) in any manuscript submitted, including its modifications thereafter, is transferred to the *ASEAN Journal on Science and Technology for Development*.

The author(s) agree that the Editors (including its Editorial Advisory Committee and its Board Members) of the *ASEAN Journal on Science and Technology for Development* will have world-wide rights, perpetually, to the manuscript (and the final published article with all its amendments), including the right to distribute the article in whatever form deemed appropriate in the information dissemination process (including the use of internet and WWW). This transfer includes the right to adapt the manuscript/article for use in computer systems and programme, including reproduction in machine readable form and incorporation in retrieval systems.

The author(s) retain the rights to:

i. Any intellectual property rights to any process of procedure described in the manuscript.
ii. Photocopy or make copies of the published article for their own personal use or use by colleagues, including for classroom teaching purposes, provided the copies are not offered for sale and are not distributed in a systematic way outside their employing institution; and
iii. Compile the article into their own collection of printed works.

The author(s) should however, include an indication that the copyright ownership of article rests with the *ASEAN Journal on Science and Technology for Development*, and provide a full citation of the Journal source.

Warranties and Copyright Transfer

The author(s) warrant that the article is the author's original work that has not been published elsewhere. The author(s) warrant that the article contains no material that infringes the rights of other or are of a libelous nature. The author(s) warrant that if excerpts from copyrighted works are included, permission of the relevant copyright owners have been obtained and due acknowledgement given in the article.

If the article is prepared jointly with other author(s), the signing author has informed the co-authors of this copyright transfer and has obtained their permission to sign on their behalf. If copyright is held by the employer, the employer or an authorised representative of the employer must sign. If this assignment is signed by the author, it is taken that the author has the authorisation of the employer and that the terms and conditions of this transfer are with the acceptance of the employer.

Signature of copyright owner(s) : ______________________________
(Please indicate if signing on YES/NO (Delete as appropriate)
behalf of all co-authors)

Full name (Please print) : ______________________________

Name and designation if : ______________________________
employer representative

Company or institution : ______________________________

Date : ______________________________

PLEASE RETURN AN **ORIGINAL** COPY OF THIS COMPLETED FORM, together with the relevant manuscript to the Editor-in-Chief. We regret that manuscripts without the copyright transfer form will not be considered for publication.

ASEAN JOURNAL ON SCIENCE AND TECHNOLOGY FOR DEVELOPMENT
(*ASEAN J. Sc. Technol. Dev.*)

SUBSCRIPTION FORM

The annual subscription rates for two issues per volume including CDs are as follows:

ASEAN countries: USD10.00
Outside ASEAN: USD30.00

Note that the above rate does not include the air mail charge. The air mail charge will be available individually for each subscriber upon request.

Please use the following form, to be returned together with the bank draft or send separately if you pay through bank:

I wish to subscribe to the ASEAN Journal on Science and Technology for Development.

Name of Subscriber: ______________________________

Name of Contact Person: ______________________________

Telephone No.: ______________ Fax No.: ______________

E-mail Address: ______________________________

Mailing Address: ______________________________

Cheque/Bank Draft No.: ______________ Amount: ______________

Signature: ______________________________

Date: ______________________________

All subscription correspondence should be addressed to:

Prof Emeritus Dr Md Ikram Mohd Said
Editor-in-Chief
School of Chemical Sciences and Food Technology
Faculty of Science and Technology, Universiti Kebangsaan Malaysia
43600 UKM Bangi, Selangor D.E.
Tel: +603 8921 5445
Fax: +603 8921 5410

Or
You can send information through e-mail:
(e-mail:kiamco65@gmail.com; kiam@ukm.edu.my)

ADVERTISEMENTS

(a) Scientific conferences/Seminars/Training courses
(b) Books/Publications
(c) Scientific instruments/Company/Industrial products
(d) Technologies for licensing/research collaboration
(e) Vacancies and appointments
(f) General publicity on science and technology matters of interest to the scientific community.

The terms and conditions for advertising are as follows:

(a) All advertisements will be in black and white.
(b) The advertisement will be interspersed within the various pages of the Journal and will be charged at a flat rate of USD1000 per B5-sized page for two (2) issues or USD1800 for four (2) issues on a running basis.
(c) Acceptance of advertisements will be on a first-come-first-served basis.
(d) All advertisers will receive two (2) copies of each issue of the Journal and CDs free of charge for the duration of the advertisement.
(e) Requests for advertisements should be accompanied with the following information:
    - Name of Advertiser
    - Contact Person
    - Tel. No., Fax No. and e-mail of contact person
    - Mailing address
    - Bank draft/cheque number of relevant amount made payable to the *ASEAN Journal on Science and Technology for Development*.

The Advertiser shall provide the copy in print ready form, in electronic copy using a common publishing software, together with a hard copy sample of the expected final print form. Advertisements will be published on an "as-is" basis using the material submitted by the Advertiser. No proofs will be given.

The Editor reserves the right to accept or reject requests for advertisements to ensure that the scholarly intent of the Journal is upkept.

All advertising and business correspondences should be addressed to:

Prof Emeritus Dr Md Ikram Mohd Said
Editor-in-Chief
School of Chemical Sciences and Food Technology
Faculty of Science and Technology, Universiti Kebangsaan Malaysia
43600 UKM Bangi, Selangor D.E.
Tel: +603 8921 5445
Fax: +603 8921 5410
(e-mail:kiamco65@gmail.com; kiam@ukm.edu.my)

ASEAN Journal on Science & Technology for Development

Contents

ASEAN J. Sc. Technol. Dev.
Volume 31(2), 2014