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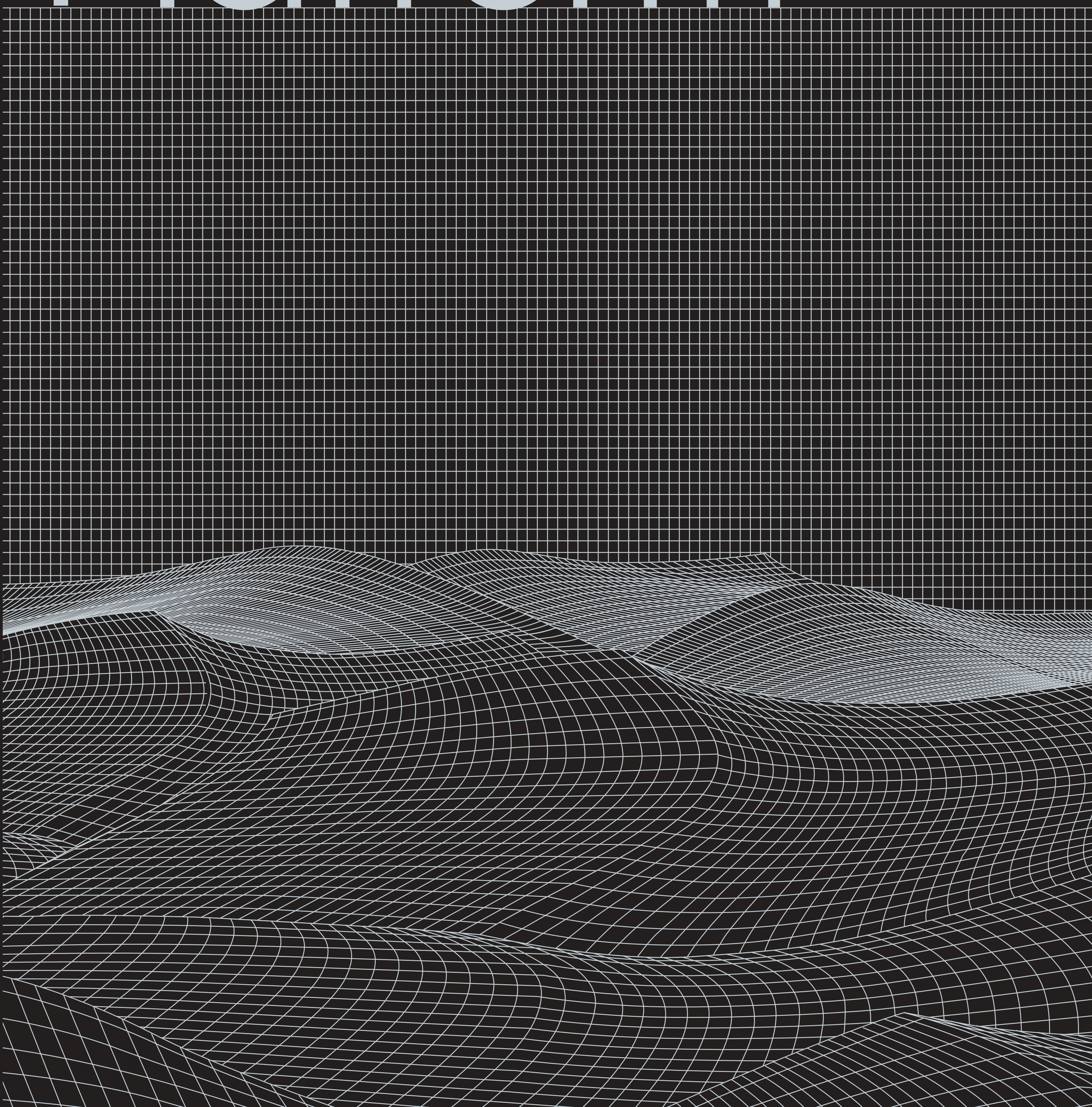

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CHALLENGES IN CHEMICAL ENGINEERING EDUCATION AND RESEARCH IN OIL AND GAS INDUSTRY

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ABSTRACT

PETRONAS formed in 1974, has a very strong presence and currently dominates the oil, gas and petrochemical industries in Malaysia. Besides strong oil and gas production facilities, PETRONAS has established a wide range of facilities for the production of many important petrochemicals. This strong presence in the oil, gas and petrochemicals fields has made PETRONAS a very important factor in the development of chemical engineering education in Malaysia. Responding to this need, chemical engineering education and programmes were first started in the University of Malaya, and is currently offered at 9 universities with an annual intake of more than 500 students. In keeping with the trend of other countries, chemical engineering education in Malaysia has also placed strong emphasis in the fundamentals. Major research programmes are being conducted at several universities in Malaysia in this field. The current globalisation scenario and high energy prices have thrown some challenges and opportunities. To take advantage of these opportunities and to meet the challenges, greater emphasis on research and innovation is required. The main challenge would be to get Malaysian researchers to focus on selected potential areas, given the limited resources in qualified manpower and funding, in order to create niches. Diversification of resources in the non-identified areas should not be ignored but need to be kept in view such that technical expertise, when available, are able to support the adoption of new technology. In this respect, perhaps the aim of making the nation "a fast follower and selective leader" of new technology in this context is appropriate.

Keywords: *Chemical Engineering Education and Research, Challenges of Chemical Engineers in Education and Research, Education and Research in Oil and Gas Industry*

INTRODUCTION

Malaysia, a predominantly agriculture, plantation and mining based economy prior to 1970, underwent rapid changes in the last three decades of the twentieth century. The changing global economic and political scenarios were advantageously utilized for the rapid industrialization of the country. The export oriented industrialization strategy was based on free import of capital as well as technology. As a result there was a tremendous growth of manufacturing industries in the areas of electrical, electronic, oil, gas and petrochemicals.

In the 1970s the Government made major efforts to transform the economy towards manufacturing. As part of this strategy, aggressive changes were made in the oil and gas industry in which PETRONAS played

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a major role. The growth of the chemical engineering profession in Malaysia is intimately related to the Oil and Gas Industry and in turn to the role of PETRONAS. PETRONAS has played a catalytic role in the promotion of the profession of chemical engineering in the country. Hence it will be illustrative to briefly examine the growth of the oil and gas industry in Malaysia and its impact on education and research in the chemical engineering profession. After this retrospect, we shall examine the emerging global and Malaysian scenarios and how the profession can adapt to the changing needs of the industry.

PETRONAS IN UPSTREAM OPERATION

The history of oil and gas in Malaysia started in the early 19th century with the first oil discovery in Miri, Sarawak, in 1910 (Bowie, 2001). However, it took almost half a century before several oil majors such as Shell, Esso and Conoco, started the exploration and commercial production of the oil and gas. Until the early 70s, the exploration and production activities were mainly by foreign concessionaires with royalty considerations to the Malaysian Government. However, the industry took a significant turn with the establishment of Petronas in 1974 under the Petroleum Development Act. Within half a decade, Petronas has already made significant contribution to the development of oil and gas in Malaysia, taking the leading role in upstream, refining and downstream activities, including petrochemical production. The establishment of PETRONAS Carigali and Malaysia Liquefied Natural Gas (MLNG) (Bowie, 2001) were among the important milestones in the history of PETRONAS. PETRONAS Carigali was established in 1978 to venture into exploration and production thus transforming the Malaysian involvement from managing production sharing contracts to an active joint partnership with oil majors in undertaking exploration and production of local oil and gas reservoirs. Currently, Malaysia produces more than 0.75 million bpd of oil and condensates.

PETROLEUM REFINING AND PETROCHEMICALS

The PETRONAS foray into petroleum refining started with a small refinery at Kertih. Even though it was very small, it has played an important role in the development of competent human resources for the operation of refineries and petrochemical plants. The Kertih refinery was later followed by the setting up of two refineries in Malacca i.e., PSR-1 and PSR-2. PSR-2 is a joint venture with Conoco. These two later refineries have the benefit of a better and more integrated design, using Pinch Technology, capable of significantly improving the energy efficiency and thus reducing production costs (Shuib, 2004).

The ASEAN Bintulu Fertiliser plant built in Bintulu in 1985 marks the first entry of PETRONAS into the petrochemicals manufacturing area. This plant produces fertilisers such as ammonia and urea.

The construction of the Gas Processing Plant (GPP) in Kertih has led to the opening of the Petrochemical Processing Complex in Kertih and Gebeng. The Kertih site was designated to focus on ethylene based petrochemical products while Gebeng was designated for propane-based petrochemical products (Bowie, 2001). The first of the two petrochemical plants built at the two sites were MTBE-propylene & polypropylene (1990 in Gebeng) and ethylene-polyethylene (1991 in Kertih). These are joint venture projects with reputable companies such as Neste Oy, Idemitsu and BP Chemicals. PETRONAS later acquired the methanol plant in Labuan (built in the 1980s) in 1992 as a strategic move to secure methanol supply for the MTBE plant.

Among the earlier products to come on-stream was the polymer production from ethylene-polyethylene in 1995 with a production capacity of 200,000 tonnes per year and this attracted attention to the Malaysian petrochemical industry. In the same year, an agreement was signed between PETRONAS and Mitsui & Co. for a Vinyl Chloride Monomer Plant in Kertih, using the ethylene produced from the ethylene plant as feedstock. In 1999, an agreement was made with Polifin Ltd, South Africa and DSM Polyethylene BV, Netherlands, for the construction of a Low Density Polyethylene (LDPE) Plant in Kertih to start production in 2002.

In Gebeng, PETRONAS signed an agreement with BASF in 1997 to own, construct and operate an acrylic acid-esters and an oxo-alcohols plant which commenced production in 2000 and 2001 respectively. The following year saw the arrival of Union Carbide Corporation (UCC), now already acquired by Dow Chemicals, for a joint venture with PETRONAS on three projects involving an olefin cracker, an ethylene oxide-ethylene glycol and a multi-unit derivatives plant, all located in Gebeng.

Other important facilities in Kertih and Gebeng are Aromatics Complex, Polyvinyl Chloride-Ammonia-Syngas Plant, Acetic Acid Plant, Ethylene Cracker, Propane Dehydrogenation Plant, Oxo-Alcohols Complex, Acrylic Acid-Acrylic Esters Plant and a Butandieol Plant.

In Pasir Gudang, which is another significant petrochemical site, PETRONAS has built two plants producing ethylbenzene and the styrene monomer, in partnership with Idemitsu. The plants commenced operations in 1997. Alongside PETRONAS, Titan Petrochemicals had earlier constructed larger facilities involving two naptha crackers, five polymer plants, a BTX unit and two cogeneration plants and their associated facilities. The development started in the 90s and to date Titan has earned the reputation of being the largest integrated olefins and polyolefins producer in Malaysia and the second largest polyolefins producer in south east Asia in terms of capacity (Anon HA, 2004). At Gurun, which is a more recent and smaller site, PETRONAS owns an ammonia and urea plant. The above brief outline illustrates the wide interest of PETRONAS in a variety of downstream chemical plants.

NATURAL GAS BUSINESS

The gas processing plants, GPP 1-4, in Kertih provided the raw materials for the petrochemical complexes at Ketih and Kuantan and supply the gas to the Peninsular Gas Utilisation Pipeline System, which extends from Kertih to Singapore along the east coast and from Malacca to Kangar on the west coast.

The setting up of MLNG in 1983, marked the beginning of PETRONAS as a major player in the world gas energy business. This plant is basically meant for gas liquefaction for export to mainly east Asian countries. To meet the growing demand for natural gas, MLNG II was added in 1990 and MLNG III in 2002. With the completion of MLNG III Malaysia created a world record by having the largest LNG complex built on a single location. Today, Malaysia produces 302 million barrel oil equivalent (BOE) of gas against 274 BOE of crude oil. In the years to come, the role of gas in the business of PETRONAS will continue to grow.

Looking at the tremendous development that has taken place involving the oil and gas industry (including petrochemicals, in view of its heavy reliance on feed material), Malaysia has successfully put together a highly integrated and complex oil and gas industry capable of producing products of significant value added designs and this has placed Malaysia as one of the world's petrochemical industry hubs.

EVOLUTION OF CHEMICAL ENGINEERING PROFESSION

Chemical engineering is among the youngest engineering disciplines, introduced in the late 19th century. Its roots can be traced to the technical chemistry courses in the German Technical Hoch Schule in the early 20th century. It was developed by a combination of the principles of technical chemistry and mechanical engineering. George Davis an English Alkali Inspector first proposed the term chemical engineering and developed the first formal class, which offered a set of 12 lectures later called the Unit Operations, at the Manchester Technical School. In the USA, Professor Lewis Norton introduced the first course, which was known as 'Course X' at Massachusettes Institute of Technology in 1888. Similar courses in chemical engineering soon followed in the University of Pennsylvania and Tulane University in 1892 and 1894 respectively. Within a century of its introduction, chemical engineering has become an established distinct and separate identity from its progenitors. While all branches of engineering were based on mathematics, physics and engineering fundamentals, chemical engineering was the only branch which had a foundation of chemistry as well. These strong theoretical foundations soon made chemical engineering a highly respected profession. Today chemical engineering is recognised together with Civil Engineering, Mechanical Engineering and Electrical Engineering as basic engineering professions.

The developments made in chemical engineering associated with education and research has been tremendous especially in the second half of the 20th century. A significant portion of this development was due to the aggressive exploitation of petroleum and gas resources to meet the increasing world energy needs and to produce new petrochemical products. Major industry players such as Exxon, Shell, BP and BASF, started to expand their operations to take advantage of the growing market demand for petroleum and gas related products. While mechanical engineers dealt with machineries, industrial chemists concerned themselves with chemical products, and applied chemists studied chemical reactions, no one before the advent of chemical engineers, had concentrated upon the underlying processes common to all chemical products, machinery and reactions. The chemical engineer, utilising a conceptual tool called "unit operations", could now claim a specific industrial territory unique to their profession (AIChE Website: History of Chemical Engineering). Later stages of developments in analysis supported the phenomenal growth of transport and process control. Topics relating to the environment and safety became part of the stock-in-trade of the chemical engineer. Biology related subjects became included in the chemical engineering curriculum. Today, chemical engineering education has strong analysis, synthesis and design basis. Not surprisingly, chemical engineering is now recognised as the 'Universal Engineering'.

CHEMICAL ENGINEERING EDUCATION IN MALAYSIA

In the case of Malaysia, the chemical engineering profession was not well established until the late '70s. When massive development in the oil and gas industry gave a fillip to the profession in Malaysia. This coincided with the setting up of PETRONAS which later formed subsidiaries to diversity into the areas of development in the oil and gas industry including petrochemicals.

The chemical engineering undergraduate programme was first started by the University of Malaya (UM) in 1975 (UM Website). At that time, student intake was limited to the small job market. The main employers were the few multi-national oil and gas corporations pursuing exploration and production activities and a number of small to medium scale chemical industries processing agricultural based products. Universiti Kebangsaan Malaysia (UKM) became the second university to introduce a chemical engineering programme in 1978 which was called Chemical Technology at that time. With the anticipated growth in demand for chemical engineering graduates in the '80s, Universiti Teknologi Malaysia (UTM) started their programme in 1983 followed by the University of Science Malaysia (USM) in 1994.

In 1995, by invitation from the government, the three major national utilities corporations namely, PETRONAS, Tenaga Nasional and Telekom, set up private universities in their names with the aim of structuring courses unique to their functions. The chemical engineering programme started at Universiti Teknologi PETRONAS in 1997. Given the strong synergy of the programme with the main activities of PETRONAS, it naturally strong support from the corporation.

Other universities joined in, to cater to the rapid development in the oil and gas industry as well as other related industries. However, the supply of chemical engineering graduates was still falling short of demand. This led to the increase in the student intake by the universities already offering courses in chemical engineering. Further, chemical engineering programmes were introduced at Universiti Putra Malaysia (UPM) and Universiti Malaysia Sabah (UMS) in the late '90s. Shortly thereafter, Universiti Teknologi MARA (UiTM) joined the rank in offering the programme in 2000. The recently formed Kolej Universiti Kejuruteraan Dan Teknologi Malaysia (KUKTEM) started their programme in 2002.

CHEMICAL ENGINEERING RESEARCH IN MALAYSIA

The number and variety of research activities in the area of chemical engineering has steadily increased over the last decade, evident by the increasing number of projects funded under the IRPA programme. Chemical engineering related fields such as chemical sciences, energy, manufacturing (chemical/ petrochemical) and environment have also been receiving growing attention. During the early years of the IRPA programme (late '80s), most of the grants were for fundamental research. In the late '90s, allocations were given to applied oriented projects related to fields such as alternative energy, process system engineering, advanced process control, waste minimisation and environment. Restructuring of the IRPA in 2001 provided for emphasis on applied projects with potential for commercialisation. Projects such as Fuel Cell, Compressed Natural Gas Vehicle (storage and dispensing flow-measurement system), Development of Nano-Catalyst and Manufacturing of Carbon Composite were among the projects that received significant funding under the category of prioritised research. Scientific publications resulting from research also showed exponential growth. For example, the 8th Symposium of Malaysian Chemical Engineers in Terengganu in 1995 had less than 20 technical papers whilst the 18th Symposium has nearly 200 technical papers covering a wide range of chemical engineering subjects.

Apart from research conducted at the public institutes of higher education and Government research institutes, the setting up of PETRONAS Research and Scientific Services (PRSS), formerly known as Petroleum Research Institute (PRI), has been instrumental in developing chemical engineering related research and development projects focusing mainly on the oil and gas industry. A Petroleum Research Fund (PRF), established in the '70s, became one of the major funds spearheading the development of research at PRSS. To date, PRSS has developed expertise in areas serving the oil and gas industry, the chemical engineering field, petroleum exploration and production, material, offshore structural engineering, process engineering, energy and environment, and automotive (mainly fuel and lubricants).

Government research organisations such as Palm Oil Research Institute Malaysia (PORIM), Standard and Industrial Research Institute of Malaysia (SIRIM), Malaysian Agricultural Research and Development Institute (MARDI), and Forest Research Institute Malaysia (FRIM) are also involved in research related to chemical engineering.

WORLD ENERGY SCENARIO TODAY – THE CHALLENGES

In October 2004, crude oil traded worldwide reached a price above USD50 per barrel. There are several possible reasons for the steep hike in the price.

The phenomenal economic growth experienced by China with gross domestic product consistently above 9% in 2003 and the first quarter of 2004 (Lyle, 2004) has resulted in a tremendous increase in the demand for oil and gas for its energy needs. Between 2000 and 2003, China accounted for nearly 40% of the total growth in world oil demand. It has been forecasted by Cambridge Energy Research Associates (CERA) that China will use about 9 percent of the world's oil demand by the year 2010 (CERA Websites). India has also shown a comparably strong growth rate at the same time. Similar trends but perhaps slower rates were observed in other developing countries. Carr (1994) predicted that the increase in energy consumption in developing countries between the year 2000 to 2010 will supercede Western Europe. Due to such aggressive demands in energy consumption within this short period of time i.e., less than 5 years, the world's oil exploration and production could not cope.

Currently, there are perceptions that the balance between the supply and demand for crude oil is indeed thin. The situation is made worse by the fact that as the reserves located in the developed and politically stable countries depleted, more and more of the new reserves were found in the unstable countries. Also, there is growing perception on the declining in world oil reserves as a result of higher consumption rates in opposed to the new discovery rate. Rifkins (2002) suggested based on the facts derived from new studies that the global oil production is expected to peak sometime between 2010 and 2020, though few of the more pessimistic one suggesting it to take place earlier than 2010. In a recent talk delivered by Lee (2004), he has suggested that the crude oil production peak will arrive at 2015 and the crude oil reserves life will hold for about 36 years more based on the current proven oil reserved of 1 trillion barrels and the current consumption of 27 billion barrels per year. However, as the crude oil price increases, further recovery from current available reserves, production from deep-water reservoir and marginal fields, and extraction of crude oil from non-conventional sources such as the Venezuelan heavy oil and Canadian tar sands become economically feasible, Lee estimates that the reserves life will hold for another 78 years at current consumption rate. Probably, this is one of the very few comforting facts available.

Recently, there was another factor found to contribute towards the significant increased in the price of especially the light crude as compared to the heavy crude. It was found that most refineries in the world are designed to process sweet crude, which is cheaper to process. As the light crude reserves depleting, only to be substituted by more heavy crude reserves, serious competition has resulted for the light crude thus pushing the price further (PETRONAS CIRU Online, Oct. 18 2004).

On the natural gas, Lee (2004) predicted a 60-year world reserve life based on current 5500 TCF proven reserve life and annual consumption of 90 TCF. While, Rifkins (2002) suggested that the world gas peak production could arrive between the year 2020 to 2030. In view of its cleaner combustion, gas has been promoted as fuel substitutes to oil and coal, and has so far used widely for power generation and domestic heating world wide. Apart from being energy source, gas played an important role as the main feedstock for petrochemical industry. In view of the significant economic growth of the developing countries, with China and India taking the lead, there was also significant demand growth for gas to provide the fuel for power and the petrochemical feedstock required. This has led to the steady increase in the gas price though not as drastic as for the crude oil.

As for Malaysia, in particular PETRONAS, significant national revenue was claimed from the oil and gas industry. The growing demand for crude oil and gas, locally and internationally, as opposed to the world wide diminishing reserves, has presented challenges as well as opportunities for PETRONAS and Malaysia. Currently, Malaysia's oil reserves is expected to last for another 18 years while its gas reserves will last for another 34 years, based on current production rate (Mohd *et al.*, 2004). Domestically, Malaysia is a currently net exporter in terms of crude oil and gas. Based on the production record history for the past 30 over years (Abbas, 2004), the production of Malaysia crude oil seems to have peak within the last 5 years. For natural gas, the production is still on the increased but is predicted to peak within the next 2 to 3 years time. As it is important to continue maintaining the self-sustainability for the oil and gas supply, effort to improve extraction rate on current reserves and to secure more local reserves is indeed crucial. These involved new and at times, unproven technology, which need to be carefully researched and evaluated. Higher investment and operating cost is expected but with the increasing crude oil price, the options may become more economically viable. In the international arena, new reserves have been discovered in several countries which have been known in the past to be less politically stable. PETRONAS and Malaysia involvement in the above region was considered to be a risky venture and was made possible through good diplomatic relations paved by its political leaders. Nevertheless, the investment made in countries such as Sudan, has so far, provided a very good return to the company. As the task of securing more reserves gets increasingly difficult and more competitive, PETRONAS has recently formulated a new company's strategy (PETRONAS CPDD, 2003) aimed at transforming PETRONAS further to ensure its long term survival and able to compete with the giant oil and gas companies such as Shell, ExxonMobil and TotalFinaElf.

CHALLENGES IN THE OIL, GAS AND PETROCHEMICAL PROCESSING INDUSTRY

The increase in the demand for oil and gas has also been partly contributed by the increasing demand for petrochemical products and the energy needed to run the industry. In particular, the feed materials, which were derived from naphta and natural gas. In the past, industry has taken the challenges through the effort made in reducing operating cost to maintain competitiveness. Effort such as good housekeeping to ensure minimal losses of raw material and energy was among the earliest one instituted. This was later followed by the combination of better design techniques, superior performing equipment and good operational practices, which was as a result of the achievements made in research and development. Even the increase in the scope of petrochemical product utilisation and the new products invented was the result of the research and development made over the years.

In the case of crude oil refinery and gas processing, similar efforts were made in the attempt to maintain competitiveness. The profit margin seems to be decreasing as the raw materials price increases. The practice of providing subsidy by some government due to the strategic nature of the industry is expected to reduce slowly in view of the increasing crude oil and gas price. Environment, an important issue nowadays as a result of increasing awareness on its' impact to the well-being of the world population, is expected to be taken up more seriously as a global agenda. Introduction of Kyoto Protocol demonstrates the world commitment to reducing the emission of green house gases (United Nation Website), which is known to cause global warming and weather pattern changes (PETRONAS CIRU Online, Aug. 24 2004). Tighter regulations have been formulated by local and international authorities, generally compelling industries, including the oil and gas, to increase investment either through addition or modification of equipment to meet the emission standard.

For Malaysia, the technology used for driving its oil and gas processing industry has been mainly obtained from the developed countries such as the USA, Japan, European countries and others through smart partnership established with reputable companies such as ExxonMobil, Shell, Halliburton, Schlumberger, Conoco, Union Carbide, BASF, BP, Amoco, Mitsui, Mitsubishi Chemicals, Westlake groups and others. Though the Malaysian companies have learnt significantly from these 'technology partners' but much of the knowledge gained was related to project management, plant operation and perhaps, the engineering design of plant infrastructure and standard equipments. The essential technology components involving advanced knowledge such as the process design and licensing, catalyst technology and some advanced process equipments were still under the control of the 'technology partners'. A slight exception has to be made to the oil and gas exploration and production related companies, as they were perceived to have done better in acquiring the technology and has now able to export their services.

Nevertheless, the emerging technology, which is key for future success, still remained with the 'technology partners'.

With the emergence of China, India and other developing countries capable of offering competitive environment similar to Malaysia, the partnership arrangement that Malaysia has privileged in the past, could be lost to these countries. There was indication of such happenings where petrochemical industries were continually growing in China, India and some Middle East as compared to Malaysia. Thus there is a need for Malaysia to develop and hold technology leadership in certain selective areas to provide some niche for international competition.

CHALLENGES IN CHEMICAL ENGINEERING EDUCATION AND RESEARCH

After a century of development in Europe and the USA, chemical engineering has matured to become a well-rounded discipline (Lin, 2003). It has made a significant contribution to the growth of the oil, gas and petrochemical industry to the extent that the industry is considered to be one of the pillar industries supporting the world economy.

With the perception of declining oil and gas reserves, significant research has been commissioned in energy recovery and conservation, apart from finding alternative sources that could replace oil and gas in the future. The use of hydrogen as the potential future source (Rifkin, 2002) in addition to the other renewable energy sources would require more multidisciplinary research using the combination of chemical, material and electrical fundamentals before a breakthrough leading to its mass commercialisation could be envisaged.

In new technology such as nano-technology and bio-technology, chemical engineers have also known to be involved heavily in its development which are again perceived as multidisciplinary fields. In a workshop conducted in Woodland, Texas (Zukoski *et al*., 2002) to review the directions of Chemical Engineering discipline, the need to understand biological process up to molecular level has been highlighted strongly in view of its importance not only for human health but also for other traditional sectors such as energy, material, fuel, chemicals and food.

With the rise of these new technologies affecting chemical engineers, Lin (2002) pointed that the broadening of the curriculum to account for the inclusion of these additional knowledge, has significantly stretched the cohesiveness of the current one. This has led to a constant pressure to strike a balance between specialisation and generalisation. In addition to the biological system, newer area such as Process System Engineering, which is expanding as a result of tremendous development in computer technology (Ponton, 1995), is expected to also contribute significantly to the specialisation area in addition to the existing areas such as Heat and Mass Transfer, Separation Processes etc.

Another significant change seemed to be taking place across all disciplines, as a result of rapidly changing economic environment, is the requirement of practicing professionals to master various skill-sets other than their self-technical discipline (Lin, 2002). Not only that this covers the knowledge on other technical disciplines required as a result of more multidisciplinary approach needed, better soft skills have also been increasingly demanded from the professionals. In a Master Plan for academic developed by Universiti Teknologi PETRONAS (UTP, 1998), six additional attributes were identified in addition to the technical competency, as the elements of the soft skills looked on by current potential employer. These skills, among others, involved the ability to communicate well, to continuously learn new knowledge, to have practical aptitude and business acumen and to have the ability to be critical and creative in finding solution.

The rapidly changing economic environment has also led to increasing pressure on research and development (R&D) to deliver commercial value. The keynote speech by the Malaysian Prime Minister in a National Innovation summit has indicated a strong aspiration from the government to see more R&D outcome to be exploited commercially to support Malaysia economy (Malaysian PM Speech, 2004). Currently, the Malaysian ability of conducting leading research in certain areas has been acknowledged but the ability to take the research outcome for commercialisation is still relatively low. Worldwide, the corporatisation of several R&D units and the outsourcing of R&D activities by several large oil and gas companies, in a way, provided the manifestation of such pressure. Even the public funding for R&D has come under increasing scrutiny and the future situation is not expected to be no easier. However, various incentive schemes have been introduced to promote commercially inclined R&D such as awards, royalty and others.

The advent of IT technologies have created unprecedented changes at global scale, impacting various industries including education. The conventional mode of delivery, which requires students' physical presence in university, has in the past limited the competition for students to only within regional area. However, due to the significant development made on computer (including its networking) and telecommunication technologies (especially the world wide web), and simulation programmes, the conventional approach is now coming under tremendous pressure. Access to contents are becoming easier and in some cases, being made more interactive with possible self-assessment. There are cases where 'live delivery' of lectures being made available through the web. The only set back to the author's present knowledge is probably the approach of conducting student assessment and even this is being addressed significantly now. Competition for quality students and education is expected to be more open with a potential for wider access to student market.

THE WAY FORWARD AND ITS CHALLENGES

It is a well-known fact that oil and gas production and processing (including petrochemicals) is a highly technology-oriented industry. Technology has in the past, helped Malaysia to increase its oil reserves from 1.4 billion barrels in 1981 to 3.5 billion barrels recently and has also reduced the minimum production cost from USD 5-6 per barrel of oil to USD 1.50 by the late 1990s. (PETRONAS VP Education, 2004).

However, most of the available reservoirs especially for oil were observed to have approach or reached maturity stage. Given the recovery factor for most oil reservoir, based on traditional production technology, are found to be relatively low, technology for enhancing the oil recovery such as the proven water or CO_2 injection, would proved to be useful. Other technologies such as air injection, chemical injection and the use of microbes have also shown potentials. The ability to understand the different mechanism for enhanced recovery and the characteristics of local reservoir would prove detrimental in helping the Malaysian exploration and production industry to select the best method (Abbas, 2004). Also, as the easily accessible oil and gas reserves available onshore and in shallow water are maturing and reducing in output, the exploration and production is now shifting to deep water where significantly higher cost of exploration and production is expected. Thus technology will be more dependent upon to reduce the cost and overcome the challenges. For a start, a more accurate subsurface modeling and simulation has to be achieved to increase prediction accuracy on location and potential size of reservoirs, thus avoiding costly error as a result of drilling "empty" or low potential reservoir. Also, the rig technologies for deep water could also be expected to be more complex and difficult.

In the case of natural gas, mainly the reservoirs' maturity is yet to come, which means there are still potential to increase production. Nevertheless, the increasing production is expected to come more from the higher CO_2 content reservoirs (Abbas, 2004), reaching as high as more than 50%. While the production rate from such reservoirs are still low, blending the gas with those coming from the low CO_2 reservoirs can be used as a solution. As the production from such reservoirs increases, acid gas management becomes more important. Better separation technologies are required to separate the high CO_2 content prior to reaching the gas processing facilities onshore. In a feasibility study conducted (PETRONAS, 2001) to address the high CO_2 content, amine absorption was found to be inadequate but a hybrid separation method combining them with membrane was recommended as a potential solution. However, a technically and economically proven case is yet to be seen and this requires considerable research and development effort. On the separated CO_2, a different paradigm could be adopted in the sense of viewing them as a potential feed material for upgrading process or for commercial usage.

Although, the economy of the world has gradually recovered post 2003, bulk of the development in the petrochemicals industry has been concentrating in the North East Asia region with China taking the lead. The import of ethylene entering North East Asia has more than doubled from 1998, to nearly 6 million tons in 2003. The figure is expected to exceed 8 million tons by 2008 (Tan, 2004). In meeting with the demands within the medium term, the growth will be mainly met by the additional capacities built in the Middle East to take advantage of the low cost feed material. In longer run, larger capacities have been planned for construction in China. For propylene, the demand figure for North East Asia is forecasted to reach approximately 3 million tons by 2008 in view of the growth expected for polypropylene (Tan, 2004). Currently, the demand is met by production facilities in Japan, South Korea and South East Asia. Nevertheless, with the completion of several new facilities in China soon, the region will be expected to change their standing as net exporter instead. For polyethylene and polypropylene, much of a similar observation was reported, with the demand growth was mainly by China. Again, the Middle East is targeted in building the new facilities for meeting the demand growth due to low cost feedstock advantage (Yap, 2004).

Considering the situations above and the limitations on the capacity of natural gas that could be produced, the likelihood of petrochemical industry in Malaysia expanding further especially involving olefin and polyolefin, would be quite limited. There may be some opportunities where increasing plant capacities through debottlenecking exercise, as undertaken by Titan (Anon HA, 2004), could help increase production. However, much of the expected challenges would involve plant operational issues, such as achieving best practices in operation and maintenance and high equipment reliability. The use of Knowledge Management for improving operational performance group wide has been initiated by BP with the focus of helping their world-wide business units to assess their performance and effectively sharing the developed best practices tools and the good operational practices (Anderson, 2004). The use of new technology such as better catalyst, innovative processes, advanced process control and better integration across plants should also be considered.

A new area which deserves consideration, is the development of new and flexible product and processes to create new niche market. Development of new and flexible products would require increasingly specialised material, active compounds and special effect chemicals, which need micro scale approach to provide better understanding of the complex processes at molecular level (Charpentier and Mc Kenna, 2004). An example is the production of low density and highly branched structures polyolefins resulting in more amourphous products using a high-pressure free radical process. New technology involving advanced materials, bio-technology and nano-technology could contribute towards such development. On flexible processes, agile manufacturing has been suggested as the new paradigm whereby a manufacturing plant will no longer be producing physical products only but also capable of producing solutions to its client (Lin, 2003).

Personalised or customised products will be made available at the right time and at a mass production price. The concept of prime industry and 1st and 2nd tier suppliers adopted from the electronics and automobile industry is envisaged as a result of new process technology leading to different optimisation being made not only on profitability but also on sustainability (Benson, 2004).

As for crude oil refineries, similar initiatives for achieving operational excellence could also be expected. Additional issues which will continue to affect their operational performance would consists of global over capacity which results in low margins, cleaner fuels requirement and refinery emissions causing costly investments and deregulating of oil industry by many countries leading to the disappearance of the "healthy" protected margin enjoyed previously. These have led to stiffer competitions worldwide, forcing refineries to undertake more drastic measures to improve their profitability. An example of such measures is the putting up of cogeneration facilities as implemented by PETRONAS refinery in Malacca to improve the energy efficiency of the complex and to lower the energy cost (Shuib, 2004). Others, involve the more recent integration between Oil and Chemical Interface (OCI), to create synergy between refinery and petrochemicals processes. Three case studies were demonstrated by Shell Global Solutions using their Hydrocarbon Management Review method (Moorthamer, 2004) to produce benefits ranging from USD 60 to 120 per tonne of ethylene produced.

Education role in Malaysia has evolved significantly and is expected to come under increasing pressure to not only produce relevant workforce for the industry but to also continue updating them with knowledge developments. Malaysian universities will have to increase their awareness of the industry needs and be versatile in reviewing their curriculum. Exposing graduates with the current and leading edge technologies would enable them to keep pace with the latest development thus making them a 'fast technology follower'. However, as new and revolutionary technologies are developed, wider coverage could be expected out of the curriculum. This will affect the depth of knowledge coverage possible given the limited time for the undergraduate program duration. Balancing the curriculum breadth and depth while at the same time fulfilling the growing industry needs will prove to be increasingly difficult for universities. Close collaboration with industries would prove vital as the universities progress into the future.

As mentioned earlier, development of graduate soft skills are becoming more important. Introducing additional courses for developing these skills alone may not be sufficient but the ability to inculcate these skills through non-conventional approach of delivering courses and creative assessment methods could prove to be a better option. The advent in information technology should be exploited to support the initiative such as providing the course materials flexibly and in an interactive manner.

In research and development, a review on most of the potential areas has been presented earlier. While some areas may not present attractive opportunity for Malaysia in view of the established position especially by the developed nations such as the USA, Britain, Japan and others, there are other areas that could still provide the avenue for Malaysian researchers to develop the niche required. Creating niches especially in selected technology would be highly important especially when the industry has global scale operation. PETRONAS is already leading a few other Malaysian companies in going global. The current highly competitive environment would not permit for a company such as PETRONAS to develop a comprehensive R&D programme for developing all the required technology in house. With the constraint on resources, it is expected that only selective technology could be focused on, in order to achieve the 'selective leadership' needed to give the edge while the remaining could be obtained through smart partnership from the 'technology partners'. Choosing the right technology would proved to be essential and even more important, aligning the available expertise to support the selected technology would provide the crucial factor. Even with the existing platform available within PETRONAS i.e., TSD, PRSS and UTP, there are still much that could be done by the Malaysian universities in making the above a reality. The recent move by the Malaysian government to seriously promote innovation through research and development is considered timely

Ultimately, the greatest challenge for the oil and gas industry over the long run is the search for new energy source that could substitute hydrocarbon. Although, gas and coal still present large potential reserve world wide, it will be completely utilised by the end of this century. Hydrogen has been extensively promoted in the form of fuel cell but the current technology, especially the hydrogen generation still depend much on the hydrocarbon as the source. A breakthrough will not only ensure energy sustainability for the world but also a cleaner form of energy, which are also environmentally friendly.

CONCLUSIONS

Malaysian oil and gas industry has developed significantly in the last thirty years. From a relatively small industry with mainly local operation, it has evolved to become more global as reflected particularly by the PETRONAS development. Malaysia is now considered to be one of the important petrochemical hubs of the world supplying products to various countries including the developed ones. PETRONAS, has extended its international operation to over thirty countries thus transforming the company into becoming more multinational.

Malaysia oil and gas industry will be expected to face tougher challenges in the future. The decline in the production of crude oil and gas will force the exploration and production to move into deeper water and more international venture to secure additional reserves. Though smart partnership was established to provide the technology edge required but over a long run, the need to establish in-house technical capability and technology is inevitable. Similar circumstances are expected for the downstream sector to provide the competitive edge needed for the future.

In this respect, education provided by the Malaysian universities has an important role to play in producing graduates with the required competency needed by the industry. Universities will have to play more active role in reviewing and ensuring their curriculum remains updated and relevant to industry requirements. Continuous learning to update current work force through professional courses or postgraduate program should be made available through close collaboration with industry. Smart partnership at global scale should be considered to support needed areas where in-house expertise are not available. Through such effort, the future generation workforce for Malaysia could be depended upon to better achieve the 'fast technology follower' standing which will be essential in supporting further growth in the industry.

As for research and development to support the oil and gas industry, Malaysia has yet to make a visible impact through its own technology development that could provide the edge needed. Although the developed countries have progressed far ahead in their research and development mainly due to their much earlier establishment in the industry, there are still new areas worth competing given that not many discoveries have been made so far. These are the areas where attempts should be made to garner the limited resources available to create the selected niche needed for becoming competitive.

Over a longer run, the greatest challenge that will face the oil and gas industry is finding the new source of energy and feed material for Petrochemical processes which produces material used widely for manufacturing of various consumer products.

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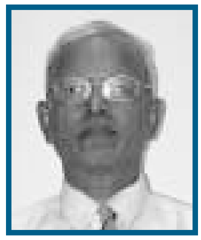

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CARBON CREDIT TRADING FOR CO_2 REDUCTION: OPPORTUNITIES FOR MALAYSIA

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ABSTRACT

Global warming is a complex modern problem involving the very survival of the human species in the world. Poverty, population growth and the hopes of economic development of billions of people in the developing world are involved in this complex issue. The solution to this pressing problem will not be easy and ignoring it is certain to lead to disaster. Carbon dioxide (CO_2) concentration in the atmosphere has gradually increased during the past 150 years from 278 ppm to a current high of 370 ppm. The major factor in this high CO_2 concentration is the increased emission of greenhouse gas from various sources especially from heavy industries, power generation from fossil fuels and the extensive use of hydrocarbons as the fuel for transportation. The continuous increase of CO_2 concentration in the atmosphere is found to result the in the 'greenhouse effect', causing an increase in global atmospheric temperature by 1.2°F in the last century. The Kyoto Protocol was negotiated in 1997 to take urgent remedial measures to arrest the increase in the greenhouse gases (GHG) in the atmosphere. Under the protocol, the emission of carbon dioxide and other greenhouse gases is required to be reduced and necessary steps need to be taken directly or indirectly for storing or utilizing the emitted carbon dioxide. The Kyoto protocol divides the nations into Annex B and non-Annex B countries. The Annexure I countries have to play significant roles in reducing their carbon dioxide emission levels. Several mechanisms such as International Emissions Trading (EIT also known as carbon trading), Joint Implementation (JI) and Clean Development Mechanisms (CDM) have been recognised to reduce the emissions from both the Annexure I as well as the non-Annexure I countries. In nature, biomass and ocean are the principal means of converting carbon dioxide and sequestrating it. These must be further explored and exploited. Hence, innovative and novel technology has to be developed for minimizing the release of carbon dioxide to the environment. Otherwise, carbon-trading facilities have to be used as prescribed in the Protocol. Malaysia has ratified the Kyoto convention. As a non-annexure country, Malaysia does not have any commitment to reduce the emission level. However, under the Clean Development Mechanism there is considerable scope for Malaysia to take advantage of the provisions of the Protocol not only to reduce the emissions but in so doing, could derive economic benefit. Some of these avenues such as alternate energy, and conversion of carbon dioxide to chemicals offer attractive research opportunities to chemical engineers.

Keywords: *Carbon dioxide, Greenhouse Gases, Global Warming, Carbon Trading, Clean Development Mechanism, Joint Implementation*

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INTRODUCTION

In 1992, the United Nations Conference on Environment and Development (UNCED), also known as the Earth Summit, was held in Rio de Janeiro. One of the important documents resulting from the summit was the United Nations Framework Convention on Climate Change (UNFCC)[1]. The ultimate objective of this Convention is the stabilisation of greenhouse gases (GHG) concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. This stabilisation should be achieved in a certain timeframe so as to allow the ecosystem to adapt naturally to climate change and to ensure that food production is not harmed. In addition, the economic development must be able to proceed in a sustainable manner while achieving the targeted level of GHG concentrations.

The greenhouse effect occurs when concentrations of GHGs in the earth's atmosphere block the sun's energy, received by the earth, from escaping back into space. Naturally occurring greenhouse effect, keeps the earth's surface warm by acting like a blanket. Examples of naturally occurring GHGs are carbon dioxide, methane, water vapour and ozone produced by moderate human activities such as agriculture and animal husbandry as well natural phenomena such as organic decay and volcanic activity. However, beginning with the Industrial Revolution, industrial and transportation activities have substantially increased both the naturally occurring GHGs as well as artificial GHG emissions thus making the blanket "thicker". This consequently increases the earth's surface temperature. According to the Third Assessment Report (TAR) by Working Group I (WGI) of the Inter-governmental Panel on Climate Change (IPCC), when GHGs reached the highest values as recorded in the 1990s, 1998 was found to be the warmest year [2]. The United States Global Change Research Program (USGRP) stated that the concentration of carbon dioxide has increased by about 30% since the late 1800s from 278 ppm to 370 ppm and this has caused world global warming [3].

According to the US Climate Data Centre report in 2001, global temperature rose by 1.2°F during 20th century. More importantly, more than half of this rise occurred after the year 1975 [3]. The increase of global temperature has resulted in disastrous environmental consequences like increased frequency of storms, floods and droughts. It has been recorded that global sea levels has increased by 10 to 20 cm during the 20th century. This is due to the melting of glaciers and melting of the polar ice cap, which increases the total amount of water in the oceans and the expansion of sea water as its temperature increases. If this phenomenon continues unabated, it is predicted by 2100, further increases of sea levels of 9 to 99 cm is likely to happen. Such an increase can have disastrous consequences for countries with heavily populated coastlines such as Bangladesh and the Maldives Islands. In addition to this, agricultural yield is expected to drop especially in tropical and sub-tropical regions due to drying up of agriculture lands and it could lead to the disruption of food supply and its associated problems.

The main objective of this paper is to highlight the salient points pertaining to the Kyoto Protocol and how developing countries especially Malaysia can capitalise on the opportunity as prescribed.

KYOTO PROTOCOL

In view of the projected alarming increase in global temperatures of 1.4 to 5.8°C by 2100 if GHG concentrations in the atmosphere rise unabated, it is recognised that a major international effort will be required. In December 1997, governments participating in the United Nations Framework Convention on Climate Change (UNFCC) Treaty agreed to adopt the Kyoto Protocol [4]. The protocol represents an international treaty that stipulates actions to be taken by nations to combat global climate change. This treaty is similar to the UNFCC Treaty except that under the UNFCC, the countries listed in Annex I (APPENDIX 1) have non-binding responsibilities in reducing GHGs. On the other hand, the Kyoto Protocol sets legally binding targets and timetables for reducing emissions of GHGs by developed countries according to the amounts as listed in Annex B (Appendix II).

Under the Kyoto Protocol six greenhouse gases have been specified in Annex A (Appendix III) as shown in Table 1. Most of the countries listed in Annex I have agreed to reduce their collective emissions of GHGs by an average of 5.2% below the 1990s level in the commitment period of 2008 and 2012, while developing nations (non-Annex B) are not subject to emissions caps. The Kyoto Protocol will be enforced when at least 55% of the countries (developed countries accounted for more than 55% of CO_2 emissions) in 1990 have ratified. Until recently, the total percentage of emissions by Annex I parties is 44.2%. News on the 22nd October 2004, reported that Russia's parliament has ratified the Kyoto Protocol in a historic vote which means that the United Nation's global warming pact is now virtually guaranteed to enter into force. The United States of America and Australia especially under the present administrations are unlikely to ratify the treaty.

The release of these GHGs is mainly due to human activities and carbon dioxide is by far the most important due to its high concentration in the atmosphere. Carbon dioxide accounted for over four-fifths of the total GHGs emission from developed countries in 1995. The main source of this emission is from combustion of fuels, automobiles, farming and animal husbandry. Methane is the next important gas listed in the Protocol. It is released from rice cultivation, cattle rearing and disposal and treatment of garbage and human waste. Nitrous oxide is emitted mostly from the use of fertilisers. Levels of methane and nitrous oxide emissions in developed countries are either constant or declining.

The other GHGs are long-life industrial gases such as synthetized called as halocarbons. Most of them are already regulated under the Montreal Protocol (a treaty for the protection of the ozone layer) except for HFCs and PFCs. The use of these gases is expected to increase because they are adopted as ozone-safe replacements for chlorofluorocarbons (CFCs). However, they are found to be 'unfriendly' GHGs. Sulfur hexafluoride is used as electric insulators, heat conductors and freezing agents. Comparing sulfur hexafluoride and carbon dioxide, the former global warming potential is thought to be 23,900 times greater than the latter [5]. As shown in Table 1 all the GHGs can be measured in terms of equivalent CO_2 units by multiplying by their corresponding global warming potentials (GWP) and can be expressed as CO_2 equivalents.

Table 1: Greenhouse gases and their possible sources

Greenhouse Gases	% contribution to global warming	Global Warming Potential (GWP)	Sources
Carbon dioxide (CO_2)	50	1	Fuel combustion, Deforestation
Methane (CH_4)	20	21	Rice cultivation, Cattle rearing and disposal, Treatment of garbage and human waste
Nitrous oxide (N_2O)	10	310	Fertiliser
Hydrofluorocarbon (HFCs)	15	140-11,700	Refrigerant
Perfluorocarbon (PFCs)	trace	140-11,700	Refrigerant
Sulphur hexafluoride (SF_6)	trace	23,900	Electric insulator, heat conductor and freezing agent

KYOTO PROTOCOL MECHANISMS

The Kyoto Protocol is helping Annexure I countries to achieve reductions in their emissions in the most economical manner through three possible mechanisms:

a. **Kyoto Protocol Flexibility Mechanisms** known as **International Emissions Trading (EIT).** It is the trading of rights to emit GHGs between Annex I countries. The assigned amount of emission, known as Assigned Amount Units (AAUs), may be traded from any Annexure I country that have surplus credits to another Annexure I country that is facing problems in achieving its emission targets.

b. **Joint Implementation (JI).** It is also known as project-based mechanism. An Annexure I country can implement a project that reduces emissions or increasing removals by sequestration in the territory of another Annexure I country, where the required investment is lower compared to when the project is developed in its own country. These reductions count as Emission Reduction Units (ERUs) against its target. In this way, one country gets the credit for reducing emissions and the other country receives foreign investments, advanced technologies and finally the global GHGs emissions are reduced.

c. **Clean Development Mechanism (CDM)**. The previous two mechanisms discussed apply only when two Annexure I countries are mutually participative. Non-Annexure I countries may participate in the Kyoto Protocol through the Clean Development Mechanism (CDM). CDM is a project-based mechanism between Annexure I and non-Annexure I countries. Any Annex I country may execute a project in any non-Annex I country that reduces emissions in that country and use the resulting Certified Emissions Reductions (CERs) to help meet the former's targets. Through CDM, developing countries receives help from developed nations by means of capital and technology. Hence, the standard of living in the developing nations may eventually improve and global reduction of GHGs emissions will also be met.

ACTIVITIES ELIGIBLE UNDER KYOTO PROTOCOL

The eligible activities noted in the Protocol are carbon sequestration via forest management, afforestation, reforestation, increased efficiency in power generation, alternate and renewable power generation such as hydro, geothermal, wind and tidal energy. There have been projects based on coal bed methane recovery as well as methane recovery from landfills. Table 2 shows some examples of international CDM projects that are currently in progress.

Projects related to carbon offsets and renewable energy have been listed in the reference [6]. In addition, project listed on the Marrakesh Accords are also eligible, i.e. forest management, cropland management, grazing land management and revegetation. GHGs removed from these generate credits known as removal units (RMUs). However, any GHGs emissions from any of the listed eligible activities, must in turn be offset by greater emission cuts or removal elsewhere.

CARBON TRADING

Carbon Trading Concepts

The fundamental concept of the Kyoto Protocol mechanism stated above is about the various options of buying and selling credits for greenhouse gas emission reductions. Under the Kyoto Protocol, emission trading of GHGs is known as carbon trading. This trading enables Annex B countries to meet their emission reduction target. The countries and companies with high internal emission reduction costs would be expected to buy certificates from countries and companies with low internal emission reduction costs. This type of pollution trading is not something new in the environmental arena because the United States has already implemented trading of sulphur dioxide (SO_2) for limiting its emissions since 1995.

Table 2: International carbon sequestration projects [6] – some examples

Location	Scope
Laguna Tiger Project, Paraguay	Performed on-site audits for the assessment, monitoring and verification of carbon sequestration in 50,000 Ha of forestry land using forest rangers for ground validation studies and correlated with satellite remote sensing techniques.
Sabah, Malaysia	Performed on-site audits for verification of carbon offset and sequestration studies in pilot program of 1,000 acres using "Reduced Impact Logging" techniques at rain forest. Protocols for monitoring and verification of carbon emission reduction activities abroad were developed.
Salta Province, Argentina	Performed an assessment of carbon sequestration by sustainable forestry management and resource-integrated management. The assessment used existing and related project data, and interpolate with satellite images. Carbon sequestration inventory was assessed for the project and areas identified for improvement with recommendations for carbon sequestration benefits such as improved logging practices, conversion of pasture to forestry, lengthen rotation cycles etc.
Indonesia	Carbon emission offset.

However, carbon trading covers an unprecedented size and scale when comparing with sulphur dioxide trading. This is because the latter is restricted to localised pollutants, unlike the former where it involves global trading.

The carbon trading is done globally as the GHGs effect is not limited to the source location and its immediate surroundings, but also affects changes in global climate. Thus, having a global market will enable the world to meet its target concentration of GHGs faster, lower cost and consequently protecting the environment. Economically, having a global market will give options for some countries that are facing astronomical costs to achieve the targets set and solve their problems with the cooperation of some countries at significantly lower costs.

Basically, the carbon trading methodology is based on credits such as RMUs, AAUs, ERUs and CERs. These are the amounts of credits earned calculated as the difference between the level of emissions with the project and the level of emissions in an imagined alternative future of 'what would have happened otherwise' without the project. Once these credits are allocated or created, these credits act as fully fungible commodities where they can be bought, sold, traded or (sometimes) banked for future use.

'Carbon trading' is not limited to carbon dioxide only as is reflected in its name. It includes the other five GHGs listed in the Kyoto Protocol. For ease of measurement, each of the six listed GHGs in the Kyoto Protocol has an internationally agreed 'Global Warming Potential' (GWP) assigned to it as given in Table 1. GWP is a measurement of the impact of that particular gas in retaining heat through the addition of its concentration in the atmosphere. For example, sulphur hexafluoride can heat the earth 23,900 times more than carbon dioxide. These GWP factors are used to convert each of the five gases that are not carbon dioxide into tonnes of carbon dioxide equivalents (CO_2e), which is the standard unit for trading.

Carbon Trading Market Price

Today, tens of millions of tonnes of CO_2e reductions have been transacted. GHG emissions reduction is a reduction in actual emissions, avoidance of potential emissions or the creation of emissions offsets. Prices

Table 3: Emission trading-examples of transactions [8]

Participants	Emission Type	Transaction	Cost($ per unit)
British Petroleum (1998-)	CO_2	49,000 metric tons of CO_2 emission. Refineries, pipeline and chemical plants in US, UK, Spain and Australia	USD$17-22 per metric ton of CO_2
Consorcio Norouego and the Government of Norway (1996)	CO_2	200,000 creditable, tradeable offsets (CTOs) from Costa Rica	USD$10 per metric ton of carbon
Greenhouse gas emission reduction trading (GERT) pilot project in Canada	CH_4	Various projects in compost management	USD$3.8-USD$4.33 per tonnes of CO_2- equivalent
US EPA acid rain SO_2 trading program (1994-)	SO_2	Chicago Board of Trade	USD$69-USD$212 per ton

per one tonne CO2e have ranged from USD0.11 to USD20.00 [7]. Table 3 shows some examples of gas emission trading, transaction and cost.

For example, in 1998, BP launched a pilot program of internal emissions trading across selected diverse business units worldwide. The plan is to achieve the 10% reduction by 2010. The first trade allowances were at USD17.00 per metric tonne of CO2e and have now increased to USD22.00. Another example is of methane took place in Canada – Greenhouse Gas Emissions Reduction Trading (GERT) pilot project. Methane was traded between USD3.80 to USD4.33 per tonne of CO2e. Under United States Environmental Protection Agency (EPA) Sulfur Dioxide Trading Program, the price per tonne of sulfur dioxide fluctuated between USD69.00 (March 1996) to USD212.00 per tonne (May 1999). Another example is emission trading of NO_x, the cost was listed at USD1,000.00 to USD4,500.00 per tonne. This took place under the Ozone Transport Region NO_x Allowance Market [8].

When comparing between these emissions trading, the carbon trading prices are not as high compared to other pollutants emission trading. This factor will encourage the enforcement of the Kyoto Protocol. Once it is in force, the price of carbon is projected to increase to more than USD30.00 per tonne and it may reach USD300.00 if the market is well regulated and restricted [8].

Other factors that influenced the price of carbon are the prices of coal and gas, GDP growth and even weather conditions. The price must be set right a price that is too high will encourage companies to undertake emissions reduction within their own operations. If the price is too low, companies will take the easy way out by purchasing allowances from the market. This eventually will lead to the concept of "the right to pollute" thereby defeating the Kyoto Protocol's main objective.

Market Size

A study by Cantor Fitzgerald and Price-Waterhouse-Coopers in CO2e.com [9], forecasts that the size for future GHG market ranges from USD10 billion to USD3 trillion by 2010. They also estimate that as countries and regions make considerations for emission control legislation and as green energy markets develop, the GHG market may evolve to include or to link other instruments including renewable energy certificates, acid rain markets and, national and regional GHG markets.

In the European Union (EU), it is estimated that by the year 2010, the EU scheme will trade as much as USD1 billion in allowances each year [10]. Eventhough the US has not ratified the Kyoto Protocol, trading of GHGs will be almost certain in Europe and probably in Canada and Japan [10]. The fact that the EU has passed laws irregardless of whether the Kyoto Protocol will be in force or not, shows that they are really committed towards preservation of the environment. The EU market for carbon trading is scheduled to open in January 2005. This makes the EU a sure market for carbon trading.

Implementation of the Kyoto Protocol

In order to implement the carbon-trading concept effectively, it is mandatory for international regulatory bodies to enforce the rules pertaining to carbon trading. This body must also monitor the emissions trading activities and keep track of emissions reduction credit. Specific guidelines are also required for defining project details for eligibility under the Kyoto Protocol mechanism.

MALAYSIA'S PARTICIPATION IN THE KYOTO PROTOCOL

Malaysia has ratified the UNFCC on the 13th of July 1994 and also ratified the Kyoto Protocol on the 4th of September 2002 [11]. This country is listed under Non-Annex I countries of the UNFCC. There are only two possible ways for Malaysia to take part under the protocol, through carbon sequestration via forest management and clean technology projects under Clean Development Mechanism (CDM).

Clean Development Mechanism

The Kyoto Protocol has two objectives, one has been mentioned before which is reducing GHGs emissions. The other objective is to contribute towards sustainable development, including poverty alleviation. CDM is one of the mechanisms in achieving both aims. The Kyoto Protocol only legally binds Annex B countries for compliance. However through CDM, a window is created to facilitate voluntary actions from non-Annex I countries to participate in the GHGs emission reduction on a sustainable manner.

CDM is the interaction of between any Annex I countries and any Non-Annex I countries as stated earlier. This mechanism gives an option for the former to achieve its reduction targets presumably at a lower cost in the latter regions. This is done by providing funds in emissions reduction projects in Non-Annex I countries. Currently the Non-Annex I countries per capita emissions is way below those of Annex I. However, it was found that the aggregate emissions of Non-Annex I countries are growing much faster and may overtake Annex I countries beyond 2020. Thus, through CDM, the projects could help curb the fastest growing component of global emissions without compromising the legitimate social and developmental needs in the host countries.

The Kyoto Protocol has also set some elements in operating the mechanism. One of it is that the project activity must not in anyway impede the host countries' national development priorities and needs. According to Article 12.5 of the Kyoto Protocol, in order for the project to be eligible:

- Voluntary participation are to be approved by each party involved.
- Real, measurable and long-term benefits related to the mitigation of climate change have to be stated.
- Reductions in emissions that are additional to any that would occur in the absence of certified project activity should be declared.

Another feature of CDM is the monitoring and certification requirements. It has to be more stringent because the host country does not have a binding commitment for emissions reduction and therefore there are possibilities of cheating, resulting in inflation. Provision for banking is allowable under CDM. This means that any reduction made before 2008 can be "banked" for use during the first commitment period of 2008 – 2012. This provision is an incentive for taking early action on mitigation [12]. A CDM Registry and a

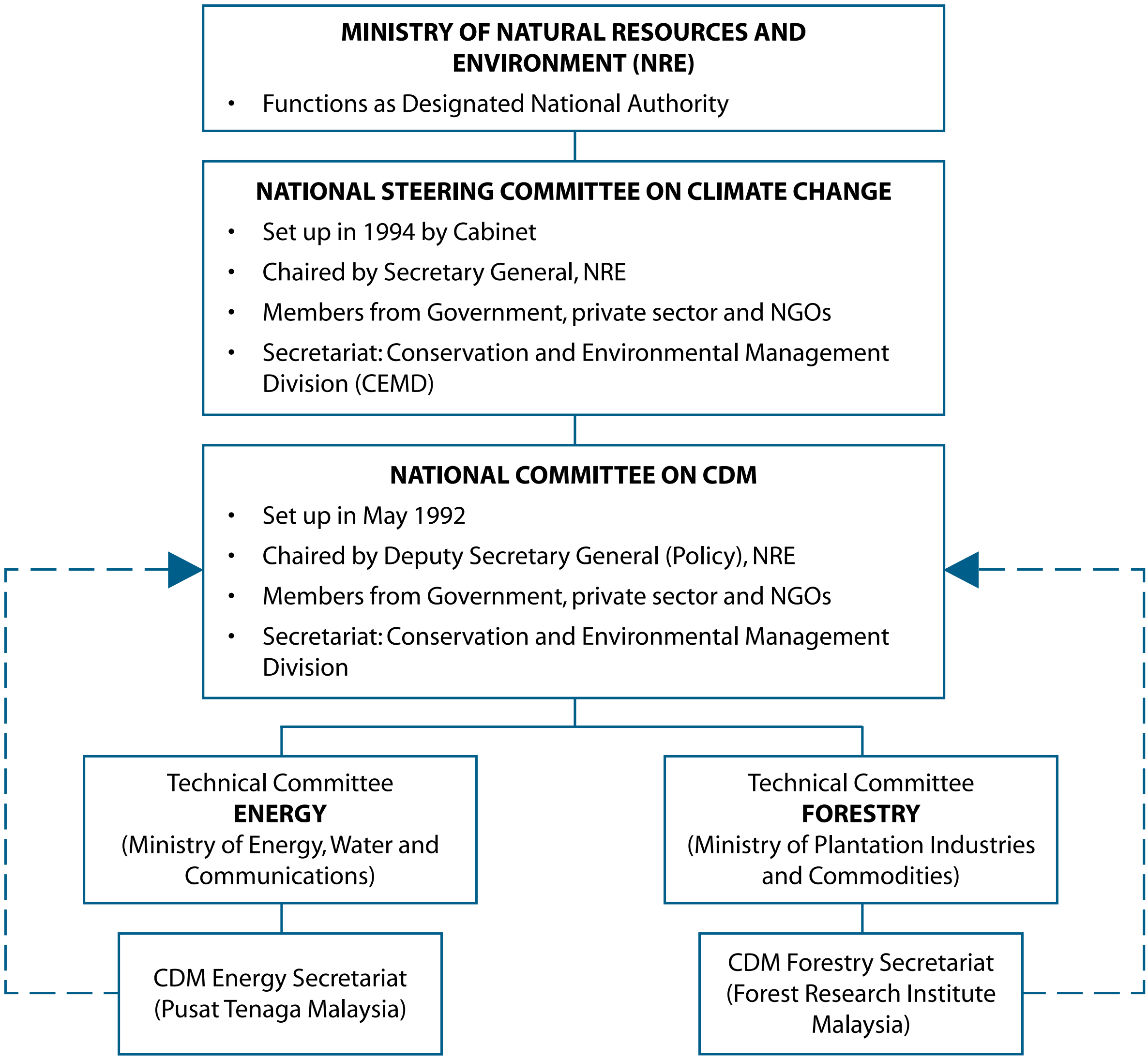

Figure 1: Malaysia's CDM Institutional Framework

CDM Executive Board has been setup at an international level to approve CDM proposals made by different national authorities.

Currently, CDM priority projects in Malaysia are renewable energy projects, energy efficiency projects and forestry projects. The Ministry of Natural Resources and Environment (NRE) is the custodian of CDM projects in the country. Pusat Tenaga Malaysia (PTM) and Forest Research Institute Malaysia (FRIM) are the secretariats for the CDM project under the energy and forestry sectors, respectively. The detailed framework is given in Figure 1 [11]. Through CDM projects, they provide opportunities for developing countries like Malaysia to further develop economically and socially in a sustainable way.

Clean Energy Technologies

Clean energy technologies use renewable energies such as solar, wind, biomass, small hydropower, geothermal and others. In addition, projects that use energy efficiently also fall under clean energy technologies. Other associated types of projects are cleaner technology and green technology. The main objective of these projects is to reduce the dependence on fossil fuels as a source of energy. Consequently, reducing GHGs emissions by using less fossil fuels thereby emiting less carbon dioxide and using renewable energy will encourage sustainable development. Recently a project for coal bed methane recovery has been approved in China.

Globally these types of projects are already ongoing. Estimated total market for CDM, excluding participation from the USA, is USD10 billion up until 2010 [13]. The Dutch government, for instance, has recently committed to invest about USD600 million through a series of GHGs mitigation projects and initiatives. Among these is the Dutch carbon-purchasing programme, EruPT – Emissions Reductions Unit Procurement Tender, a scheme that will focus on clean energy projects in developing countries under CDM [14].

It has been reported [11] that Malaysia has five small-scale energy projects proposed and as of September 2003, three projects have received conditional approval from the Designated National Authority (DNA) as shown in Table 4.

The alternative of using biomass and methane for electricity production rather than depending on oil is very encouraging and promising especially with the current trend of escalating and unstable world crude oil price. By this, carbon trade can be earned and the electricity rate can be maintained as low as possible unaffected byprice increases in crude oil products especially diesel and petrol.

Carbon Sequestration Via Forest Management

Sixty-two percent (62%) of Malaysia's land is covered by natural forest and together with oil palm and rubber plantations the total covered area comes to 74% [11]. These values show that Malaysia has a vast potential for carbon sequestration via forest management projects. The definition of sequestration in this context is a natural biogenic process where atmospheric carbon dioxide is removed and stored by trees or other plants, which are referred to as "carbon sinks".

There are significant potentials in managing carbon dioxide gas levels in the atmosphere through forest management. The IPCC Second Assessment Report found that for the period of 1995 to 2050, slowing deforestation, promoting natural forest regeneration and encouraging global reforestation could offset 220 – 320 billion tonnes of carbon dioxide (12 –15%) of fossil emissions. This could be done by various methods namely preservation of forest thus reducing deforestation, proper and excellent forest management to enhance the existing carbon sinks and planting new trees on degraded forest sites thus creating new carbon sinks. Table 5 shows a better picture of utilising good forest management to reduce GHG concentrations in the atmosphere. It was found that the main causes of deforestation are forest fires, conversion to other land uses (usually agriculture) and logging. The government can play two roles in implementation of all actions. One is as an initiator such as to improve land management and develop alternative income opportunities. Another role is as a regulator such as improving forest fire management; planting trees and decreasing waste in log production.

Table 4: CDM projects under energy sector in Malaysia [11]

Type of Project	Grid-connected CHP plant	Off-grid CHP plant	Grid-connected biomass power plant	Grid-connected biomass power plant	Grid-connected gas power plant and methane recovery
Location	East Malaysia	East Malaysia	West Malaysia	West Malaysia	West Malaysia
Fuel	Empty fruit bunches	Empty fruit bunches	Empty fruit bunches and shell	Empty fruit bunches and shell	Methane gas
Project Size	Small scale (14 MW_e)	Small scale (7 MW_e)	Small scale (6 MW_e)	Small scale (9 MW_e)	Small scale (2 MW_e)
Status	Approval from DNA	Approval from DNA	Approval from DNA	Waiting for approval	Waiting for approval

Table 5: Actions required for reducing greenhouse gas emissions from forests

Objective	Sub-objective	Solution	Action
Reduce greenhouse gas emissions from forests	Reduce deforestation (decrease depletion of carbon stocks)	Reduce forest fires	Improve forest fire management
		Reduce conversion to other land uses	Develop alternative income opportunities
		Reduce logging[a]	Decrease net log production volume[b]
	Increase reforestation (carbon sequestration)	Accelerate natural forest regeneration	Decrease waste in log production (RIL)
		Accelerate forest regeneration artificially	Improve land management
			Plant trees

[a] Includes non-commercial collection of wood for own consumption
[b] Officially registered commercial logging volume net of waste

In Malaysia, major problems faced by the government are forest clearing for agriculture found to be quite rampant in the Cameron Highlands and housing development encroaching the Sg. Buloh Forest Reserve area. Another problem is due to unregistered log production. The government needs to develop mechanisms to overcome the loopholes evident by these illegal activities. Although this is major task for the government to undertake, the formation of better mechanisms will bring many benefits such as generating income through carbon trading, and creating new channels of funds towards beneficial projects for its citizens. Other secondary benefits are the preservation of Malaysia's vast biodiversity. Through the planting of trees, degraded land could be revitalised and restored. Besides environmental benefits, social benefits could also be achieved by employing the indigenous people to help restore the forest.

Malaysia is participating in an international carbon sequestration project in Sabah using a technique called Reduced-Impact Logging (RIL) which is an environmentally non-destructive logging technique. UtiliTree Carbon Company, a non-profit corporation established in 1995, is the main of sponsor this project. Other collaborators are New England Power Company, Rakyat Berjaya Sabah Sdn. Bhd. of Malaysia, Forest Research Institute of Malaysia, Sabah Forestry Department, Center of International Forestry Research Bogor, Indonesia and Rainforest Alliance. The RIL project lies on 2,500 acres of land in Sabah and is anticipated to reduce CO_2 emissions by 147,000 tonnes over its 40-year life [11].

RESEARCH AND DEVELOPMENT OPPORTUNITIES

There are vast opportunities for research and development due to the objectives set by the Kyoto Protocol. Article 2 of the protocol [4] encourages research on new and renewable forms of energy, of carbon dioxide sequestration technologies and innovative environmentally sound technologies. Some detailed interpretations of this clause are required to clearly define the eligibility of research and development projects for carbon trading. It is anticipated that over the next decade, energy efficiency initiatives are required across almost all sectors of the economy. Complementing that is the increased use of renewable energy in this country. R&D will focus on generating non-hydrocarbon based electricity like hydro and wind, reducing the energy use for commercial and residential facilities and equipment i.e. high efficiency equipment and appliances and improving urban transit and vehicles fuel efficiency.

Severals areas may be explored under the energy sector as follows:

Renewable energy

Focus on the usage of natural sources for the production of electricity using non-hydrocarbons such as hydro and wind. The electricity can be on-grid or off-grid [11]. The natural sources of renewable energy can be from:

Hydropower
Malaysia has sufficient water sources to be used for this purpose. Via hydropower, Malaysia has the potential to play a significant role in stabilising the emission of GHGs, particularly carbon dioxide. It can emerge as both, small or large scale. However, large-size hydro is normally associated with destruction of local environment, rivers, lakes, habitats and human settlements.

Biomass
Biomass in the form of wood, wood waste from manufacturing activities, agriculture products and residues, or municipal wastes can be used to produce energy (bioenergy). The major potential is in ethanol as a fuel, electricity generation and process generation. The use of biomass will reduce carbon dioxide emission/production ratio. The system is efficient which improves the cost-effectiveness of the facility. Energy produced may be sold to the grid for economic gains.

Solar
Since Malaysia is a tropical country, the use of solar energy for residential, commercial and industrial building applications has a very bright future. Solar energy can be used to supply warm water instead of using electricity in residents.

Tide energy
Almost the whole of West and East Malaysia are surrounded by beaches and subject to the open sea with high tides especially coasts facing the South China Sea. This may be explored for electricity production.

Wind energy
Some areas in Malaysia, especially the coastal regions have high wind velocities, and wind farms could be set up to utilise this energy.

Landfill methane generation
The use of land fills for generation of methane has been practiced in Europe and the United States. Potentially this is a method which could solve the twin problems of solid waste treatment as well as greenhouse gas generation.

Municipal waste bio-generation
Anaerobic treatment of municipal wastes has become an important energy source in countries such as France. The methods employed, as opposed to the conventional aerobic treatment practices in Malaysia, produce methane in place of carbon dioxide. This is a important area for further research by chemical and environment engineers.

Other methods
Methods such as coal bed methane generation and geothermal energy generation are not of importance in the Malaysian scenario.

Energy efficiency

Energy efficiency focuses on the usage of less amounts of fuel to generate more power. Research and development could focus on the design of highly efficient engines and alternative fuels [15], such as:

- Alternative fuel technologies for vehicles – electric & hybrid vehicles, fuel cells
- Fuel efficiency – 25% reduction in fuel consumption by methods such as combined cycle power generation
- Energy conservation or efficiency-intelligent buildings, upstream oil and gas processing, chemical processing with heat integration

Besides the typical method carbon dioxide sequestration via forest management, the following projects might bring CDM benefits:

- Enriched carbon dioxide farming – Photosynthesis rate is enhanced by the present of high carbon dioxide concentrations of up to 1,000 ppm higher than the ambient 360 ppm. Production yield increases as carbon dioxide concentration increases and the amount varies depending on the type of crops used.
- Converting carbon dioxide to other compounds and fuels like methanol and dimethylether.
- Develop artificial photosynthesis process, converting carbon dioxide into glucose with the presence of sunlight and water.

These technologies are new with a lot of scope for development. Perhaps through CDM any developed nation could provide funding for projects in cleaner technology. One of the criteria in the mandate of Malaysia's CDM is that a project developer must provide technology transfer benefits and/or improvement in technology. Researchers could utilise this as an opportunity to further improve the technology provided.

ROLE OF CHEMICAL ENGINEERING

The chemical engineering profession plays an important role in utilising the opportunities presented by the Kyoto Protocol. Enhanced research in areas such as conversion of biomass, increased energy efficiency in processes, heat integration and solar energy systems are within the purview of chemical engineers. Areas of pollution research in solid waste management and landfill design need further work. Conversion of biomass and municipal waste to methane through more efficient biological processes need to be undertaken. For example, intense research work is already underway in Europe for developing anaerobic processes for biological treatment which will produce methane instead of carbon dioxide.

An attractive proposition is the conversion of carbon dioxide into other useful products. Potentially carbon dioxide can be converted to methanol by direct hydrogenation or to diethyl ether. Even more fundamentally by dry reforming natural gas with carbon dioxide, synthesised gas could be produced which can then be converted to almost any petrochemical. Such projects will effectively change the paradigm of looking at carbon dioxide as a pollutant to a useful raw material. For most of these processes viable catalysts have to be discovered. The economics of the process must be favourable. Since there are currently no CDM projects in this category, this could be a research opportunity for Malaysia because of its vast natural gas resources.

CONCLUSION

Global warming is a modern problem involving the entire world. It is complicated because it is tangled up with difficult issues such as poverty, economic development and population growth. Dealing with it will not be easy and ignoring it will lead to disaster.

CDM projects provide opportunities for developing countries like Malaysia to help address the problem and still be able to further develop economically and socially in a sustainable way. Chemical engineers play a very important role in this process by developing new technologies in areas such as renewable energy, solid waste management and conversion of carbon dioxide to useful chemicals.

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APPENDIX 1

Table A1: ANNEX I countries, signatories in the United Nations Framework Convention on Climate Change (UNFCC) in the Rio de Janeiro declaration in 1992

Country
Australia
Austria
Belarus*
Belgium
Bulgaria*
Canada
Czechoslovakia*
Denmark
European Economic Community
Estonia*
Finland
France
Germany
Greece
Hungary*
Iceland
Ireland
Italy
Japan
Latvia*
Lithuania*
Luxembourg
Netherlands
New Zealand
Norway
Poland*
Portugal
Romania*
Russian Federation*
Spain
Sweden
Switzerland
Turkey
Ukraine*
United Kingdom of Great Britain and Northern Ireland
United States of America

* Countries that are undergoing the process of transition to a market economy.

APPENDIX II

Table A2: ANNEX B countries listed in the Kyoto Protocol in 1997

Party	**Quantified emission limitation or reduction commitment** *(Percent of base year or period)*
Australia	108
Austria	92
Belgium	92
Bulgaria*	92
Canada	94
Czech Republic*	95
Denmark	92
Estonia*	92
European Community	92
Finland	92
France	92
Germany	92
Greece	92
Hungary*	94
Iceland	110
Ireland	92
Italy	92
Japan	94
Latvia*	92
Liechtenstein	92
Lithuania*	92
Luxembourg	92
Monaco	92
Netherlands	92
New Zealand	100
Norway	101
Poland*	94
Portugal	92
Romania*	92
Russian Federation*	100
Slovakia*	92
Slovenia*	92
Spain	92
Sweden	92
Switzerland	92
Ukraine*	100
United Kingdom of Great Britain and Northern Ireland	92
United States of America	93

* Countries that are undergoing the process of transition to a market economy.

APPENDIX III

ANNEX A

Greenhouse gases
Carbon dioxide (CO_2)
Methane (CH_4)
Nitrous oxide (N_2O)
Hydrofluorocarbon (HFCs)
Perfluorocarbons (PFCs)
Sulphur hexafluoride (SF_6)

Sector/source categories
Energy
- Fuel combustion
  - Energy industries
  - Manufacturing industries and construction
  - Transport
  - Other sectors
  - Other
- Fugitives emission from fuels
  - Solid fuels
  - Oil and natural gas
  - Other

Industrial Process
- Mineral products
- Chemical industry
- Metal production
- Other production
- Production of halocarbons and sulphur hexafluoride
- Consumption of halocarbons and sulphur hexafluoride
- Other

Solvent and Other Product Use

Agriculture
- Enteric fermentation
- Manure management
- Rice cultivation
- Agricultural soils
- Prescribed burning of savannas
- Field burning of agricultural residues
- Other

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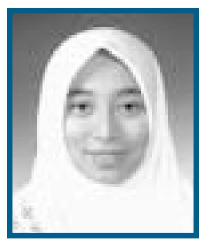
He has deep research interests in the area of natural gas purification using membrane process. Currently, he is leading a research project under the Separation & Utilisation of Carbon Dioxide research group. In this project, the removal of the impurities from natural gas, in particular, carbon dioxide, is being the key focus of the study. In addition, he has a research interest in environmental issues particularly wastewater treatment and carbon trading.



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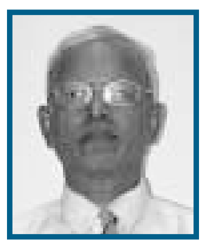

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CARBON DIOXIDE SEPARATION: TECHNOLOGICAL ISSUES AND SOLUTION

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ABSTRACT

Currently there has been widespread global concerns on the increase of greenhouse gases particularly carbon dioxide (CO_2) in the atmosphere and its consequent global warming. An international effort has been carried out to reduce CO_2 emissions to the environment through the Kyoto Protocol, which legally binds the commitment of developed countries to reduce their emissions level of six greenhouse gases by at least 5% below their 1990 levels by the year 2012. One of the major obstacles and challenges to achieve this target is to find cost effective and efficient technologies for the separation of a wide range of CO_2 concentrations suitable for industrial applications. In this paper, technical issues related to the separation of CO_2, available technologies for CO_2 separation and possible solutions for the separation of a wide range of CO_2 concentrations of industrial interest are discussed.

Keywords: *Carbon dioxide, Carbon dioxide separation, Carbon dioxide technology, Carbon dioxide capture*

INTRODUCTION

Carbon dioxide is the main greenhouse gas other than methane and nitrous oxide that contribute to global warming and climate change. These greenhouse gases in the atmosphere block infrared radiation from escaping directly from the earth's surface to the atmosphere. This results in warmer conditions on earth than it would otherwise be.

Climate change has never been a concern until anthropogenic activities seriously interfered with climate patterns all over the world. In the past 40 years, global surface temperatures has increased by about 0.2 – 0.3°C and this change is acceptable on top of the inevitability natural greenhouse effect which keeps the planet warmer than it would otherwise be. However, in the 20th century, average global temperatures have risen by about 0.6°C and it has been predicted that it will further rise by about 1.4 to 5.8°C by the year 2100. This change in temperature is be much larger than any climate change experienced over the last 10,000 years and it is obviously attributable to human activities.

In general, the faster the climate changes, the greater will be the risk of damage to the environment. As sea levels rise, there will be flooding of low-lying areas and other damages. Other effects could include an increase in global precipitation and changes in the severity and frequency of extreme events. Climatic zones could shift poleward and vertically disrupting forests, deserts, rangelands and other unmanaged ecosystems. As a result, many of these will decline or fragment and individual species could become extinct.

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Human society will face new risks and pressures. Food security is unlikely to be threatened at the global level but some regions are likely to experience food shortages and hunger. Water resources will be affected by changing precipitation and evaporation patterns around the world. Physical infrastructure will be damaged particularly by rise in sea levels and by extreme weather events. Economic activities, human settlements and human health will experience many direct and indirect effects. The poor and disadvantaged are the most vulnerable to the negative consequences of climate change.

MAJOR CONTRIBUTORS OF CO_2 EMISSION

Natural sources of carbon dioxide such as respiration from humans, animals and plants do not contribute to global warning as it is naturally consumed by natural processes such as photosynthesis or dissolving in the oceans. The major carbon dioxide contributors are due to human-related activities such as transportation, combustion of fossil fuels from power plants, cement production, deforestation and natural gas production.

The greatest contributor to greenhouse gases emissions is from processes that generate energy for the country, primarily from fuel combustion in the transport sector as shown in Table 1. In terms of CO_2 emissions, it makes up 58.5% of the total greenhouse gases emissions in that year. Treatment of waste contributes 0.22% of the total emissions. Changes due to land usage such as deforestation emit about 5.3% whilst industrial processes like cement production contribute 3.4% of the total emissions.

Among Asean countries, Malaysia is the third highest carbon dioxide emitter after Brunei and Singapore. In 1994, Malaysia emitted 144 million tonnes of greenhouse gases, which is being measured in CO_2 equivalents. Of these emissions, carbon dioxide makes up 67.5% and the rest are methane and nitrous oxide. For comparison, the United States emitted about

Table 1: Summary of National Greenhouse Gas Emissions and Removal in 1994

Sectors		CO_2 Equivalent (Gg)
Energy	CO_2	84,415
	CH_4	13,335
	N_2O	102
Subtotal		97,852
Industrial processes	CO_2	4,973
Subtotal		4,973
Agriculture	CH_4	6,909
	N_2O	16
Subtotal		6,925
Land use change and deforestation	CO_2 (emission)	7,636
	CO_2 (sink)	-68,717
	CH_4	3
	N_2O	0.3
Subtotal		7,639
Waste	CO_2	318
	CH_4	26,607
Subtotal		26,925
Total (emission only)		144,314
Net total (after subtracting sink)		75,597

(Source: Malaysia Initial National Communication, 2000)

42 times this amount, Japan close to 9 times and Thailand 1.5 times.

In terms of world statistics, Russia is the major contributor of greenhouse gases whereas United States is the country with the most increasing amount of greenhouse gases emissions. Russia accounts for 17.4% of greenhouse gas emissions at 1990 levels while United States, a profligate consumer of fossil fuels, is the biggest carbon dioxide emitters in the world. In the year 2000, Korea emitted about 134,459 tonnes of carbon as reported by the Korea Institute of Energy Research (Byoung-moo Min, 2003). Indeed, the figure keeps increasing (comparison of carbon emissions in the previous years).

In order to reduce the amount of greenhouse gases emitted to the atmosphere, especially carbon dioxide, an internationally recognized agreement known as the Kyoto Protocol was established in 1997. The Kyoto Protocol laid down legally binding commitments of developed countries to reduce their collective six greenhouse gases (CO_2, CH_4, N_2O, HFC, PFC and SF_6) by at least 5% below their 1990 levels in the period 2008–2012. The protocol has also set up an emissions trading regime and a "clean development fund" to facilitate countries to fulfill their commitments. Although the Kyoto Protocol has yet to come into force, many countries and companies, especially those in Europe, Japan and South Korea, are already adhering to it. The Protocol has also led to growing interests in new and advanced technologies to control carbon dioxide concentration levels released to the atmosphere. It is widely accepted that the current technologies are unable to fully meet the agreed targets due to the many problems faced by industries in to removing, storing and utilizing the carbon dioxide at source on the scale set out in the Kyoto Protocol, whilst meeting the cost, safety and environment requirements.

CO_2 SEPARATION TECHNOLOGIES

To ensure the success of efforts in carbon dioxide reduction and to meet the Kyoto Protocol requirements, there is a need to establish various technologies related to carbon dioxide separation, utilization and storage. This paper will discuss carbon dioxide separation technologies in detail. The goal of the carbon dioxide separation technologies is to separate carbon dioxide at source in a suitable form for transportation to sequestration or to a utilization system.

The separation methods require large point source of carbon dioxide for the system to be feasible and economically viable. Thermal power generation and natural gas processing are the main sources that produce large concentrations of carbon dioxide, and hence, more amenable to technical solutions. In natural gas processing, carbon dioxide content must be removed to meet the pipeline quality gas requirement. Without the removal of its carbon dioxide content natural gas cannot be further processed, liquefied, transported or commercially sold. Other significant sources of carbon dioxide emissions such as from automobiles which are collectively large, require better and more challenging separation methods such as carbon dioxide reduction catalysts or alternatively, to use cleaner fuels such as fuel cells and solar energy.

Many of the technologies suitable for separation of carbon dioxide have been used in other applications such as in acid-gas removal system in natural gas processing. However, these technologies have limitations when applied to a wide range of carbon dioxide concentration of industrial interest. Therefore, further research and development is needed to further improve carbon dioxide separation technologies to meet industrial requirements and specifications. The possible options for the separation of carbon dioxide are absorption, membrane, adsorption, low temperature distillation, and hybrid system. The summary of carbon dioxide separation and recovery methods and their features is given in Table 2.

Absorption

Absorption is a well-known process adopted world-wide for acid gas removal in natural gas processing.

Table 2: Features of carbon dioxide separation and recovery methods (Koichi Sasaki, 2004)

Separation & recovery method		Features
Adsorption		Carbon dioxide is brought into contact with activated charcoal or some other adsorbent, and physico-chemically adsorbed by its micropores. The carbon dioxide recovery rate and purity are reported between 90 and 99%, respectively.
Absorption	Physical absorption	The chemical reaction of a carbon dioxide absorbent is applied to separate carbon dioxide. A large amount of energy (steam) is needed to extract the absorbed carbon dioxide. The method yields a carbon dioxide recovery rate of 90% and a purity of 99.9%.
	Chemical absorption	An absorbent is utilized to physically absorb the carbon dioxide, which is then recovered through pressure reduction (heating). The recovery rates and purity are on about the same level or slightly below those of chemical absorption (by the amine method).
Membrane separation	Polymer membrane	Carbon dioxide is separated by means of the difference between gas speeds of transmission through the polymer membrane.
	Liquid membrane	A membrane holding a carrier substance that selectively transmits carbon dioxide separates carbon dioxide from main gas stream. At present, this method is at the stage of basic research.
	Inorganic membrane	Separation is affected by surface diffusion flow arising in transmission through a porous material.
Oxygen combustion		Fossil fuels are combusted in oxygen to raise the carbon dioxide concentration of exhaust gas to nearly 100%. Testing has confirmed that this method can obtain exhaust gas with carbon dioxide concentrations of 94 or 95%.
Sublimation		carbon dioxide in gas is sublimated and recovered in the form of dry ice.
Cryogenic separation		A mixture that is a gas at normal temperature is cooled to a low temperature and separated into its constituent fractions by partial liquefaction for distillation or partial condensation.

The chemical absorption employs amine or carbonate solvents to react with carbon dioxide and requires a large amount of energy in the form of steam to extract the absorbed carbon dioxide. Some of the chemical solvents used are mono-ethanolamine (MEA), di-ethanolamine (DEA), methyl di-ethanolamine (MDEA) and hot potassium carbonate. Chemical absorption is preferred for low to moderate carbon dioxide concentrations. Depending on the carbon dioxide concentration, the partial pressure of carbon dioxide vary from 3.5 to 21.0 kPa (US Dept. of Energy, 1999). At such pressures, alkanolamines are the best solvents for CO_2 recovery. However, the usage of these solvents will cause high energy penalties for regeneration using steam-stripping. Impurities present in the carbon dioxide source such as SO_x, NO_x, hydrocarbons, particulates, etc. reduce the absorption capacity of amines a well as create operational problems such as corrosion. Pretreatment and/or the use of chemical inhibitors may be required to separate the impurities.

On the other hand, physical absorption utilizes temperature or pressure to absorb carbon dioxide and a regeneration system is needed to support process system recovery. A common physical solvent for carbon dioxide removal is polyethylene glycol. Both chemical and physical absorption yield as much as 90% recovery rate and near to total purity of CO_2(Yong et al., 2004). Billerbeck et al. (1999) reported that high contact efficiency is achieved using a gas driven ejector for carbon dioxide and oxygen absorption.

Absorption is a proven technology for removal of hydrogen sulphide and carbon dioxide but requires proper maintenance to ensure smooth operation of the equipment. If proper maintenance is not conducted, several problems could result such as formation of heat stable salts, forming, corrosion and loss of solvent. Application to the flue gas may increase the degradation of the absorbents due to acid gas and oxygen contained in the flue gas. Research and development to improve the absorbent for better absorption capability, anti-degradation, corrosion resistance, and minimum energy consumption during regeneration are at the highest priority.

Adsorption

Adsorption is one of the common methods in carbon dioxide separation technology. The continuous cyclic adsorption-desorption process for carbon dioxide separation are possible using Pressure Swing Adsorption (PSA). Bouchard (2001) reported that PSA is able to efficiently separate carbon dioxide, but its applicability is limited to low carbon concentrations. Burchell et al., (1997) claimed that Electric Swing Adsorption (ESA), using low voltage electrical current passing through carbon-based materials, is able to enhance carbon dioxide adsorption and desorption processes. The adsorption process is better for small scale operations and high purity production.

There have been number of commercial adsorbents developed over the past years and each one is distinctly characterized by different size and distribution of micropores. In spite of this, more enhanced properties of adsorbents are being discovered and at a level of permitting practical utilizations. The most commonly used adsorbents for carbon dioxide removal are zeolite, activated carbon and molecular sieve carbon. Chue et al. (1995) indicated that zeolite 13X shows better performance than activated carbon. A high purity of carbon dioxide (up to 99%) could be produced by zeolite 13X. Improved and better adsorbency for separation of carbon dioxide from natural gas was also developed based on carbon fiber composite (Kimber et al., 2003).

Research and development is needed to produce better adsorbents for practical separation of carbon dioxide for a wide range concentrations with industrial applications. The adsorbents must be tested in the dynamic adsorption bed, using PSA, TSA, ESA or a combination, to identify the best system for carbon dioxide separation.

Membrane

Membrane separation technology promises a higher purity of separation and recovery. It would be in the form of polymer, liquid and inorganic membrane. Each of these types of membrane separates carbon dioxide by different factors but achieves a similarly high degree of separation. The separation produces permeates which consist of high carbon dioxide content and a retentate stream that is high in product gases. The use of organic membranes for the separation of carbon dioxide from natural gas resulted in high natural gas losses to the waste stream, of the order of 10% (Meyer and Gamez, 1995). The recovery of the desired product and carbon dioxide content can be improved by having multi-stage membrane separation units with recycle streams. The use of an electric potential across the membrane minimizes natural gas losses and improves system efficiency (Xiao and Li, 1997). Gas pre-treatment prior to the membrane separation is important to minimize maintenance and to extend the life span of the membrane. Membrane technology is most suited for bulk separation of high carbon dioxide concentrations. It requires minimum maintenance and could be designed in a compact modular form to optimize floor space. However, loss of product gas is high and membrane life is short, typically 2.5–3 years (Yong et al., 2004).

The cost of membrane technology is considered high in terms of operations and maintenance and hence preferably suited to for large-scale industries. It also requires high-pressure operations and backpressure is among the critical parameters that should be taken care of for the benefit of safety and operations. Aging problems are anticipated depending on the material of the membrane. Therefore further research is needed to develop improved materials for the membrane.

Low Temperature Distillation

Low-temperature distillation is commercially used for the liquefaction and purification of carbon dioxide from highly pure sources (typically > 90% CO_2) (US Dept. of Energy, 1999). In this process, a low-boiling-temperature liquid is purified via evaporation and subsequent condensation for direct production of liquid carbon dioxide that can be stored or sequestrated at high pressure. Other components that have freezing points above normal operating temperatures must be removed before the gas stream is cooled to avoid freezing and blockage of the process equipment. The application of low-temperature distillation is confined to feed sources at high pressure and high carbon dioxide concentrations.

Hybrid Separation System

Hybrid separation is another impending technology that offers a good solution when dealing with a wider range of carbon dioxidecarbon dioxide concentration. A hybrid system is obtained by combining two or more separation technologies in sequence such as membrane/adsorption, membrane/absorption or adsorption/absorption. Estevez and Mota (2002) demonstrated that the hybrid membrane-PSA system increases the efficiency of carbon dioxide removal. Nersi (2003) has recommended hybrid absorption-membrane systems compared to single-technology systems for carbon dioxide separation from natural gas as they give smaller hydrocarbon losses, have greater capacity to separate to ppm levels, have lower energy consumption and are not vulnerable to operating problems such as amine foaming. Such combinations could bring promising outcomes.

New Separation Technology – Twister Technology

A new technique for supersonic gas separation developed by Twister BV, with Shell Technology Investment Partnership, is available for gas dehydration, hydrocarbon dewpoint separation, and C_{5+} recovery (Yong et al, 2004). This separation technique involves expansion of gas to supersonic velocities that result in nucleation and condensation of water and hydrocarbon droplets at low temperature and pressure. A high swirl is created and the droplets are centrifuged onto the walls, thus separating the liquid droplets and dry gas. The Twister unit is light, compact, simple to operate and environmental friendly. However, gas pre-treatment is required to avoid erosion of particles at high velocities.

A WAY FORWARD IN CO_2 SEPARATION TECHNOLOGIES

There are numerous options for the separation of carbon dioxide as discussed above, and some of them are commercially available. However, there is no single technology that has been applied at the scale required as part of a carbon dioxide emissions mitigation strategy. None of the methods has been successfully used for all of the anthropogenic sources. Many issues are still remaining regarding the ability to separate carbon dioxide from anthropogenic sources and to meet the cost, safety and environmental requirements (US Dept. of Energy, 1999). Specific research and development (R&D) needs to be done in order to get

Table 3: Potential research and development for carbon dioxide separation technologies

Separation & recovery method	Potential research and development
Adsorption	• Development of adsorbents that have high adsorptive capacity and capable of producing pure carbon dioxide product • Adsorption isotherm study to identify the best adsorbent materials for carbon dioxide separation • Development of cyclic adsorption-desorption system that capable to separate a wide range of carbon dioxide concentrations • Mathematical modeling of dynamic adsorption systems to optimise the adsorption system
Absorption	• Development of low cost gas-liquid contactors compatible with alkanolamines and have high-temperature resistance • Development of novel gas-liquid contactors to minimise mass and heat transfer effects in gas scrubbing • Optimisation of existing solvents, development of new solvents, to reduce total capital and operating costs • Molecular modeling of absorption processes to aid in the selection of absorbents
Membrane	• Development of polymeric materials to increase the dissolution and diffusion rates for the desired gas components • Development of compact membrane design modules for remote application such as at oil platforms • Mathematical modeling to optimise the membrane separation system
Low Temperature Distillation	• Integration with sequestration processes to reduce operating cost • Development of efficient and novel refrigeration cycles for competitive low-temperature distillation processes
Hybrid Separation System	Development of the following systems • Adsorption-Membrane System • Absorption-Membrane System • Adsorption-Absorption-Membrane System

better systems for carbon dioxide separation technology. Some of the R&D requirements are proposed in Table 3.

Research related to the separation of carbon dioxide should not be done alone since the separated carbon dioxide cannot be released into the atmosphere. It must be done together with carbon dioxide utilisation or sequestration projects as an integral research programme.

CONCLUSIONS

Continuous increase of carbon dioxide in the atmosphere indicates that it is essential to maintain or balance the carbon cycle by means of reduction of carbon dioxide emissions. Among those methods of reduction are usage of efficient separation technologies and optimization of carbon utilizations. Nevertheless, there is no single technological way in solving problems about excessive carbon dioxide emissions. Indeed, a combination of a methods may be needed to encounters both technical and economical aspects of industrial implementation.

These technologies need to present sound evidence on its reliability, performance, practicality, and environmental and economic considerations prior to execution.

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REVIEW OF THE POTENTIAL USE OF OIL PALM WASTE FOR ENVIRONMENTAL FRIENDLY DRILLING MUD THINNER

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ABSTRACT

Depleting reserves and an ever increasing demand for oil necessitate the need to increase drilling activities. However, the use of toxic mud additives in drilling is a subject of environmental concern. Also on the rise is the waste from the oil palm industry especially empty fruit bunch (EFB) and black liquor which could damage the environment. It is a complementary case where the black liquor from the oil palm industry could be re-used to produce environmental friendly drilling mud thinner. Early studies indicated that tannin and lignin, organic extracts from the black liquor, have the desired properties of adhesion and dispersion to act as environmental-friendly mud additives.

Keywords: *drilling mud additives, tannin, lignin, colloidal suspension*

BACKGROUND

The Far Eastern Economic Review on July 3rd, 2003 reported that PETRONAS, having international oil reserves of 4.74 billion barrels, grabbed the top spot in the REVIEW 200 Malaysia list. Back in 2002, PETRONAS was the most profitable company registering a net profit of 15 billion ringgit. This shows that demand for oil keeps increasing despite uncertainties in the world economy. It is not surprising since hydrocarbon fuels remain relatively cheap and practical as compared with other fuel sources such as electricity and nuclear. Therefore, the hunt for new oil fields prompts drilling of new wells. A drilling operation starts only when the prospect for hydrocarbon is commercially justified. This is due to high drilling cost (as high as MYR40 million per well). In the drilling process, pressure in the bore-hole, P_1, is significantly lower than pressure in the formation, P_2, as shown in Figure 1 [1]. Therefore a mechanism is needed to stabilize the system i.e. both the bore-hole and in the formation. For effective drilling, there should not be any pressure drop.

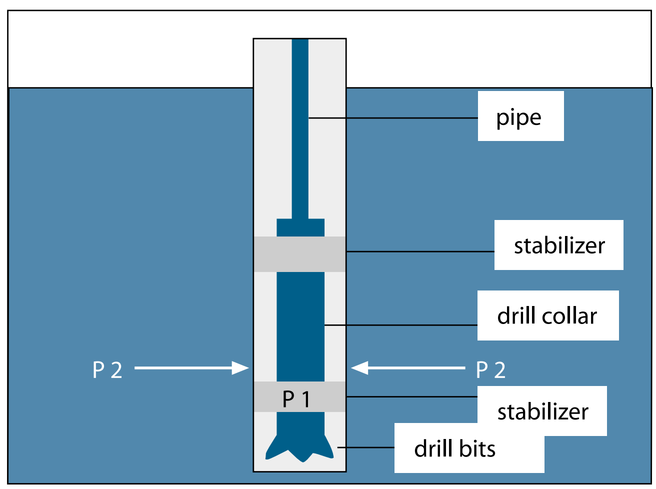

Figure 1: Schematic of bore-hole and formation during drilling

This paper was adapted from the presentation at the Regional Symposium on Chemical Engineering (RSCE) 2002, Kuala Lumpur, Malaysia, 28-30 October 2004.

Otherwise, formation fluids would burst into the bore-hole destroying expensive drilling tools, killing workers on the drilling rig and polluting the environment. This is where drilling mud is most needed to balance the high formation pressure. In addition to its primary function to transport drill cuttings to the surface, the drilling mud also helps to cool and lubricate the drill bits.

Formulation of drilling mud is one of the most important aspects in drilling engineering. This is because as drilling progresses, the mud would become more viscous and subsequently reduce the optimum speed of the drill bits. Therefore, the right formulation of drilling mud is needed to ease drilling operations. This is achieved by using mud additives that act as an agent to disperse colloidal suspensions responsible for mud viscosity. The problem with the current drilling mud system is that some of the additives are toxic such as chrome-lignosulfonate. Perhaps drilling workers are the most at risk while handling drilling operations. The scenario is more worrying if there is any leakage during drilling operation that may cause the toxic drilling mud to migrate and contaminate the drinking water zone.

OIL PALM WASTES

Besides the use of toxic drilling mud additives, the increasing amount of waste from the oil palm industry is another environmental concern in Malaysia that necessitates the need for better waste management. There are 2.5 million hectares of oil palm estates and over 300 palm oil processing plants all over the country [2]. The demand for palm oil is back on the rise regardless of the competition from other vegetable oils. This could be due to the low cholesterol content in the palm oil as well as its richness in vitamin E. Nevertheless, palm oil processing plants are facing challenges to eliminate the empty fruit bunch (EFB) from their compounds. Annually, tonnes of EFB are burned and it further exacerbates environmental pollution. Since the degradation process takes about 6 to 12 months, most of the EFB waste is improperly dumped [2]. Many did not realize that oil palm EFB contains valuable components for other uses. Perhaps fibers are the most notable among those valuable components in the EFB. It is used as feedstock for the pulp and paper industry after being subject to further processing as shown in Figure 2. Nevertheless, the liquid waste known as black liquor from the pulp and

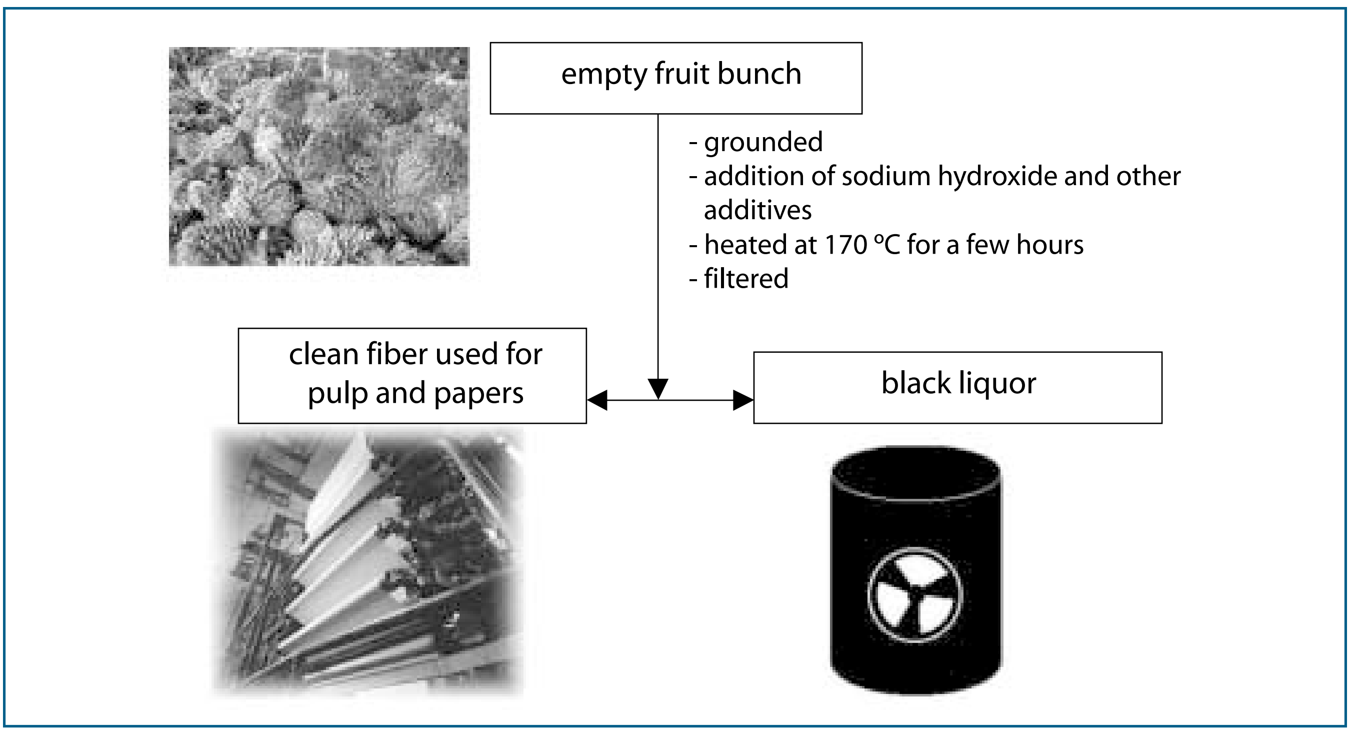

Figure 2: Flow chart in the pulp and paper process

paper industry using EFB as feedstock seldom gain attention. Usually, the liquid waste ends up in rivers. This is clearly undesirable since the black liquor also contains sodium sulfate, sodium bisulfate, chlorine, caolinite, titanium oxide and heavy metals such as chromium and mercury [3].

Black liquor

The apparent blackish color of the waste liquid is due to the presence of lignin, an organic substance. Lignin acts as a supporting structure and forms transport tissues in plants. Its content in plants varies and it is found to make up 17% in the EFB. The organic substance is known to be viscous and dispersive where its addition to concrete could enhance surface adsorbtion [4]. Thus, little water is needed to produce a good concrete. Lignin has also been used as an anti-oxidation agent in the food processing industry, a stabilizer and emulsion agent in the rubber industry [4]. Another component of black liquor is tannin forming 4.54% in the EFB. Tannin structure, shown in Figure 3 is a complex of phynol, polyphynol and flavanoid substances. Tannin is used as an anti-oxidation agent to slow down chemical changes. Its effect can be seen in a fallen leaf that does not immediately decay due to the presence of tannin. The presence of lignin and tannin in the black liquor can be applied in the formulation of effective drilling mud additives.

FROM BLACK LIQUOR TO MUD ADDITIVES

Wise drilling fluid practices can save an oil company millions of dollars, directly and indirectly. Good engineering sense can lead directly to savings by knowing when simple mud can be used satisfactorily instead of unnecessarily using sophisticated mud. While direct mud costs may constitute about 7% of the total well cost, this figure does not include time lost for circulating and conditioning the mud or other mud related problems such as stuck pipe, poor penetration rates, etc [1]. Therefore, considerably more money can be saved indirectly when good mud practices are followed.

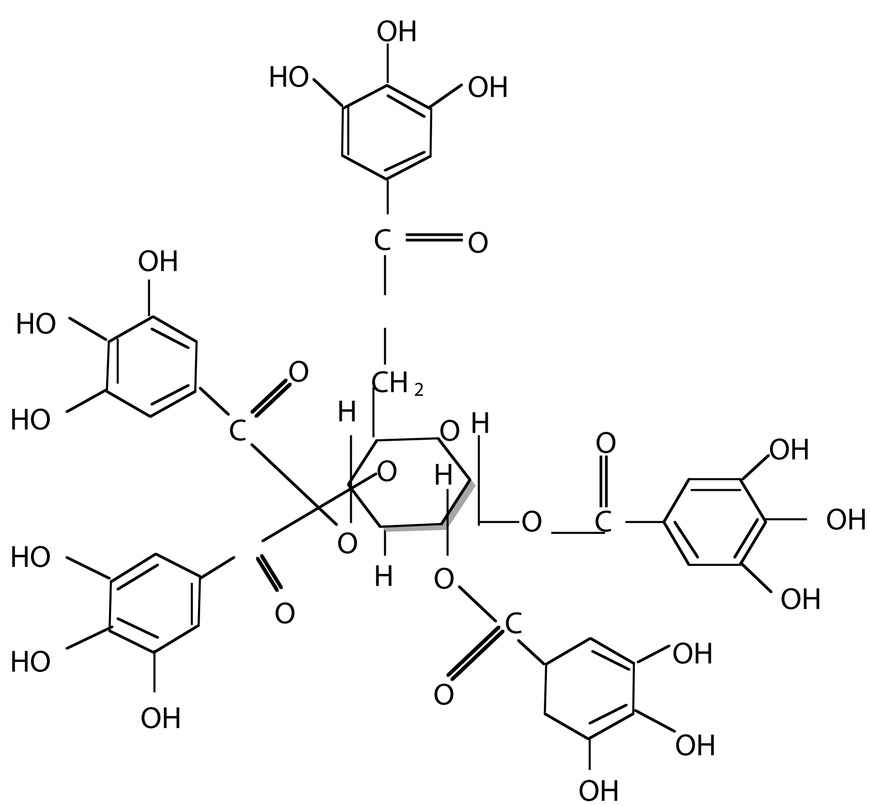

Figure 3: Molecular structure of tannin [4]

Although drilling mud has a humble name, mud engineering is by no means elementary. To explain mud properties, physical chemistry concepts must be employed. Topics such as colloidal suspensions, viscosity, gel formation, emulsion stability, flocculation, etc., are the subjects of advanced chemistry classes. In the understanding of chemical treatments and analytical tests, one needs to call upon basic chemistry knowledge. Today, lignin has been gaining popularity as one of the potentially valuable organic materials. This is primarily due to their adhesive and dispersive properties. The major derivative of lignin towards exploration drilling is as a basic material called lignin sulfonates or better known as lignosulfonates used in drilling mud thinner. Lignosulfonates are very versatile and utilized in mud to act as a deflocculant agent. Lignosulfonate molecules tend to adsorb on the clay surfaces (bentonite) and prevent the platelets from linking. Lignosulfonates are also useful valuable for stabilizing oil-in-water emulsions which give the drilling mud improved properties in control of water loss, reduction of torque on the drill stem, increase of bit life and general improvement of bore-hole conditions.

In other words, adding lignosulfonates into the drilling fluid system can reduce the viscosity of the mud and therefore it could reduce the amount of energy needed to rotate the drill stem and the drill bit. As an example of its effectiveness as a thinner, lignosulfonates with sodium hydroxide are the best treatment for salt contamination [5]. Further improvements to this complex include increasing its ability to withstand high temperature pressure. This two principle reservoir requirements is extensively being developed reported in many studies [5]. A study on tannin exposed to a range of temperatures, heat and dosage reported that this organic compound has a potential as a thinner and an anti-corrosive agent [5]. Its use as an anti-corrosive agent is important in drilling operation since the whole structure of the drill string is made of steel. Therefore, the special property of tannin as an anti-corrosive agent adds a new dimension for environments friendly drilling mud.

CONCLUSION

The study on transforming black liquor into environmental friendly mud additives is a smart approach towards reducing environmental pollution. The study provides opportunities to formulate value-added by-products from the oil palm industry as well as generating innovative techniques for drilling mud formulation.

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INFERENTIAL MEASUREMENT AND SOFT SENSORS

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ABSTRACT

Advanced Process Control (APC) has been widely recognised as one of the most important techniques to obtain better performance from process plants. APC refers to a whole suite of methods incorporating modern concepts of control theory, modeling and real-time optimisation applied to process plants. One of the very important and successful techniques in the armoury of APC is inferential controls. In developing inferential controls, suitable inferential models have to be developed. This paper gives a review of one of the most important methods for inferential measurements, i.e. based on Neural Networks. The techniques to make this method successful are also discussed in detail.

Keywords: *Inferential Controls, Soft Sensor, Neural Network, Principal Component Analysis*

INTRODUCTION

Hierarchical Control

Global size petroleum and gas processing plants are very complex in nature. For the economical and optimum operation of these very complex facilities, very sophisticated control systems are employed. The architecture of these control systems are hierarchical in nature as shown in Figure 1 [15].

The lower levels of the control hierarchy like the regulatory level and the advanced regulatory level are hardware intensive. Feedback control using PID and its variations, cascade, feed forward, ratio, batch processing, advanced PID, nonlinear gain, self-tuning, oxygen resetting, valve position control, selector controls, interlocking, startup-shutdown-emergency shutdown procedures are examples of some of the most important types of schemes which are commonly implemented at the lower levels of control. In modern refineries or petrochemical plants with DCS based systems, these levels of control can be implemented and tuned without too much difficulty.

However the higher levels of control like Advanced Process Control (APC) and On-Line Optimisation are knowledge limited. The key inputs for the successful implementation of APC is the knowledge regarding the operating plant together with the technological and theoretical know-how about implementing the advanced control techniques in a particular situation. Unlike the lower levels of control where the usual PID type solutions can act as the workhorse of most of the control problems, at the higher levels there are no ready-made solutions. Pass balancing in large furnaces, constraint control in distillation columns, internal model control, inferential controls and multi-variable

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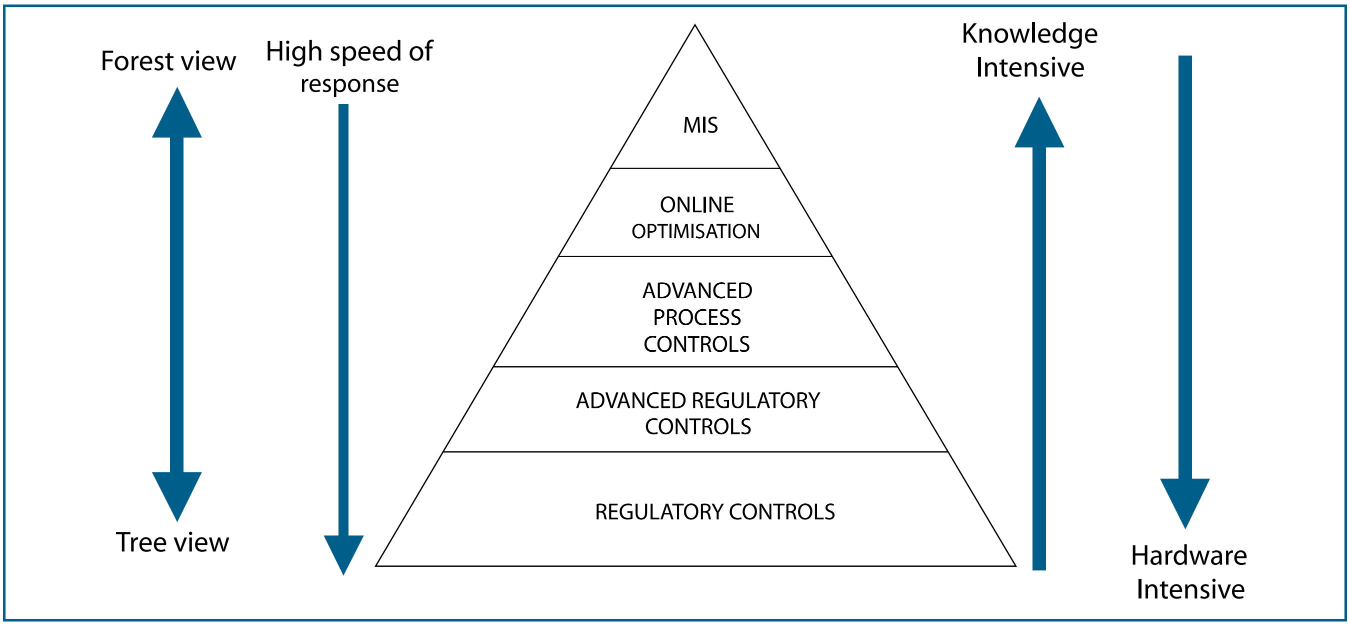

Figure 1: Hierarchical control structure

controls are some of the more important examples of APC solutions used in petroleum refineries and petrochemical plants.

APC Status In PETRONAS Plants

PETRONAS is an integrated global oil company with substantial interests in upstream, refining and down-stream operations in the oil and gas sector. In Malaysia, PETRONAS operates oil and gas production facilities in offshore Terengganu and Sarawak, two refineries in Melaka, refineries in Kertih, three gas processing and liquefaction plants in Sarawak, gas processing and pipeline distribution plants in Terengganu, petrochemical plants at Kertih, Gebeng and Kuantan and fertiliser and methanol plants in Labuan.

These plants are well advanced in regulatory and advanced regulatory control systems. The Melaka Refinery has implemented model-based multi-variable predictive controller to control variables such as kerosene flash point, diesel pour point, LSWR pour point, condensate naphta 95% distillation point, light naphta RVP, reformate RVP and RON. The APC in the PSR-1 Refinery at Melaka is based on the Setpoint DMC-PLUS multi-variable controller. Seven such controllers are in use for each plant area such as CDU, CND, GRP, NHT, CRU, CCR and COC. The Malacca PSR-2 plant advanced process control is based on 13 multi-variable controllers from Honeywell-Robust Multi-variable Predictive Control Technology (RMPCT) [12]. They have reported a pay back period of 8 months for this APC project. The MLNG plants in Bintulu have embarked on an ambitious APC programme, based on Shell Multi-variable Optimising Controller (SMOC). A total of 18 multi-variable controllers were planned [14]. The refineries at Terengganu has also completed APC projects in the refineries based on the Honeywell RMPCT platforms [11].

Some of the most important lessons learnt during the implementation of these APC projects were the following:

1. If the regulatory and advanced regulatory controls are not in place and well tuned, then little can be gained by implementing APC.
2. After commissioning and once operational, more fine tuning has to be performed by the plant instrumentation and control engineers to obtain the proper benefits.
3. Estimating parameters and testing are critical to the success of the APC project.

4. Soft sensors or inferentials must be working properly. (Quote from one of the senior APC engineers: 'Otherwise your life will be miserable – talking from experience.')

The other learned plenary speakers have addressed some of the important issues related to APC conceptualisation and implementation. I shall concentrate on the fourth point above, on how to develop and fine-tune soft sensors, and hopefully, reduce the misery of our APC engineers.

SOFT SENSORS

Soft sensors or the more generic name, inferential measurement, refers to the technique where the control variable of importance is not measured but is inferred from secondary measurements. The well known technique of distillate composition control using the top temperature measurement is the simplest case of an inferential control. Here the distillate composition's real control variable is not measured, but a secondary variable, the top plate temperature which is closely related to the control variable of interest, is measured and used as the signal for obtaining a manipulated variable – the reflux flow rate. The reason for not directly measuring the controlled variable could be:

- High cost of the analyser
- Analysis method may be laboratory based and not suitable for online application.

Further, online analysers are highly prone to breakdowns and require constant maintenance. Hence an attractive alternative to using an analyser or in addition to an analyser is the application of a soft sensor or inferential technique.

A soft sensor means a software based sensor. While variables like temperature, pressure, flow, level etc. are directly measured using appropriate transducers, there are many variables in petroleum processing which are not amenable for direct measurement using transducers. Many of these variables are called 'quality variables' which measure some significant quality parameter of the product. In a refinery, variables such as Research Octane Number (RON), Reid Vapour Pressure (RVP), Gas Oil Colour, ASTM Distillation Cut Points, Freezing Point, Cloud Point, Pour Point etc. are quality variables. These variables in general cannot be measured online using simple transducers. Analysers are used for this purpose. Many analysers are offline equipment. In this method, a sample has to be taken from the process, analysed using the analyser to obtain a particular property and the result entered into the DCS system to be used as control signal. Hence, this signal is available for control only periodically which may be 10 minutes or more. Such offline analysers does not offer a normal closed loop control solution even if sampled data systems are used. Further, most online analysers suffer from reliability problems and if an the analysis is available its output need to be independently verified for reliability. A plant would not be able to operate optimally due to these substantial delays in the analysis loops. Operations are conducted at conservative levels to avoid violating the quality. This gives rise to what is called 'product give-away' where a more costly product is mixed with a less costly product, and therefore sale has a reduced value. An example is in a distillation column. If RVP is not maintained in the extraction of aviation turbine fuel (ATF), it would have to be "given away" as the less costly kersosene.

A practical solution to this problem is the use of soft sensors. In using software sensors, the quality variable which cannot be directly measured is inferred or calculated by basic measurements. These quality variables are in all cases functions of several other operating variables with in the system. For example, the RVP of the kerosene side-draw of an atmospheric column (assuming the draw to be in plate 25) could be dependent on the temperatures in plates 23, 24, 25, 26 and 27, the quantity of the kerosene draw, the column pressure, steam rate to stripper and other parameters. (Figure 2) All these variables are normal process operating variables read off any time on the regulatory level instruments and displayed in the DCS system. By finding the complex relationship between RVP and these measurable variables an instantaneous

RVP value can be inferred and used for control like any other process variable. A model for the calculation of RVP from the basic process variables would be useful as this relationship is highly complex and nonlinear. The methods employed for generating this relationship are multiple nonlinear regression techniques combined with principal component analyses known as Partial Least Squares (PLS), and neural networks (NN). There are strong proponents for both types of approaches [7], [4]. Both methods have advantages and disadvantages. Neural networks are more commonly used and is presented in this paper.

APPLICATION OF SOFT SENSORS

There have been several reported successful applications of soft sensors based on neural networks for industrial applications. Bhartiya and Whiteley (2001) presented a step by step methodology for data processing and network training of a soft sensor. The example was a soft sensor trained to predict the 95% ASTM end point of the kerosene fraction in a refinery distillation column. A PCA tool was used for post processing sensitivity analysis of the soft sensor. Radhakrishnan and Maruti Ram (2001) used a neural network with fundamental modeling to develop a complex algorithm for the control of the bell-less top charging system of a blast furnace. The method used was a simple mechanistic modeling of the solid trajectories at the top of the blast furnace combined with an NN model for the gas-solid moving bed interactions. Neelkanatan and Guiver (1999) presented a comprehensive survey of NN applications in the hydrocarbon processing industry.

Radhakrishnan (1999) applied neural network techniques in the modeling of a ball mill (for grinding)

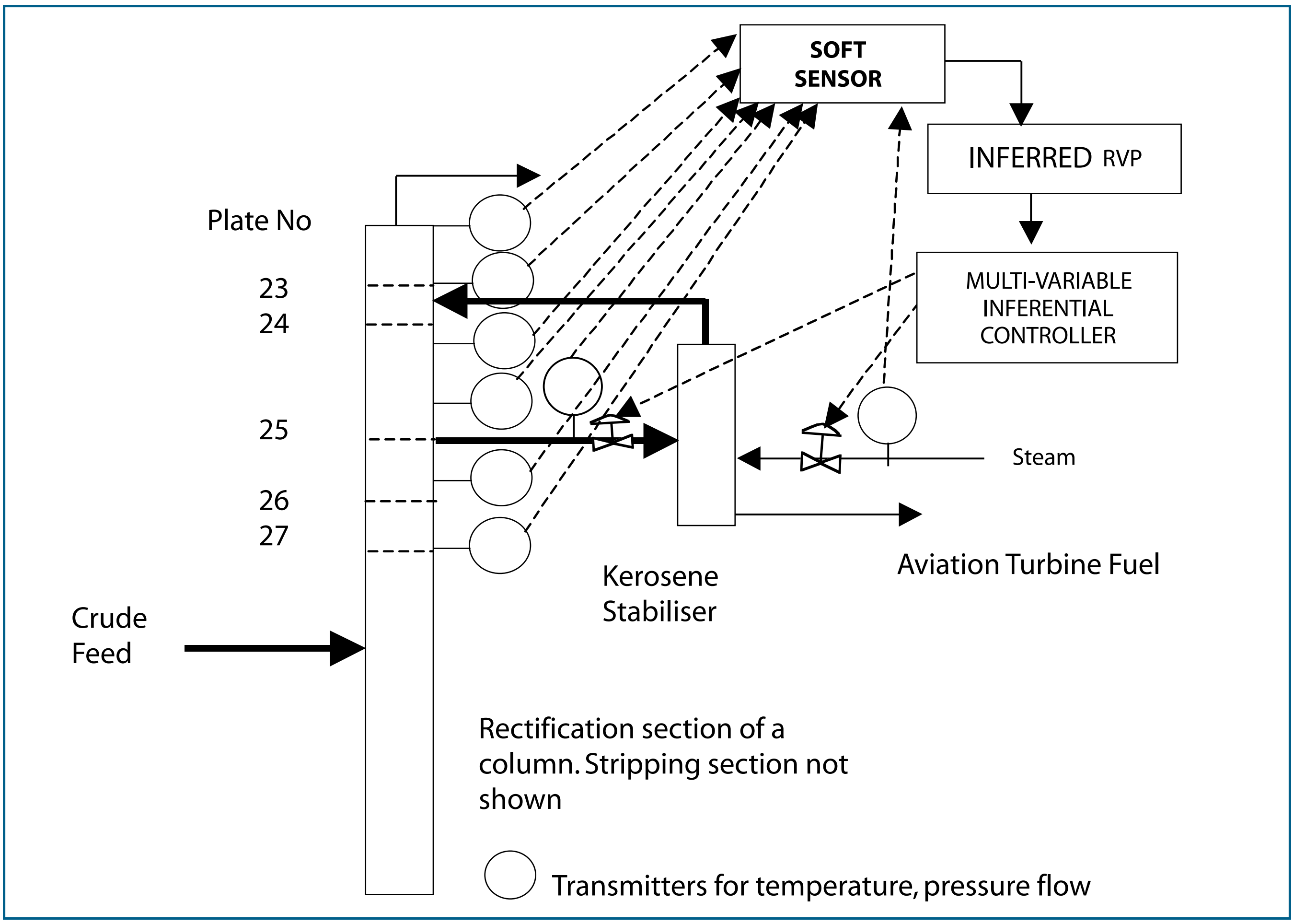

Figure 2: Schematic diagram of a soft sensor for Reid Vapour Pressure (RVP)

in mineral process operations. Radhakrishnan (2000) also successfully utilised an NN-based soft sensor technique to predict composition of hot metal in a blast furnace. This technique has now been successfully commercialised in an integrated steel plant in India. A.Chouai et al. (2000) used an NN-based inferential control on a laboratory scale liquid-liquid extraction column while Ramachandran and Rhinehart (1995) presented similar studies for a distillation column. Lennox – et al. (2001) presented their findings on a series of industrial applications of NN sensors. It was a 2-year study on industrial undertakings conducted with several UK-based industries with on applications of soft sensors. The paper presented case studies of successful applications in a variety of areas such as, a vitrification process, polymer extrusion process, gasoline engine monitoring and rapid gravity filtration process. Sabharwal et al. (1999) successfully used NN to predict the C_9+ contamination at the top product of a xylene tower. They reported a high coefficient of correlation of the order of 0.913.

In another successful application, Baratti et al. (1999) demonstrated the use of NN soft sensors for predicting the composition of the distillate in several refinery columns such as the butane splitter and gasoline stabiliser. All these are successful applications of neural network soft sensor approach for inferential controls. However, this method is not straight forward and easy. Failures in applying this approach insufficient attention on collection and pretreatment of data, and poor optimisation of the network as a result of unsuitable analysis.

The approach to inferential measurements can be sub-divided into:

i. data collection and preprocessing;
ii. identification of a subset of p measured variables for the inference of the unmeasured variable, y;
iii. approximation of the relationship between the unmeasured variable y, and the subset of measured variables x_i as identified.

The following is a brief discussion on these important aspects of network development.

DATA COLLECTION AND PREPROCESSING

One of the most important stages in the development of an NN-based soft sensor is the collection of appropriate data and its pretreatment. This plays a key role in the success or otherwise of the final product. A soft sensor cannot perform better than the data on which it is trained. If the data is erroneous or does not represent the process correctly, the neural network will give in accurate results.

Variable Selection And Data Collection

Large and complex processes contain a number of controlled variables and usually a larger number of measured variables. If a given variable y, cannot be measured, then it must be inferred using a suitable subset pf p measured variables $\{x_i,\ i = 1, p\}$ selected from the larger set n candidate variables. The choice of the p variables from the larger set of n variables may be based on past experience and insight of the process. The compilation of this data set is often undertaken by discussion with the process plant operators. A Delphi type approach can often be successfully used for this purpose. Variables excluded from this candidate list need not be further considered in the soft sensor development.

The data collected must be representative of the conditions under which the soft sensor will be used. In order for the NN-based soft sensor to predict the output accurately, the window of data should contain all the expected states and conditions of the proces. For example, if there are short duration local transients they may be excluded by averaging over several samples. Similarly, if one of the inputs is data with a sampling time of 10 minutes while an other is available every 200 ms, then the faster data may be averaged to give one sample based on the longer sampling interval. The data set must contain the entire range of conditions of the operation. It is not the number of datasets which is important but that it should represent the whole horizon of operating conditions.

Data Preprocessing

For the successful implementation of a soft sensor project, the raw data has to under go preprocessing based on statistical techniques. The raw data collected could contain observations that are inconsistent with the statistical character of the remainder of the data. For simple situations statistical tests for outlier removal like !5ρ band method could be used. However the data in most cases are multivariate in nature and such simple procedures may not be always successful. The observation may not show an extreme on any two-dimensional plots. Joliffe [1986] proposed a method based on principal components to remove such multivariate outliers. Another important statistical test used is the determination of normality and skewness.

Data normalisation is to ensure that all data fall within the range of 0 to 1. In the plants, different data have different magnitudes and units. For example, a temperature variable could have a value between 450 to 460°C. Another variable, a composition, with mole percent value between 0.01 to 0.016%. When used directly in an NN, the temperature variable with a much larger magnitude will influence the network weights much more than the composition variable which has a much lower magnitude. To avoid this biase of weights by larger magnitude variables, all variables are normalised in the range 0 to 1 using the formula,

$$x = \frac{(x' - x_{min})}{(x_{max} - x_{min})} \qquad (1)$$

When all the variables are normalised to a range of 0 to 1, each will have the same influence on the weight training.

Reduction Of Data Sets

A data set identified by experience and heuristic knowledge may still be too large. In general if the number of input variables used for an NN is too high then it will be sensitive to noise and hence will not be very stable and robust. The addition of too many variables almost always increases the variance of the predicted response [21]. Hence, it is always a good policy to try and reduce the variables entering the NN as inputs. Techniques available for reducing input data sets are by scatter plots, simple correlation coefficients and partial correlation coefficients.

Scatter plot is a graph of each independent variable versus the dependent variable on a two-dimensional plot. This enables a visual search for any underlying relationships. Points lying along a straight line can denote a linear relationship and points along a curve, a non-linear relationship. Similarly absence of any pattern may denote that no significant relationship exists between the dependent variable and the specified independent variable. Similarly, simple correlation coefficients provide a measure of linear association between two variables. Variables having low values of its correlation coefficient with the dependent variable can be omitted from the NN scheme.

In the case of multivariate systems the most powerful method is the method of partial correlation coefficients [Steele and Torrie, 1990]. The partial correlation coefficient adjusts for the effect of the other variables when considering the effect of a particular independent variable on the dependent variable. By these methods the number of variables are reduced to a manageable size.

The input data set can be further reduced by using the technique of C_p statistic [8]. If the number of independent variables selected is p and the total number of available independent variables are r then, the C_p statistic is defined as,

$$C_p = \frac{\text{residential sum of squares of subset model with } p \text{ parameters including an intercept}}{\text{residual variance of fullmodel}} - (r - 2p)$$

Good models typically have the (p, C_p) coordinate close to the 45° line on a C_p versus p plot. Since this method inspects all combinations of variables, the number of possible subsets are very large. Hence, this method is useful only after reducing the possible set of independent variable to a low value by other methods such as by partial correlation coefficients. The use of the C_p statistic is a means of refining the set of independent variables from an initial set constructed from heuristics and simple partial correlation coefficients.

NEURAL NETWORK MODELS

Basic Principles

NN is a method for the nonlinear mapping of the inputs and outputs. The connectivity between the nodes are shown in Figure 3. Feed forward, back-propagation is the generalization of the Windrow-Hoff learning rule to multiple-layer networks and nonlinear differentiable mapping functions. This rule utilizes inputs and outputs to train the network. The method is also known as the Delta Rule. It is basically an error minimisation algorithm, in which the differences between the inputs and targets is used to make changes in the weights in connections between the nodes. Such a network is loop-free or feed-forward. Here, the inputs are fed through the network layers without any feedback of information. Back-propagation normally utilises a gradient descending method, such as the Newton-Raphson or the Marqardt algorithm, where the weights are moved along the negative gradient of the performance function. The manner in which the gradient is generated for nonlinear multilayer networks varies in different methods. Generally, a feed forward NN consists of nodes which are connected to each other as shown in Figure 3. There is no limitation on the number of inputs and outputs. In between the input layer and the output layer there will be one or more hidden layers. The mapping occurs in the hidden layers. All nodes in one layer are connected to all nodes in the next layer. Inputs which are denoted as x_i are connected to the nodes in the input layer. Similarly the outputs, y_p are obtained from the output layer. The connectivity strength between the output of node i with node j is given by weight W_{ij}. The values of the weights lie between 0 and 1. A value of 0 indicates that there is no transmission of signals between the nodes and value of 1 shows full transmission signal strength from node i to node j. At each node all incoming signals are added and the bias is added to the sum to give the total activation as shown in Equation 2. The output is calculated as a nonlinear function of the total activation as in Equation 3.

$$zj = \sum_{i=1}^{n} x_i W_{ij} - b_j \qquad (2)$$

$$\text{Output of node j, } x_j = \frac{1}{1 + e^{z_j}} \qquad (3)$$

A nonlinear function which is commonly used for the transformation of the summed signal (Equation 3) is the Sigmoid function. The purpose of the mapping function is to limit the output to certain range of values. Other commonly used mapping functions are Logsig, Tansig and Purelin.

During the training, the tuples in the training set are applied to the network one by one and the output calculated. The error between the predicted output and actual value of the output is calculated and

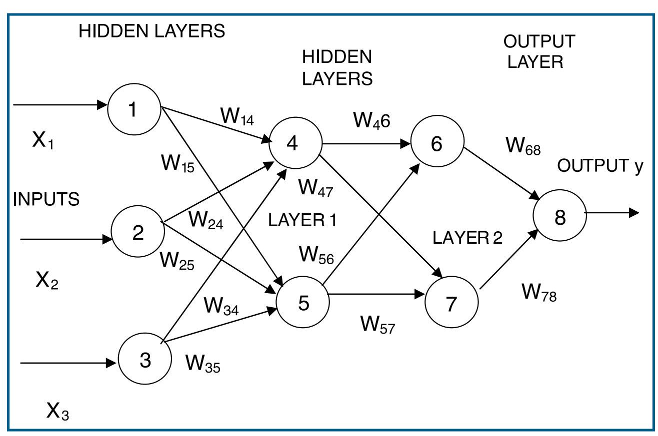

Figure 3: Feed forward neural network

summed over all the tuples of the training set. The weights are changed in a suitable error minimisation algorithm using a gradient descent method like the Marquardt algorithm. The training proceeds till the error between the input and output is less than a specific value. A tuned network is then used to predict the value of output for a given new set of inputs. There is no general rule governing the choice of the number of nodes and number of hidden layers used for modeling a particular set of data. A trial and error procedure is performed to identify the optimum network configuration that will minimize the error in the prediction.

Network Architecture

Network Topology

The architecture of a neural network is dependent on the type of neural network used. A common type of architecture which find widespread application for modeling in the process industry is the feed forward network illustrated in Figure 3. The number of neurons in the input layer is fixed as the number of independent variables. Similarly the number of neurons in the output layer is fixed as the number of dependent variables. There are no hard and fast rules regarding the number of hidden layers and the number of hidden layer neurons. A trial and error approach is usually used for determining the number of hidden layers and hidden layer neurons.

Activation Functions

Several common types of activation functions are available [6]. Some of the common types are Purelin which is a linear function, Satlin which is a linear function with saturation, Tansig which is hyperbolic tangent sigmoid transfer function, Logsig which is a logarithmic sigmoid transfer function, and Hardlim which is the hard limit transfer function. For inferential models, Purelin is used for the input and output layers and Logsig for hidden layers.

Network Training

Network training is an error minimisation algorithm. At the start, an initial value of all the weights is assumed. The independent variables are presented to the network and the predicted value of the output calculated. The predicted value of the outputs are compared with the actual value calculated. The procedure is repeated over the whole training set of data and the sum of squares of the error calculated. The weights are then adjusted in such a manner that the SSE decreases till a minimum is reached. The two common algorithms used for this purpose are Newton-Raphson and Marquardt-Levenspiel.

Some Common Errors In Network Training

Over Training and Cross Validation Technique

One of the common errors which arise during the training of NN is a phenomenon known as over-training. When the network is trained in back propagation mode, we are essentially using an error minimisation technique such as the Marquardt-Levenspiel algorithm where the error between the predicted value of the output and the actual value over the total data horizon is minimised by adjusting the weights connecting the different neurons. As the network training proceeds, the error which is originally at a high value progressively decreases. The errors keeps decreasing over several epochs of training. However, if the trained network were used to predict by using an other set of inputs, the accuracy is found to be less. The reason for this deteriorating performance is that after several epochs of training, the network under training actually tries to fit the new weights to the specific variations in the training data set rather than follow the overall trends. This shows up as reduced error during training. Therefore when this trained network is used with the new data set which does not have the same specific characteristics, the prediction accuracy fails.

Cross validation is a method for overcoming over training error. The original data is partitioned into three parts using random numbers. An ANOVA test is used to ensure that the three sets belong to the same population and hence represent the same physical phenomenon. For this purpose, it is necessary to have a sufficiently large initial data set. One set is designated the training set. A second set is designated the validation set, and a third set is designated the testing set. The training set is used for training the neural network. Training is continued for a few epochs. The prediction error comes down with the training of the weights. At this stage, the training is stopped and the trained network is tested against the validation set, to determine the error. The network is again trained for a further few epochs using the initial training set. The training is then stopped and the network re-tested against the validation data. If the validation set data is lower than the previous value, testing with the testing set continues. This procedure is repeated until the point when the error in the validation set increases. Training is then stopped. The reason why the error continues to decrease using the training set, is that after a certain stage, the neural network tries to further improve by fitting itself to the minor specific features of the training set data rather than the overall trends. At this stage there is no further improvement when using the validation set data and the prediction accuracy decreases. Hence the training is stopped at that stage. After the training is completed the final trained network is used to test the prediction accuracy using the test data which is only used for this purpose.

Linear Relationships

Where the process model contains a linear elements the prediction accuracy of NN tends to be poor. In tackling such situations the linear and non-linear part are separated into what are known as Wiener or Hammerstein type models [Radhakrishnan and Sujendran 2004]. While the Hammerstein and Wiener models have a series structure, the linear part may also be modeled as a parallel structure with the NN [10].

Process Dynamics

Where the process model has a time varying element several techniques are available which can be used together with the NN. One approach is to use the philosophy of ARMAX models and time-lagged data in the model [3]. The second approach is to use a Hammerstein model with the dynamics represented in serial by an appropriate first or second order filter. [22]. A different approach is to incorporate the dynamics in the layer structure by using what is known as recurrent networks [23].

CASE STUDY I: INDUSTRIAL HEAT EXCHANGER

The first case study presented here is the development of a process model for a large heat exchanger used in the crude preheat chain in the Malacca Refinery as shown in Figure 4. The heat exchanger has one shell pass and 4 tube passes. The heat transfer area is 295.2 m^2 and the heat rating is 6.21 MW. The crude oil flows through the shell side and the LSWR streams from the atmospheric column which flows through the tubes. This heat exchanger is one of the principal units in the crude preheat train and plays an important role in energy recovery.

Hence it was considered appropriate to implement advanced control strategies such as Internal Model Control for this heat exchanger to improve the control performance. The NN model of the heat exchanger was developed as part of the IMC requirement.

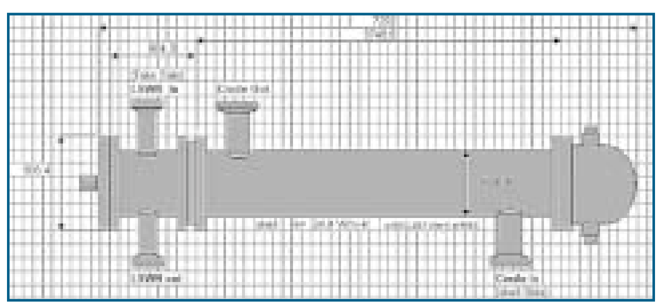

Figure 4: Heat Exchanger

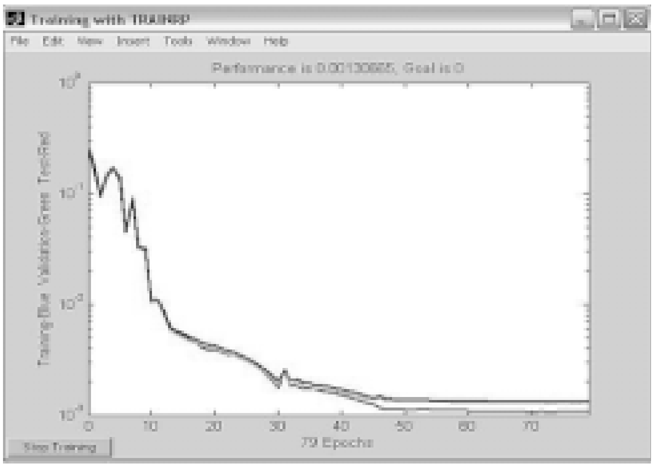

Figure 5: Training and validation of heat exchanger model

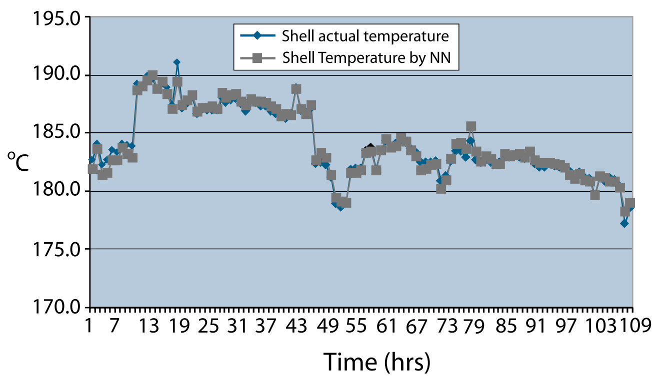

Figure 6: Comparison of predicted and actual crude oil outlet temperatures

A set of 795 data points spanning 15 working days of the heat exchanger was used for the NN development. Cross validation technique was used to prevent over training. A back propagation network with 3 layers, Purelin, Logsig and Purelin were used. The number of neurons were, 10-20-2 in the three layers respectively. The training was carried out using 73 epochs by cross validation as shown in Figure 5. The trained network was used to predict the cold fluid outlet temperature as shown in Figure 6. An accuracy of the order of 4.2% was achieved. As shown in the figure, this can be considered as a very successful application of an NN modeling technique. This model would be used to develop an Advanced Process Control System (Model Predictive Control- MPC) for the heat exchanger.

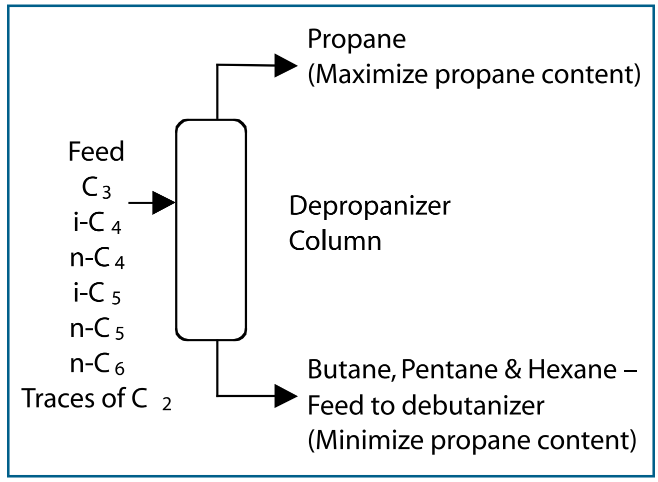

Figure 7: Depropaniser column

CASE STUDY II: PROPANE CONCENTRATION IN DEPROPANISER COLUMN BOTTOMS

The second case study presented here is the development of an inferential controller or soft sensor to predict the propane concentration in the depropaniser bottoms as shown in Figure 7. An online chromatograph with a sampling interval of 10 minutes is available to measure the propane concentration. A real time measurement of this variable is very important for the advanced control of the depropaniser and debutaniser column variables. The objective of the soft sensor is to predict the depropaniser bottom composition in real time. For this purpose a neural network based soft sensor was developed. The soft sensor had 26 input variables, being the flow rates and temperatures in different plates in the debutaniser column. The optimum network architecture was determined by trial and error. The cross validation technique was again used to prevent over training. A 3 layer network was used with 38 neurons in the input layer, 27 neurons in the hidden layer and one neuron in the output layer. Logsig transfer function was found to give best results in all the layers. Training was carried out over 100 epochs.

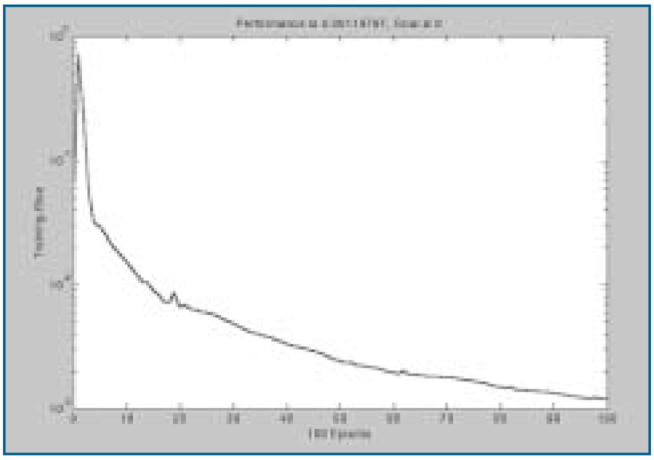

Figure 8: Training of depropaniser column model

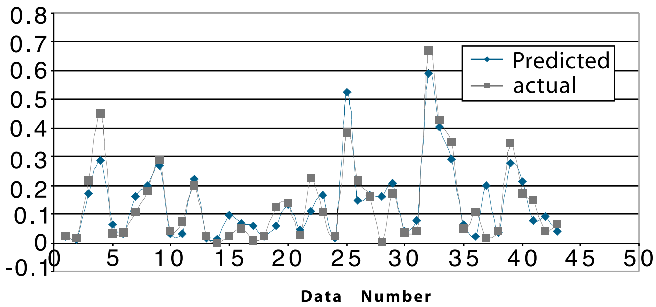

Figure 9: Prediction accuracy of the propane soft sensor

The trained network gave a performance function of 1.76 x 10^{-3}. The performance of the neural network in predicting the actual output against the test data is shown in Figure 9. The RMS accuracy of prediction was 6.72%. Work is still in progress to improve on this accuracy.

CONCLUSIONS

Neural network based inferential models are powerful methods which play an important role in implementing many Advanced Process Control techniques. However soft sensors are expensive. Considerable effort and care is required to collect appropriate data and to preprocess the data to meet the statistical quality requirements. Powerful tools like PCA are available for this purpose. Two case studies, one on a heat exchanger and the other on a distillation column showed that this method can be successfully developed using industrial plant data.

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NOMENCLATURE

C_p	=	statistic defined in the text
b	=	bias
p	=	number of independent variables selected
r	=	total number of independent variables
W	=	weight of connectivity between two nodes
x	=	variable, without super or subscript represents normalised value
z	=	activation of a node

superscripts:

′	=	nonnomalised variable
min	=	minimum value
max	=	maximum value
i, j	=	node numbers

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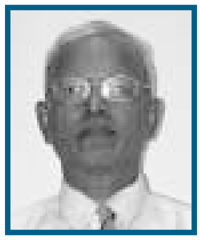

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AUTOMATIC LOAD RESTORATION IN POWER SYSTEM

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ABSTRACT

This paper describes an automatic load restoration method implemented following automatic load shedding. Load restoration is usually initiated manually at the discretion of the authorities. Load restoration after load shedding can only be executed after the system has recovered completely and its normal frequency is restored. Loads should be restored in small blocks sequenced by time delay between successive restorations to allow frequency stabilization. Simulations were performed using the ERACS Power System Software. Important design considerations for this scheme were the maximum anticipated overload, number of load shedding steps, size of load shed at each step and frequency relay settings. A case study was carried out at PETRONAS Penapisan Melaka, whereby a load shedding and load restoration scheme was designed for its upcoming cogeneration plant. Simulations performed indicated that the load shedding and load recovery design is feasible and able to halt frequency collapse due to generation loss, and enables loads to be restored automatically in stages after the system has recovered. The design strategy, calculations and justification are presented in this paper.

***Index terms**: Load Shedding, Load Restoration, Underfrequency, Overload, Inertia Constant, Rate of Frequency Decline*

INTRODUCTION

Electric load shedding is one of the most crucial and effective strategy to retain the generation power margin at nominated level and prevent the widespread system collapse [10]. This involves promptly cutting off power supply to some electric circuits, hence reducing the stress on the electric system. The objective is to prevent frequency and voltage decay and maintain equilibrium between generation and load when there is loss of generation [4]. Load recovery or load restoration is the reclosing of feeders which have been tripped for load shedding. Normally it is left to the discretion of system or station operators. Load restoration service is usually initiated manually after ensuring that the system frequency has completely recovered [8]. Frequency relays can also be used either to supervise restoration or restore load [1]. In this design, automatic load restoration scheme was implemented using ERACS Power System Software.

This paper was presented at the National Power & Energy Conference PECon 2004 organised by IEEE Power Engineering Society Chapter of Malaysia at Kuala Lumpur, Malaysia, 29-30 November 2004.

LOAD SHEDDING DESIGN CONSIDERATIONS

Important parameters

The ratio of moment of inertia of a generator's rotating components to the unit capacity is defined as H. It is the kinetic energy in these components at the rated speed. The H for an individual unit is available from the manufacturer or may be calculated from:

$$H = (0.231)(WR^2)(RPM^2)(10^{-6})/kVA \qquad (1)$$

For a system, a composite value is calculated as follows:

$$H_{system} = \frac{H_1 MVA_1 + H_2 MVA_2 + ... + H_n MVA_n}{MVA_1 + MVA_2 + MVA_3 + ... + MVA_n} \qquad (2)$$

The decelerating power in per-unit of connected kVA is represented as ΔP

$$\Delta P = \frac{\left[\begin{array}{c}\text{Total load to be shed in design} \\ -\text{ Load being removed}\end{array}\right]}{\text{Remaining generation}} \qquad (3)$$

df/dt is the rate of frequency decline.

$$df/dt = -(\Delta P / 2H) \qquad (4)$$

Maximum anticipated overload

Underfrequency relay should be able to shed a load equal to the maximum anticipated overload. The system should be studied with respect to the overload that would result from the unexpected loss of key generating units, transmission ties and busses. The load reduction factor, d was considered, since it would reduce the overload once the frequency dropped. To design a conservative scheme, was safest to assume that d equals zero.

$$\%\ overload = (Total\ generation\ loss\ / Remaining\ generation) \times 100\% \qquad (5)$$

Load shedding schemes

Load shedding schemes use a few groups of relays, one operating at a lower frequency than another and each shedding some percentage of the predetermined load [10]. The higher-set relays would trip first, halting the frequency decline. For more severe overloads, the frequency will continue to drop, although at a slower rate, until the second group of relays operate to shed another block of expandable load. Most utilities use between two and five load shedding steps.

The size of load shedding steps was related to expected overloads. When a study of the system configuration revealed that there was a relatively high probability of losing certain generating units or transmission lines, the load shedding blocks was sized accordingly. Each step sheded only enough loads to handle the next more serious contingencies. Each step was evenly spread over the system by dropping loads at diverse locations.

Frequency settings

The frequency at which a step will shed load depends on the system's normal operating frequency range, the operating speed and accuracy of the frequency relays and the number of load shedding steps [4]. The frequency of the first step was just below the normal operating frequency band of the system, allowing the variation in tripping frequency of the relay. The remaining load shedding steps was selected as follows:

(i) Based on the best estimate of P, calculated df/dt using equation (4). Employing relay tripping curves, calculated the actual frequency at which load will be shed by the first step relays for the most severe expected overload.
(ii) Set the second step relays just below this frequency, allowing a margin that would tolerate any expected frequency drift for both sets of relays.

(iii) Calculated the actual frequency at which the second load shedding step would occur. The rate of frequency decline by the second-step relays could be calculated as that resulting from the most severe expected overload minus the load shed in the first step.

LOAD RECOVERY DESIGN CONSIDERATIONS

Frequency would be allowed to return to normal before any load is restored.

(i) Load would be restored in very small blocks to avoid overload. The load would be restored in blocks of 1% to 2% of system load. Reconnecting small blocks of load would cause a few frequency dips which could be handled by the governors.
(ii) Each successive block would be allowed a slightly longer time delay than the previous one. After restoring the first block of load, the frequency would be re-establish at the normal system frequency. Then, the second block relays would time out and reclose, followed by the third block. This process would continue until all blocks are restored or the spinning reverse is exhausted.

CASE STUDY ON PETRONAS PENAPISAN MELAKA

Introduction to cogeneration plant

A cogeneration plant is designed to generate electricity and HP steam required by the refinery complex.

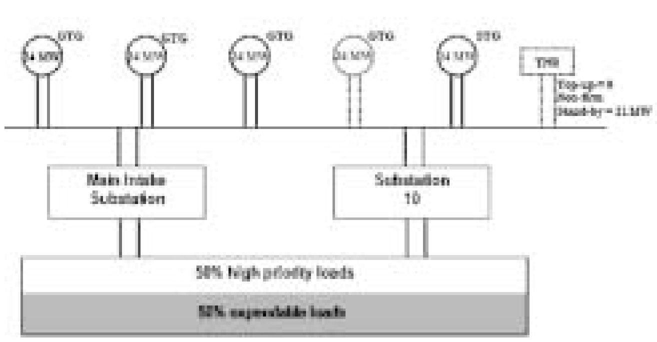

Figure 1: COGEN electrical distribution diagram

Under normal operating conditions, 3X24 MW (GTG) and 1X24 MW (STG) operate, supplying 96 MW. The maximum generation loss designed for by the scheme was 50% or 48 MW at system peak. The spare 1 X 24 MW (GTG) and TNB non-firm stand-by (dotted lines) would be activated to ease overload and restore load after load shedding.

Design strategy

Typically, underfrequency load shedding design begins with a classic or static model, where generally the number of steps, step frequencies and load shedding quantum is determined. The discrimination between load shedding stages and between last stage and machine tripping stage were checked in the static model. Then, load shedding feeders were assigned based on the required quantum and other criteria. Finally, simulations were performed to verify the performance of the design.

Design and calculations

Initial Generation:	50% (48 MW)
Initial Demand:	100% (96MW)
System frequency:	50 Hz
System inertia:	H = 5 for GTG
	H = 7 for STG
Relay + CB opening time:	0.150 sec

Load shedding priorities

Load shedding priorities were determined based on the criticality of the loads. The least important loads were shed in the first stage and the very important ones were shed in the last stage. Those units which were compulsory to ensure the safe operation of the plant were not included in the load shedding scheme. The whole plant would have to be shut down if there was insufficient supply to the compulsory units. In this load shedding design, five categories of load were defined.

The non-essential loads were in the non-process area, including administration building, workshop and

Table 1: Final load shedding scheme and relay settings

Step	Load shed(%)	Total load shed(%)	Freq. relay setting(Hz)	*df/dt* (Hz/sec)	t_{trip}(sec)	Load shed freq.(Hz)
1	12.5	12.5	49.50	-4.545	0.260	48.82
2	Add 12.5	25.0	48.77	-3.307	0.165	48.27
3	Add 12.5	37.5	48.22	-2.205	0.173	47.91
4	Add 12.5	50	47.86	-1.042	0.198	47.70

laboratory. End product units, such as Distillate Hydrotreater Unit (DHT) and LPG Treating Unit (LTU) were in the essential loads category. Following the process flow, the crucial category included downstream units, such as Hydrocracker Unit (HCK), Delayed Coker Unit (DCU) and Sulphur Recovery Unit (SRU). This was trailed by the very crucial category, covering Catalyst Regeneration Unit (CCR) and Saturated Gas Plant (SGP). Finally, the most critical units which could not be shut down in the load shedding system fell under the mandatory category. Upstream units, such as Crude Distillation Unit (CDU) and Vacuum Distillation Unit (VDU) were in this category. Besides that, the Main Control Building (MCB) and Utilities were also very critical and compulsory for the plant.

Load restoration service

If the load shedding program were to be successfully implemented, the system frequency would stabilize and then recover to 50 Hz. Load restoration service would be initiated manually after authorized personnel ensures that system frequency has completely recovered and sufficient generation reserve is confirmed to be available. Looking at the network size, the typical delay time for peaking of generator and reclosing tie-lines would be 30 seconds to several minutes. In this design, 45 seconds was allocated for these purposes and the first block of load was restored after another 10 seconds. The system frequency would dip when additional load was connected and eventually returned to normal frequency as the spinning reverse became active or the generator picked up the load. Each successive block of load was restored with additional 2 seconds time delay than the previous one to allow frequency

Table 2: Total load of each load shedding step

Priority	Load shedding sequence	Total load
Mandatory	Never	47085 kW 49.05%
Very crucial	Step 4	11746 kW 50.95%
Crucial	Step 3	13164 kW 38.72%
Essential	Step 2	11984 kW 25%
Non-essential	Step 1	12021 kW 12.52%

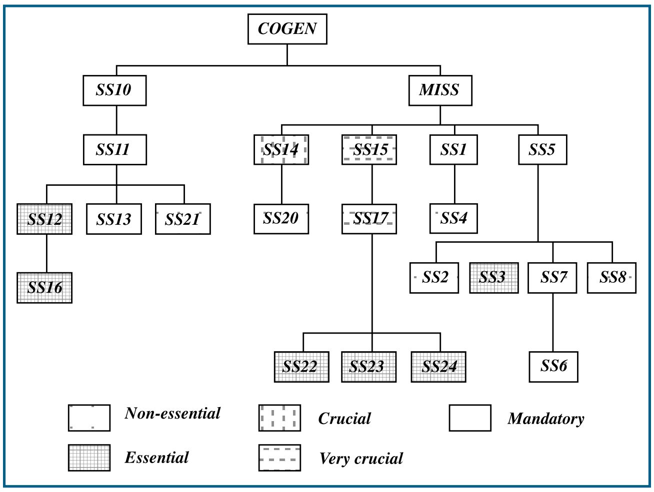

Figure 2: Illustration of load shedding priorities

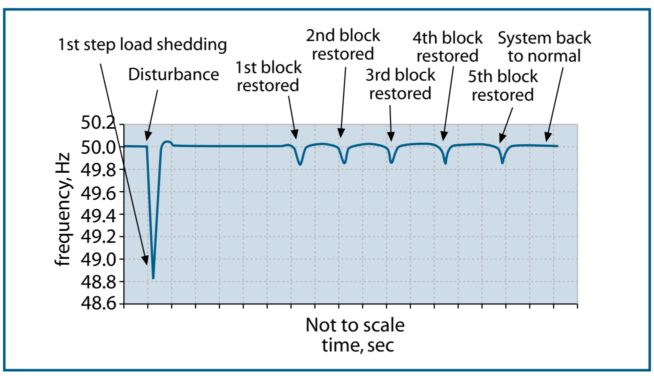

Figure 3: Frequency-time curve for load restoration service (1st step)

Case1: Loss Of 12.5% Of Generation At 0.5 sec Without Load Shedding

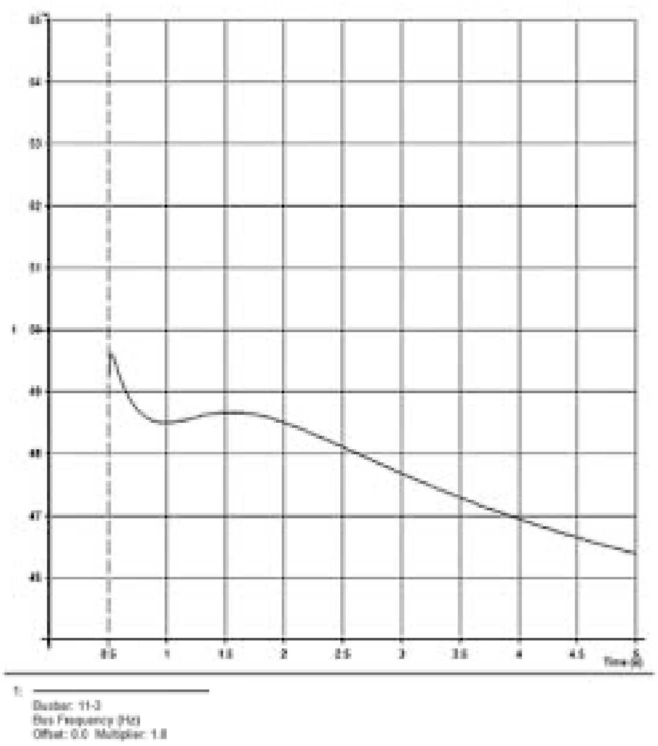

Figure 4: Loss of 12.5% generation without load shedding

Case 2: Loss Of 12.5% Of Generation At 0.5 sec With Load Shedding Activated At 0.76 sec

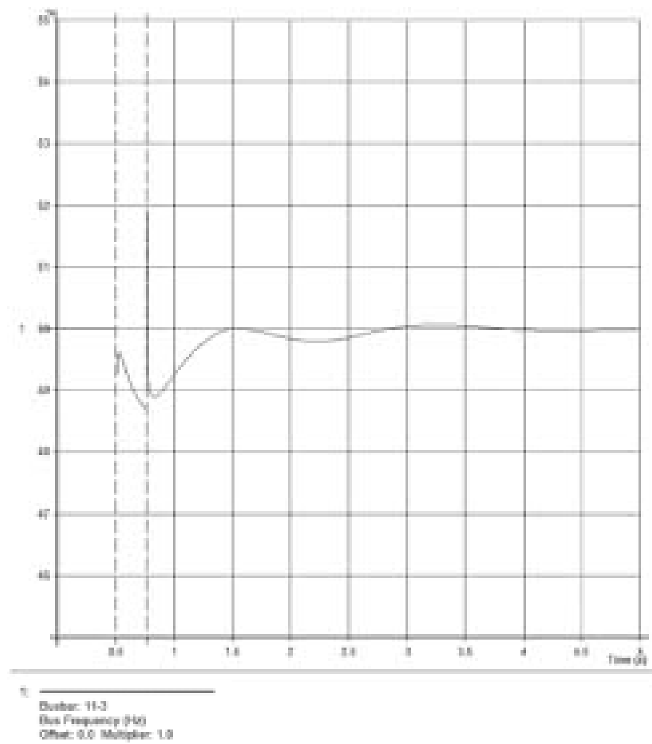

Figure 5: Loss of 12.5% generation with load shedding

stabilization as the system became burdened with more load. Loads were connected on distributed basis to minimize power swing across the system. For the first stage of load shedding, loads were restored in 5 blocks sequentially.

RESULTS OF DYNAMIC SIMULATIONS

In verifying the load shedding scheme designed, first a stability study was conducted to observe the decay of system frequency when generation is lost, without any load shedding. Using this frequency decrement curve, estimates were made for the amounts of load to be shed and the frequency and time delay settings for the underfrequency relays. Then these data was used in the stability study program to calculate the system frequency versus time curve with the proposed load shedding. If sufficient load was shed fast enough to prevent system collapse, the validity of the proposed relay scheme and settings would be confirmed. Usually several runs were made with different system conditions in each load shedding analysis. In this section, dynamic simulation results of the first 2 steps of load shedding scheme designed is presented.

From Figure 4, system frequency collapsed at the instance of generation loss. At about 1 sec, the system frequency stopped decreasing as the spinning reserve of generators tried to relieve overloads. However, since the overload was much greater than spinning reserve, the system failed to recover and frequency continued dropping at a slower rate as time went by due to load reduction factor.

From Figure 5, initially, the system frequency dropped rapidly. At trip time, when the predetermined loads were removed, the frequency rose rapidly due to sudden removal of excessive loads. The frequency dropped again almost immediately and rose gradually.

Case 3: Loss Of 25% Of Generation At 0.5 sec Without Load Shedding

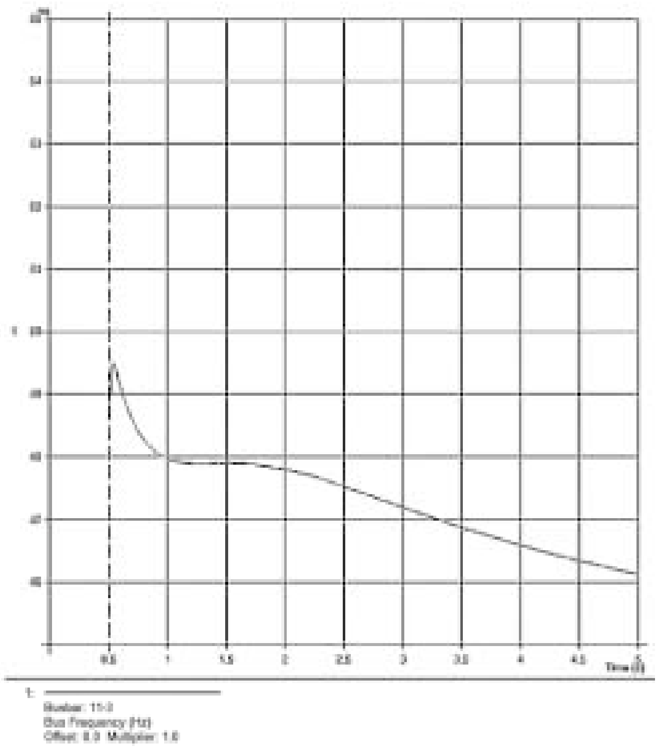

Figure 6: Loss of 25% generation without load shedding

Case 4: Loss Of 25% Of Generation At 0.5 sec With Load Shedding At 0.76 Sec And 0.925 sec

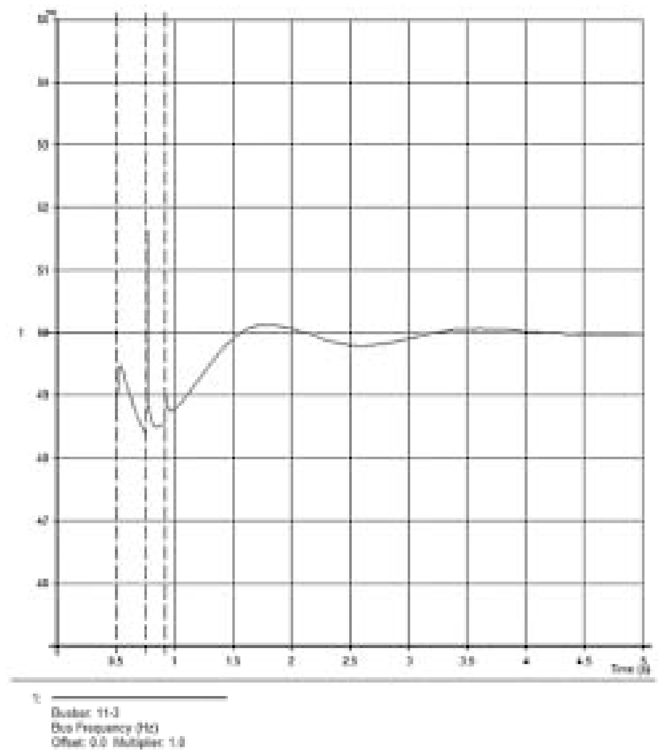

Figure 7: Loss of 25% generation with load shedding

Since the amount of load shed was not less than overload, the system eventually stabilized and normal frequency was restored.

From Figure 6, this case was quite similar to case 1. System frequency collapsed at the instance of generation loss. At about 1 sec, the system frequency stopped decreasing as the spinning reserve of generators tried to relieve overloads. However, since the overload was much greater than spinning reserve, the system failed to recover and frequency continued dropping at a slower rate as time went by due to load reduction factor. Compared to case 1, the rate of frequency decay in case 3 was slightly higher due to higher generation loss and overload.

From Figure 7, at the instance of generation loss, the system frequency dropped rapidly until load was shed at 0.76 sec (first stage). The amount of load shed was equal to 50% of the lost generation. The frequency shot up initially due to the sudden removal of loads but dropped again since the amount of load shed was less than overload. The frequency continued to decay but at a slower rate. This was insufficient to stop further decrease in frequency and restored frequency to normal. At 0.925 sec, another 12.48% of load was dropped (second stage). The frequency stopped dropping as the amount of load shed equaled the overload. Eventually, the system slowly stabilized and frequency returned to normal.

The dynamic simulation results showed that the load shedding scheme designed is feasible, since has been able to prevent system collapse due to generation loss and normal frequency could be restored after load shedding.

CONCLUSION

A load shedding scheme for the upcoming cogeneration plant in PETRONAS Penapisan Melaka was proposed. The total installed capacity of the cogeneration plant is 120 MW. The peak load is 96 MW. The maximum generation loss designed for by the load shedding scheme was 50% or 48 MW at system peak. This was followed by the execution of dynamic simulations using ERACS Power Analysis Software to verify the load shedding design and to gauge the performance of the proposed scheme. Transient stability studies were run and it was clear that system frequency decays when generation is lost, without any load shedding. Soon after load shedding was incorporated, system frequency stopped decaying and normal frequency was restored. This result applied to four case studies which showed a loss of 12.5% and 25% of generation with and without load shedding. The validity of the proposed relay scheme and settings were confirmed since sufficient load was shed fast enough to prevent system collapse during generation loss.

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A FUZZY LOGIC TECHNIQUE FOR SHORT TERM LOAD FORECASTING

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ABSTRACT

The application of Fuzzy Logic to the short-term load forecasting is demonstrated. This technique allows a qualitative description of the system's characteristics and data without the need for exact mathematical formulations. It is demonstrated that Fuzzy Logic technique achieves a logical and practical answer of short-term load forecasting. The simulation is based on historical sample data from the National Grid [1]. In this paper, the special day forecast like religious festival, long weekend and long festival duration were not assigned. This study considered the duration of historical data taken from 14th until 25th February 2003 that did not coincide with any major religious festival or long weekend. The paper illustrates the forecasting of the load demand for the 26th February 2003. Error in the result is compared with the actual and forecast values and the total average error shown is less than 1%.

Keywords: *Fuzzy Logic, Short-term load forecasting, National Grid, Fuzzy Membership Functions, Rule Based*

INTRODUCTION

Short-term load forecasting plays an important role in the planning and operations of power systems and it is necessary for economic scheduling of generating capacity of economic allocation. The accuracy of this forecast value is important to decide when and where the station should shut-down or start-up. The use of fuzzy logic has received increased attention in recent years because of its usefulness in reducing the need for complex mathematical models in problem solving [2].

Fuzzy Logic's strong abilities in finding solutions made it easy to approximate any complicated non-linear relations. The ability of fuzzy logic to capture system dynamics qualitatively and execute this qualitative idea in a real time situation is an attractive feature for short-term load forecasting. In this paper the simulation was demonstrated with the fuzzyTECH 5.52 software [3]. The model is based on the data gathered from actual national load demand. The National Grid network is distributed along Peninsular Malaysia.

This paper was adapted from the presentation at the Regional Symposium on Chemical Engineering (RSCE) 2002, Kuala Lumpur, Malaysia, 28-30 October 2004.

Its coverage starts from the northern state of Perlis down to the southern state of Johor. The National System Planning is located in Petaling Jaya, Selangor, where all data were gathered before sending to each of the power plants.

SHORT-TERM LOAD FORECASTING

The power system's average load changes periodically from Sunday to Saturday. The lowest load appears on Saturday and Sunday, whilst the highest load appears on weekdays. However, the changing regularity of daily load is almost the same, and on the same weekdays of neighbouring weeks, the magnitudes of the loads and their regularity of change are similar.

In this paper *n +1* day (where *n* is a current day), load demand is forecasted for all $t_{00}...t_{23}$ hours. The forecasting processes or simulations basically ran at *n* day and before t_{12} of that *n* day. To forecast the hourly *n+1* day load demand, the model needed few input variables. There were three input variables needed in order to forecast the *n+1* day load demand, i.e. the previous load demand temperature and time.

Short-term Load Forecasting Model

This paper basically forecasts the hourly load demand of the national load demand. Using the fuzzyTECH 5.52 software, the model for the study was developed, simulated and analysed. The model had 3 inputs and 1 output, with rule blocks.

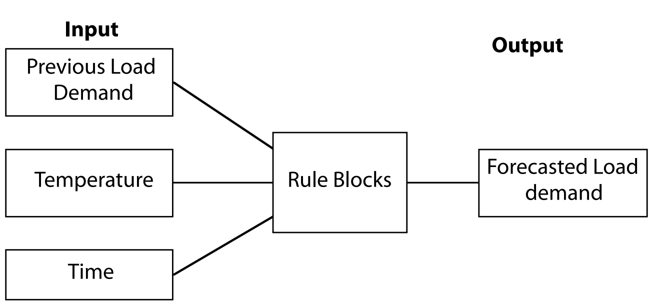

Figure 1: Shows the model of the short-term load forecasting

Figure 1 shows the model of the short-term load forecasting and Figure 2 shows the flowchart of the short-term load forecast by fuzzyTECH.

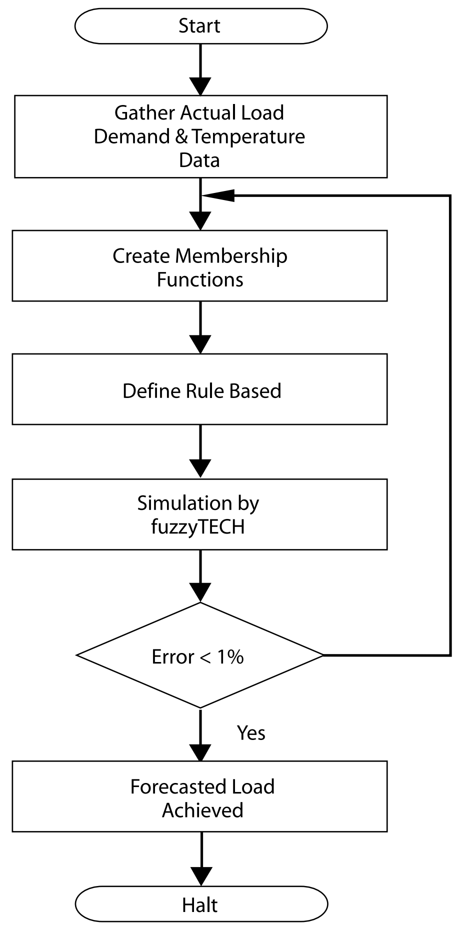

Figure 2: Flowchart of the short-term load forecast by fuzzyTECH

The previous load demand, temperature and time were specified as the input to the model. The output is load demand, which is the forecasted load demand at a given time variable. The input membership functions were assigned as follows: membership functions for the particular previous load demand were presented as, Prev {very_small, small, medium, large, very_large}. For the hourly temperature, the membership functions were reported as temp {low_temp, medium, high_temp}. There were 24 memberships for time, which indicated hourly time from midnight to next midnight, and this was represented as time $\{t_{00}, t_{01}, t_{02} ... t_{23}\}$.

The short-term load-forecasting model was applied for the task of hourly electrical load forecasting. Since the task is to forecast hourly, the input parameters are concerned with previous load demand, temperature and time. By following all the steps in Figure 1, the results of membership functions for all inputs were carried out. This data was classified as the input data. The output was presented as load demand. Table below shows the number of membership functions that were used in this model.

Table 1: Input and Output Membership Functions

Input	
Previous load demand	5
Temperature	3
Time	24
Output	
Load Demand	5

Fuzzy Sets Associated with Input and Output

After identifying the fuzzy variables associated with input and output, the fuzzy sets defining these variables were selected and normalised between 0 and 1. The sets defining the input and output variables were as follows:

Previous load demand (MW)
= {very_small, small, medium, large, very_large}

Temperature (°C)
= {low_temp, medium_temp, high_temp}

Time (Hours) = $\{t_{00}, t_{01}, t_{02}, \ldots, t_{22}, t_{23}\}$

and,

Load Demand (MW)
= {very_small, small, medium, large, very_large}

The triangular and trapezoidal shapes are chosen for each fuzzy input and output variable for the membership functions. For convenience, approximately 25% to 50% is the suggested overlap between neighbouring sets [4].

Rule Blocks

Once these sets were established, the input variables were then related to the output variables by the *If-Then* rules as in the Rule Blocks shown in Figure 2. Generally, each rule can be represented in the following mode:

If (antecedent) *then* (consequence)

Previous load demand, temperature and time were considered as input variables and load demand as the output variable. For example:

If (previous load demand is small *and* temperature is low_temp *and* time is 00) *then* (load demand is small)

This relation can also be written as:

Load demand = {Previous load demand} *and*
{Temperature} *and*
{Time}

Based upon these relationships, a total of 1,800 rules were composed. Rules that were not feasible were excluded. The rules that were eventually applied totalled 210.

Fuzzy Inference-Mamdani Method

The most commonly used fuzzy inference technique is called the Mamdani method. All steps taken in this Mamdani method is performed through the fuzzyTECH. In this paper, the centroid or centre of gravity method was chosen to be the method for the defuzzification process. This method finds the point where a vertical line would slice the aggregate set into two equal masses. Centre of gravity (COG) can be expressed as:

$$COG = \frac{\int_a^b \mu_A(x)x\,dx}{\int_a^b \mu_A(x)\,dx} \quad (1)$$

RESULTS

This paper forecasts the load of the National Grid on Wednesday, 26th February, 2003 with the above models. The result is shown in Table 2 and Figure 3 below. RE (Relative Error) and MAPE (Mean Absolute Percentage Error) were used to evaluate the result error.

$$RE = \frac{FL_i - AL_i}{FL_i} \text{ x } 100\% \qquad (2)$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{FL_i - AL_i}{FL_i}\right| \text{x } 100\% \qquad (3)$$

where FL was the forecast load, AL was the actual load and n was the number of hours.

Table 2: Error analysis on Wednesday (26th Feb, 2003)

Wed 26th Feb 2003 (Hours)	Forecast Load (MW)	Actual Load (MW)	Relative Error (%)
0000	8023	8088	-0.8102
0100	7700	7654	0.5974
0200	7413	7453	-0.5396
0300	7100	7181	-1.1408
0400	6900	7056	-2.2609
0500	6980	7035	-0.7880
0600	7188	7251	-0.8765
0700	7390	7463	-0.9878
0800	7851	7921	-0.8916
0900	9105	9180	-0.8237
1000	9740	9743	-0.0308
1100	10280	10265	0.1459
1200	10108	10187	-0.7816
1300	9990	9940	0.5005
1400	10380	10407	-0.2601
1500	10540	10522	0.1708
1600	10590	10580	0.0944
1700	10090	10102	-0.1189
1800	9320	9228	0.9871
1900	8900	8931	-0.3483
2000	9537	9551	-0.1468
2100	9545	9568	-0.2410
2200	9101	9138	-0.4065
2300	8603	8720	-1.3600
		MAPE (%)	0.6379

On Wednesday, 26th February, 2003, the average error was below 1%, with highest error at 0400 hour which was 2.2609% (under forecast) and lowest error at 1000 hour, which was 0.0308% (under forecast). For error at peak hour 1100 and 1400 both were considerably low which was 0.1459% (over forecast) and 0.2601% (under forecast) respectively.

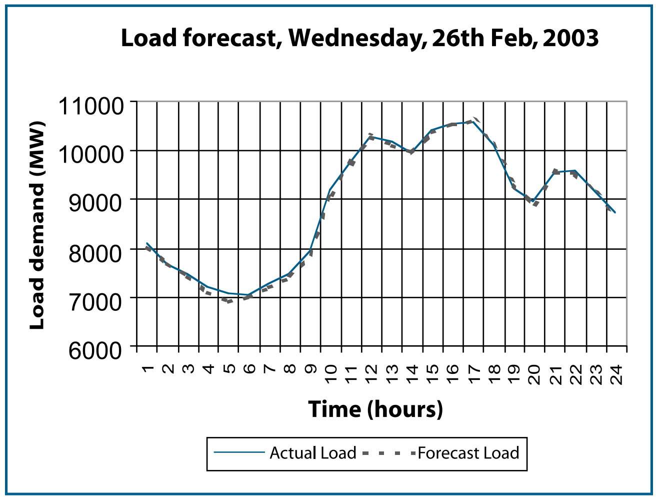

Figure 3: Curve for actual load and forecast load demand versus time (24 hours)

CONCLUSION

This work demonstrated the steps taken in computing the load forecasting value using fuzzy logic technique. The model utilised the load data of the National Grid and ambient temperature data. It was demonstrated that the fuzzy logic technique could be an alternative method to solve the short-term load forecast value.

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Hardware Implementation of Feedforward Multilayer Neural Network Using the RFNNA Design Methodology

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ABSTRACT

This paper proposes a novel hardware architecture for neural network that shall be named Reconfigurable Feedforward Neural Network Architecture (RFNNA) processor [1]. This neural network architecture aims to minimize the logic circuit as required by a fully parallel implementation. The Field-Programmable Gate Array (FPGA)-based RFNNA processor architecture proposed in this paper shared logic circuits for its hidden layer neurons and could be reconfigured for specific applications [2,3], which required different neural network structures. This was achieved by storing connection and neuron weights for the multiple hidden layers in the EPROMs and utilized the hidden layer neuron's logic circuits iteratively for multiplication, summation and evaluation purposes. In this paper, training of neural network was not considered and was performed offline using software. The resulting weights and biases were then loaded into the RFNNA processor's EPROMs for implementation [1]. The RFNNA processor was tested with the XOR non-linear problem using a 2-3-3-3-1 architecture.

Keywords: *Artificial Intelligence, Neural Network Processor, Field Programmable Gate Array, FPGA, Reconfigurable, Hardware Implementation, RFNNA, Feedforward Multilayer*

INTRODUCTION

Neural information processing is an emerging new field, providing an alternative form of computation for demanding tasks. Examples of neural network applications are character recognition and stock market forecasting [4]. Neural networks can be implemented using either software which is based on a central processing unit or on a dedicated hardware, which can process inputs in parallel and decentralized fashion [5]. The latter is a neural network processor, which can yield tremendously fast computations as required by neural network applications. Due to the heavy computation demands of a neural network, hardware based solutions are preferred.

A neural network is made up of a collection of neurons, which are arranged in layers known as hidden layers. Each neuron is an individual processing unit that performs summation and has an activation function that normalizes the result of the summation before passing the value to other neurons in the subsequent hidden layer. The number of neurons in a layer is arbitrary and the number can be between 2 and 200 neurons or even more depending on the application [6]. The number of hidden layers also depends on the application for which the neural network is designed. The allocation of resources between number of neurons and hidden layers are inversely proportionate.

This paper was presented in the International Conference on Neuro-Computing and Evolving Intelligence, Auckland University of Technology Park, Auckland, New Zealand, 13-15 December 2004.

Figure 1 illustrates a typical feedforward neural network structure with two inputs, two hidden layers with three neurons in each, and one output. The dark circle refers to a deposit of biased values, which is unique for each neuron that it is connected to.

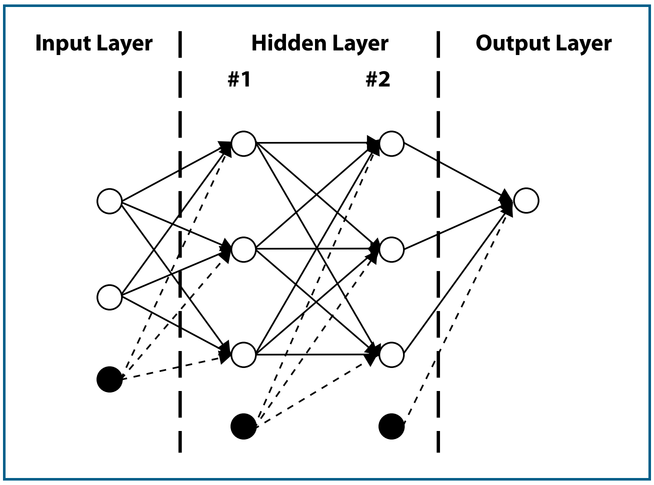

Figure 1: A 2-3-3-1 Neural Network Architecture

Current implementation of a neural network processor requires large amounts of logic resources since it is implemented with a fixed structure, allocating hardware resource for each and every neuron and connection weight.

In order to improve the hardware implementation of the neural network structure in Figure 1, this paper proposes a novel architecture called Reconfigurable Feedforward Neural Network Architecture (RFNNA) based on a paper by Zain Ali, et al. [1]. The RFNNA is a design methodology for hardware implementation of neural networks. The main advantage of using the RFNNA design methodology is that it can reduce the amount of logic gates used for a fully parallel neural network [7,8] of multiple layers to just only one single hidden layer by iterating the use of one hidden layer's resources. Theoretically, a neural network design using RFNNA can have infinite number of hidden layers; though this is constrained by the amount of resources allocated to store connection weights and biases.

ARCHITECTURE OF RFNNA PROCESSOR

Figure 2 below shows a high level view of the RFNNA processor. The Multiplication/Summation Block refered to an individual neuron. There were 3 neurons altogether, catering for the 2-3-3-3-1 architecture, that is, the processor has 2 inputs, 1 output and 3 hidden layers with 3 neurons each. The block diagram as in Figure 2 was broken down into 11 functional modules as in Figure 3 for the actual design. Selected modules are described as follows.

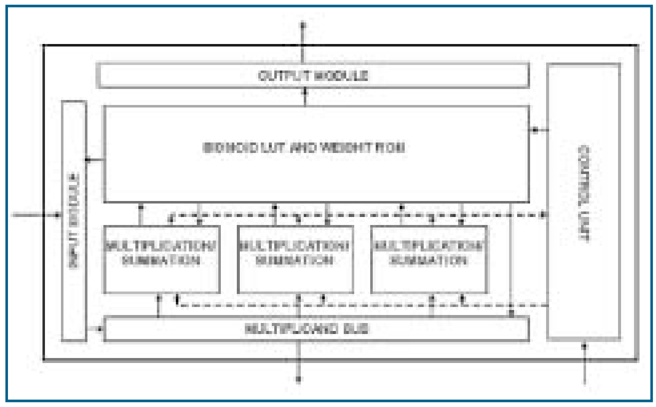

Figure 2: RFNNA Processor for XOR Problem

Input Module

This module served as buffer and multiplexer to external inputs as well as outputs from the activation function. External inputs were first converted into its equivalent value for arithmetic computation. The input module accepts and assigns values to external inputs to be stored into the multiplier buffers concurrently. However the same buffers were written sequentially when data was passed from the activation function. No conversion was required for data from the activation function. Besides receiving and storing data, the Input Module was also required to correctly broadcast the values in its buffers onto the multiplicand bus.

Bias and Weight EPROM Module

There were three Bias and Weight EPROM Modules in the designed processor. Each module was similar to the other, differing only in the weight and bias values they carried. Each module was dedicated to one neuron and stores bias and weight values for three hidden layers and one output layer. As in the Input Module, weight values were sequentially passed to the Neuron Module. Each module had an internal counter which told the module which weight value is to be passed on. External signals to the modules told which layer the bias and weights value it could select from. The bias values stored in the modules were in twos complement format while weight values were stored in signed magnitude integer. The fraction size for the weight and bias values were different. The fraction size for weight values was equivalent to 0.01 (11 bit word) whereas the fraction size for bias values was 0.0001 (21 bit word).

Neuron Module

Multiplication for the neuron module used the Add Shift Right (ASR) algorithm. This algorithm was suited for unsigned binary multiplication, which was the type of data presented to it. While the multiplication algorithm involved unsigned binary integer, a register was used to store the sign bit of the multiplicand. The sign bit acts as a flag as to whether the multiplication result needed to be complemented before it is summed up with the bias value stored in a 21 bit wide output register.

There was only one multiplier designed into each neuron, therefore multiplier and multiplicand values provided by the Input Module and the Bias and Weight EPROM Module were multiplied and summed up sequentially with the bias value which was directly stored in the 21 bit wide register. The use of only one multiplier per neuron was justified with the amount of logic saved as compared to the time used to complete iteration per hidden layer. The time factor for multiplication was now prolonged corresponding to the number of neurons N per hidden layer. Comparatively, if a fully parallel implementation were to be used, the number of logic gates for the multiplication portion would be N^2 as much. The loading of values would different for the starting of a hidden layer and the loading of values thereafter. Bias values would only be loaded once for every hidden layer into the Neuron Module whereas multiplier and multiplicand values were loaded during each iteration.

Activation Function LUT Module

The LUT, which was implemented and declared as an EPROM block in the FPGA device itself, contained many redundant entries. Addressing the LUT was an 8-bit input, which had 256 entries. Using mathematical analysis, it was possible to reduce the EPROM usage from 256 x 8 bit word entries to 63 x 8 bit word entries. This was because there were only 50 unique data that was being accessed in the LUT ranging from decimal equivalent of 50 to 99. Several of the combinations could be grouped together for an entry thus reducing the need for individual access for equivalent results.

The inputs from the Number Representation Converter Module were used to address the activation function LUT as well as to note the sign of the input argument. As was mentioned before, the LUT table could only address values from 50 to 99 corresponding to the sigmoid range of 0.50 to 0.99. These values were only valid for positive arguments. If the sign of the argument were negative, some manipulation of the LUT result had to be performed. The LUT equivalent would be subtracted from 100 to produce the correct answer.

Control Unit

The Control Unit for this neural network processor had 10 distinct inputs and 10 distinct outputs. The Control unit was able to guide the rest of the modules to function as intended at the right time.

The Control Unit provided control signals to all modules except for the Number Representation Converter Module and the Activation Function LUT Module. The system was designed such that in case of a reset, the whole processor could be set back to its initial state.

The Ready flag, which was connected to an external output pin, notifies the user whether the processor was available for processing or when processing was being performed.

ORGANIZATION OF RFNNA PROCESSOR

The modules described earlier were arranged and connected as shown in Figure 3. There were a total of 5 external inputs and 2 external outputs.

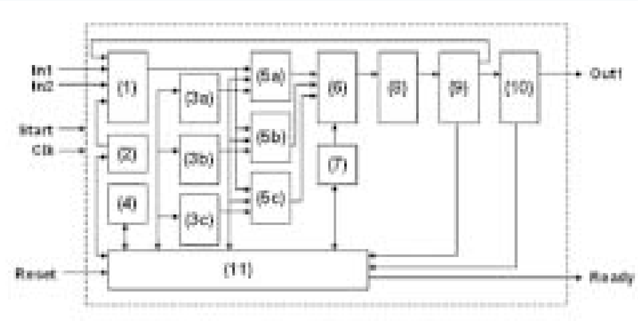

Figure 3: Block diagram for the RFNNA Processor

(1) Input Module
(2) Input Module Counter
(3) Bias and Weight EPROM Module
(4) Bias and Weight Counter Module
(5) Neuron Module
(6) Neuron Output Multiplexer Module
(7) Neuron Output Multiplexer Counter Module
(8) Number Representation Converter Module
(9) Activation Function LUT Module
(10) Output Threshold Module
(11) Control Unit

The Input Module (1) took in inputs from external inputs and also from the output of the Activation Function LUT Module (9). The output from the Input Module was simultaneously fed into the 3 Neuron Modules (5a, 5b, 5c) via a 7-bit wide data bus. Individual Bias and Weight EPROM Modules (3a, 3b, 3c) were assigned to each Neuron Module, providing two types of inputs to it; bias values (21 bit) and weight values (11 bit).

Multiplication of inputs and weights were performed sequentially and the result summed up after each iteration. By employing the ASR multiplication algorithm, all multiplication tasks in the neurons were completed simultaneously, given the same multiplier value (input) regardless of what the multiplicand value (weight) was. Therefore only one of the modules needed to provide feedback to the Control Unit (11) as all other neuron computations were synchronized.

There was only one Activation Function LUT Module. Therefore each Neuron Module output had to take turns to access the activation function resources. This task was performed via the Neuron Output Multiplexer Module (6) which multiplexed between the 3 neurons. The output of the Activation Function LUT Module was directed to 2 modules, Input Module and Output Threshold Module (10).

A neural network's neuron encompasses the summing up of weighted inputs and passing the value through the activation function. However for this design, the individual neuron's function included the multiplication of input values with the connection weights. The passing of summation results for each neuron into the activation function were detached into a separate process.

The Control Unit through the external output Ready notified the user whether the value of the Out pin was valid or otherwise.

EXPANDABILITY OF RFNNA PROCESSOR

Input values were passed to the Neuron Modules through a multiplicand bus (refer Figure 2). This bus when connected to external outputs could be used to expand the capacity of the RFNNA processor. This expandability adds to the versatility of the RFNNA processor making it possible to be used for applications which require more neurons per hidden layer that can be fitted into a single FPGA chip [1]. Figure 4 illustrates how multiple RFNNA processors can be connected together for parallel processing.

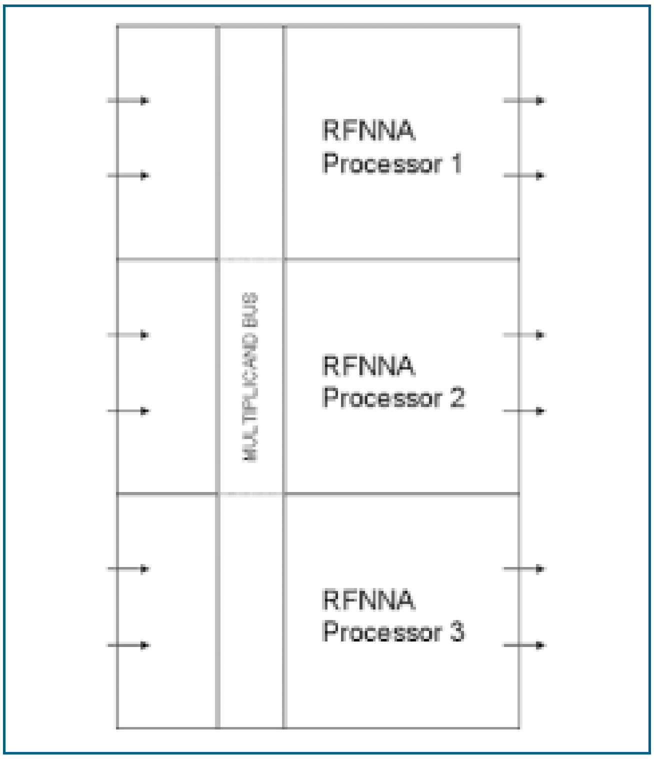

Figure 4: Parallel Processing of RFNNA Processors

CONCLUSION

The paper describes the advantages of a novel hardware architecture for neural network called RFNNA. RFNNA is a design methodology to reduce circuit area requirement in an integrated circuit. The optimization is achieved through reiteration of a single hidden layer. This approach enables the RFNNA processor to cater for applications, which require any number of hidden layer neurons. The versatility of the RFNNA processor is improved by allowing it to be connected in parallel thereby permitting a larger number of neurons per hidden layer.

The weight and bias values are stored within the processor's EPROM itself, thus limiting the number of hidden layer weights and biases that can be stored. For the RFNNA processor to cater for any application in a single chip, the design must have an external RAM to store information for weight, bias and network connectivity information. Thus when the processor is need to be run different applications, only RAM values need to be reinitialized. This general-purpose design would also be suitable for hardware implementation using Application Specific Integrated Circuits (ASICs) which is capable of faster processing speeds and a larger neuron count.

NOMENCLATURE

H	=	Inertia constant
WR^2	=	Wight of rotating parts of generating unit (lb) multiplied by the square of radius of gyration (ft)
RPM	=	Rotation per minute
H_n	=	Inertia constant of n^{th} generating unit
RPM_n	=	Rotation per minute of n^{th} generating unit
kVA	=	Apparent power
P	=	Decelerating power in per-unit of connected kVA
df/dt	=	Rate of frequency decline
GTG	=	Gas turbine generator
STG	=	Steam turbine generator
SS	=	Substation
MISS	=	Main intake substation
CB	=	Circuit breaker
t_{trip}	=	Trip time
$t_{pick\text{-}up}$	=	Pick up time

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EVALUATION ON USER NAVIGATION IN VIRTUAL GALLERY USING VIRTUAL CHARACTER

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ABSTRACT

This study focused on evaluation of the effectiveness in using a virtual character in a virtual gallery to improve user navigation. A virtual gallery was developed and a virtual character was integrated in to the gallery. Sixteen final year students were chosen to participate in the evaluation. Two main questions were posed – does the virtual character provide visual cues to help guide participants through the virtual gallery and does virtual gallery appear natural and increase realism. This has been measured by time taken to complete a task and number of mistakes made. At the same time, checklists in a questionnaire were distributed and interviews were conducted with the participants. The result showed that the usage of virtual character is more effective because of the low number of errors made and the faster time taken to navigate and explore the gallery. The overall mean of 3.7 also indicated that there is an improvement in navigation by the participants. The rating also showed that 87.5% of participants felt that the virtual character was needed in the virtual gallery. In conclusion, the use of a virtual character in a virtual environment is one of the effective ways for users to navigate through a virtual gallery by the users.

INTRODUCTION

The focus of this study is to investigate the usage of a virtual character in a virtual environment from the perspective of navigation. Navigation in a virtual environment is limited to such factors as system goals, environment types and user experience. Users will face minimal problems if they are familiar with the navigation concept in a virtual reality environment. Nevertheless, in exploring a new virtual environment such as a walk-through, application goals are hard to achieve even with experienced users.

Aim and Objective

The aim of this research project is to investigate potential uses of virtual characters in virtual environments to aid in navigation and exploration. Objectives of this research project are:

- To design and develop a virtual gallery.
- To integrate a virtual character as virtual cues in to a virtual gallery.
- To evaluate the use of a virtual character in a virtual environment in order to improve navigation and exploration.

This paper was presented in the International Conference on Computer Graphics, Imaging and Visualization, Penang, Malaysia, 27-29 July 2004.

Problem Statement

Usability problems associated with navigation and exploration of virtual environments (VE) are attributed to many causes. These include the lack of navigational cues to guide the user around rooms, buildings or through the VE itself [1]. Also, when participants get too close to objects or walls, face the direction of an object, etc. with no additional visual cues to indicate their position within the VE or walk through virtual objects when collision detection is not implemented [4] [2]. This is problematic as navigation is typically the central and most frequently performed activity in a virtual environment.

BACKGROUND

Navigation is defined as the act of navigating or the state of being navigable [6]. Visual navigation controls what the user sees as they move through the virtual environment and turn around using their input device such as a head-mounted display or mouse. It is determined by two parameters, the user's location in the virtual environment and also the gaze direction.

Changes in a user's location within the virtual environment is effected by a virtual vehicle, by the specification of a new vantage point within the environment and the execution of logical command to flay to that point or by simulated teleportals in the distance at which a user can suddenly appear without moving through the intervening space. The changes of location or user movement are also factors of how the visual scene should be change.

Guidelines developed in previous works embeds hints in the construction of the virtual environment to help the user understand the virtual "space" in order to reduce user disorientation [2]. The use of guidelines provide users with greater knowledge of the virtual space and this will aid navigation of the virtual environment [3]. For example, exit and entry points (doors, hallways, path etc.), whenever possible it must be clear to the user that there is an exit option in the area contained within the confines of the display screen (HMD or monitor) [2]. Without the use of guidelines, users can easily get lost and disoriented from the environment. Thus, the objective of the virtual application and the effectiveness of the navigation in the application will not be achieved.

There are many research studies by experts concerning this concept. Among them are avatars, virtual hosts and intelligent agents. They all differ from one another. The only similarity between these concepts is that all use a third character in a virtual environment with their own set of tasks and objectives.

In this study, the users were able to walk through a gallery, to rotate the view and have a guide that provided navigation cues to prevent the user from getting lost in the gallery. This is different from other virtual galleries because the typical virtual gallery only displays work of art and items, and navigation and interaction in the gallery are left to the user to figure out on their own. This easily distracts who users from the objective of the virtual gallery ultimately find themselves lost in the environment.

DESIGN OF VIRTUAL GALLERY

The gallery consisted of five rooms where each room had its own items and objects. Texture was placed for each object, wall and pillar. Figure 1 shows the complete design of the gallery with the gallery items and objects inside it.

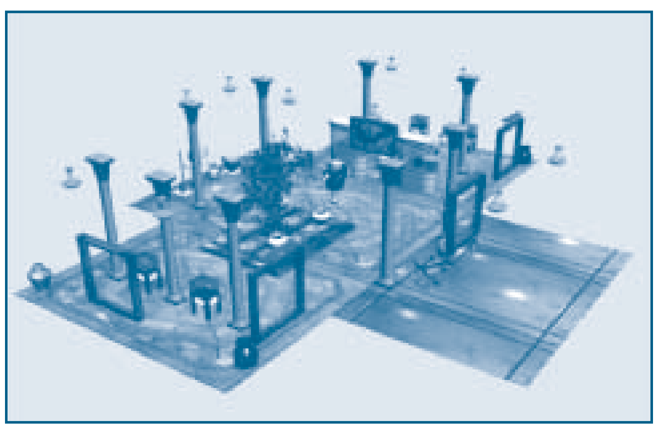

Figure 1: Complete design of the gallery with gallery items

Figure 2: Virtual Gallery with virtual character moving in the gallery

Collision detection was implemented. The purpose of having this feature was to prevent a user from walking through walls and objects. A 'beep' sound set the alarm to alert the user. The alarm indicates that the user had accidentally tried to walk through an object or a wall.

Figure 2 shows the virtual character moving in the gallery. A track follower engine was implemented. The purpose of having a track follower was to let the virtual character move with the user as they walk through in the gallery. The track was defined by a set of control points and could be followed either by an object or by a camera. Each control point was associated with a time stamp, a turn angle, roll information, and a head rotation. Only point fields were required.

METHODS OF CONDUCTING EVALUATION

The study was developed to evaluate the effectiveness of using a virtual character to reduce usability problem associated with navigation within a virtual gallery to reduce user disorientation. Effectiveness was measured in terms of time taken to complete a task and number of mistakes made by the participants [5]. The study will attempt to answer the following questions – do the virtual gallery and virtual character:

- provide visual cues to guide participants through the virtual gallery.
- appear natural and increase realism.

Sixteen final year students were chosen to participate in the evaluation of this virtual gallery. The participants were divided into two groups. The first group navigated and explored the virtual gallery with the virtual character. The second group navigated and explored the virtual gallery without the virtual character.

The virtual gallery was being evaluated by the participants and each participant was expected to perform three tasks based on complexity as follows:

Task 1: Participants need to find one object in the first room.

Task 2: Participants need to find two specified objects in two different rooms in sequence.

Task 3: Participants need to find three specified objects in three different rooms that are not in sequence.

Time taken and number of mistakes made were recorded. After the evaluation, the participants were interviewed to collect more information.

Each participant was given a checklist as a guide to perform the evaluation. The checklist is divided into two sections. In Section A, the focus is on tasks that they need to perform which includes the objective of each task. In section B, the focus is on the use of the virtual character in the virtual gallery. They need to give a rating (1 to 5) and to comment on each attribute evaluated.

RESULTS & DISCUSSION

As shown on Table 1, there is an improvement when using a virtual character compared to without using a virtual character in terms of time and number of mistakes made. For example, in Task 1, the number of mistakes was 2 and time taken was 10 s when using a virtual character. However, when the virtual character is not used, the number of mistakes was 5 and the time taken to complete the task was 14 s. This showed that using a virtual character is more effective because of the shorter time taken and less number of mistakes made to complete all three tasks.

Table 1: Section A – Summary of average number of mistakes and time taken for each task

	With Virtual Character		Without Virtual Character	
	Mistake	Time (s)	Mistake	Time (s)
Task 1 (Simple)	2	10	5	14
Task 2 (Medium)	5	15	9	20
Task 3 (Complex)	7	20	14	29

The results also show that the virtual character helped the participant by providing visual cues. At the same time, the participants would have more clues to proceed to the next step. These visual cues helped the participant construct a cognitive or mental map. The small number of mistakes such as walking through the wall or object during navigation mean that the participants could navigate and explore the gallery smoothly, without guessing where to go next.

Figure 3 shows the evaluation result based on user rating, the minimum mean is 3.5 for tendency of getting lost while the maximum is 3.9 for being able to find items correctly. The range for this section is 0.5 and the overall mean is 3.7. This indicated that there is an improvement in navigation and exploration by using a virtual character. The tendency of getting lost in the virtual gallery ranges from moderate to low. The rating from the participants on the help of virtual character in the virtual gallery ranges from important to very important. 87.5% of the participants felt that virtual character is needed in the virtual gallery.

Results from the interviews showed that 14 of 16 participants felt that a virtual character was helpful as navigation cues in exploring the virtual gallery. All participants suggested that the layout of the gallery should be expanded and more items should be added to the virtual gallery. The interaction with the virtual character should also be expanded, as this will contribute more to the virtual gallery.

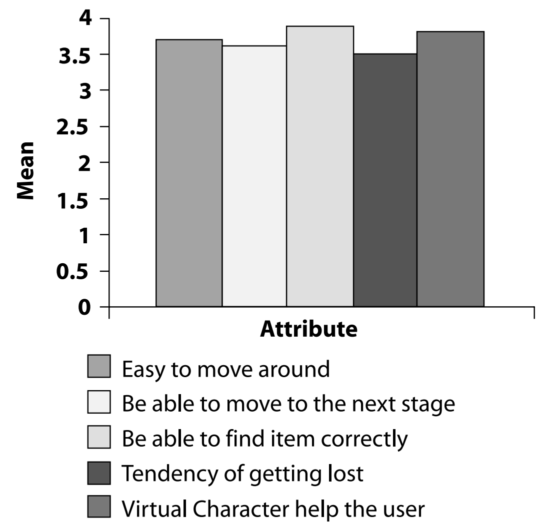

Figure 3: Histogram of result for Section B

CONCLUSION

In conclusion, this study has managed to develop a virtual gallery with a virtual character. The evaluation result demonstrated that the use of a virtual character in the virtual gallery was an effective way in helping to improve the navigation and exploration by the user. This study has also contributed to the virtual reality community for further studies on using virtual characters for exploration, navigation and also interaction.

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TELEHEALTHCARE – MONITORING OF SKIN DISEASES

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ABSTRACT

The paper describes the use of image processing techniques for monitoring the extent of skin diseases from digital images. In cases of images with well-defined lesions (i.e. the difference of brightness level between lesions and the normal skin is distinct), the method of segmentation by thresholding proves to be successful and thus allowing effective monitoring of skin diseases. The technique allows determination of the number of lesions and its area from digital images of affected skin. The development of this technique will enable the monitoring of skin diseases in a telehealthcare application.

Keywords: *monitoring skin diseases, lesions, image segmentation, telehealthcare*

INTRODUCTION

Currently, medical imaging in dermatology is used to keep records of patients with skin disease, essentially for monitoring purpose. It can also be used to provide more improved monitoring method; for example, determining the extent of disease prior and during treatment, based on the size of the affected area obtained from the digital image. This will assist skin specialists in the diagnosis of the skin disease and in gauging the effectiveness of a particular treatment.

Current examination techniques focus on physical examination, and/or biopsy [1,6]. In physical examination, a skin specialist examines patients to diagnose the problem. Biopsy is an invasive method in which the affected tissue is scraped as samples for analysis. The patients may have to wait for appointments and/or biopsy report, resulting in delayed treatment. This situation is aggravated by the lack of skin specialists and statistically, most of them are located in urban areas.

Therefore, there is a need for more efficient methods that are non-invasive and promote in early treatment. Digital medical imaging and dermatosonography (ultrasound) are the techniques that can fulfill the requirements above. In medical imaging, images of skin are digitized for analysis. In dermatosonography, an ultrasound scan provides information/view underneath the skin without requiring biopsy [7,9]. Both techniques allow the development of telehealthcare, which enable skin healthcare to be available to the masses regardless of location, in a

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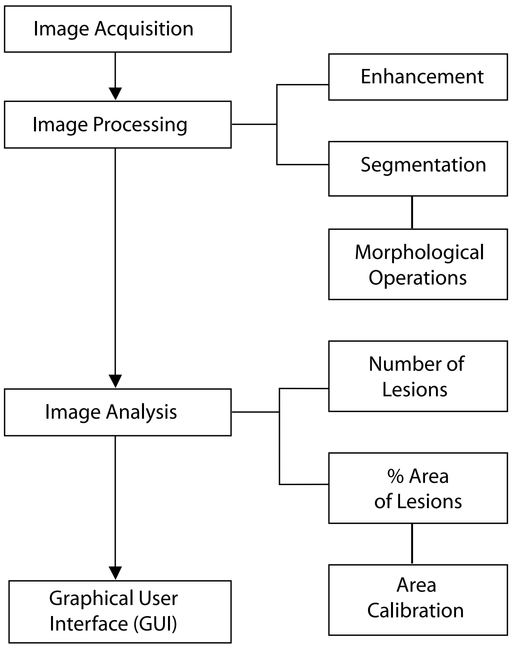


Figure 1: Image processing tasks

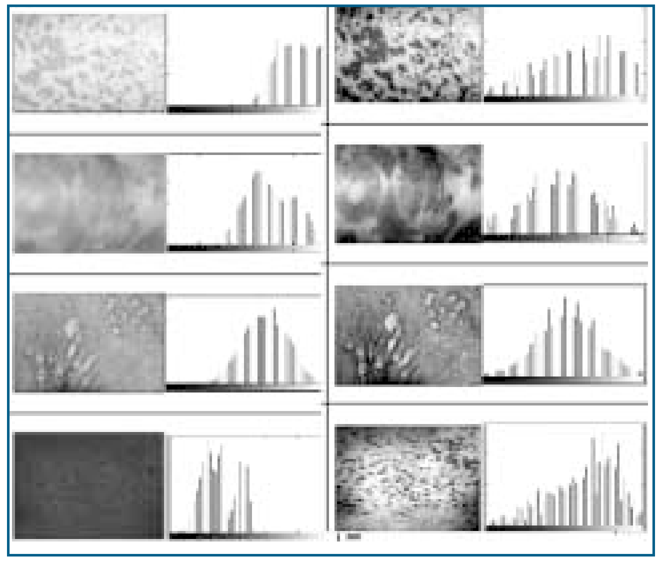


Figure 2: Left – original. Right – after contrast stretching

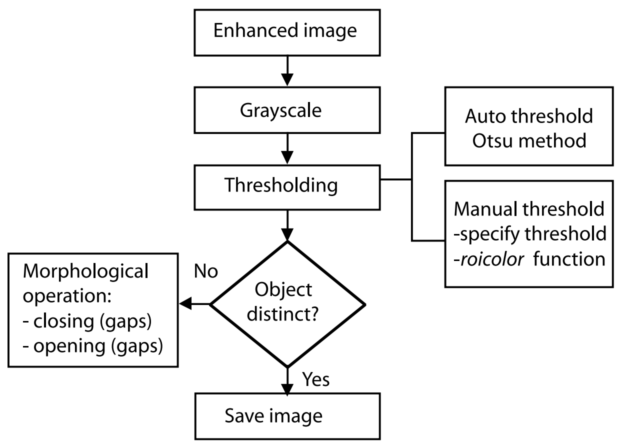


Figure 3: Segmentation process

faster and more efficient manner. In this paper, we outline a monitoring method to determine the extent of skin lesions using digital image processing techniques.

MONITORING OF SKIN DISEASES

The monitoring of skin diseases involves the determination of the number of pixels in the digital image of the skin that corresponds to the affected area or skin lesion.

This monitoring method was developed based on image processing techniques, as shown in Figure 1. A mathematical and visualisation tool, MATLAB 6 + Image Processing Toolbox was used to perform the image processing tasks [5].

Enhancement

Images were enhanced to enable effective segmentation process in the later stage. The technique used was *contrast stretching*. In this technique, the original histogram was stretched so that the whole gray level range was utilised. The histogram retains its original shape although stretched. Dark features became darker and light features became lighter with this technique. As lesions normally appear darker than the skin around it, contrast stretching was found to enhance the appearance of lesions. MATLAB functions used were *stretchlim* that automatically searched and returned values to stretch the histogram and *imadjust* that adjusted image intensity values to a new set of values. Figure 2 shows the effect of enhancement on different samples of skin lesions.

Segmentation

Figure 3 shows the segmentation process [2,4]. The thresholding process returned a gray level image as a binary image, separating objects of interest and the background based on threshold level, for example:

$$Y(i,j) = \begin{cases} 0 \text{ (Background)} & if \quad X(i,j) \leq T \\ 255 \quad \text{(Object)} & if \quad X(i,j) > T \end{cases}$$

where T is the threshold level.

In manual thresholding, a pair of threshold values were used that were selected using the MATLAB function *'improfile'*. As depicted in Figure 4, the dotted lines are lines through points of lesions (at which the grayscale values were to be evaluated). From these values, threshold values were selected: the lowest for LOW and highest for HIGH.

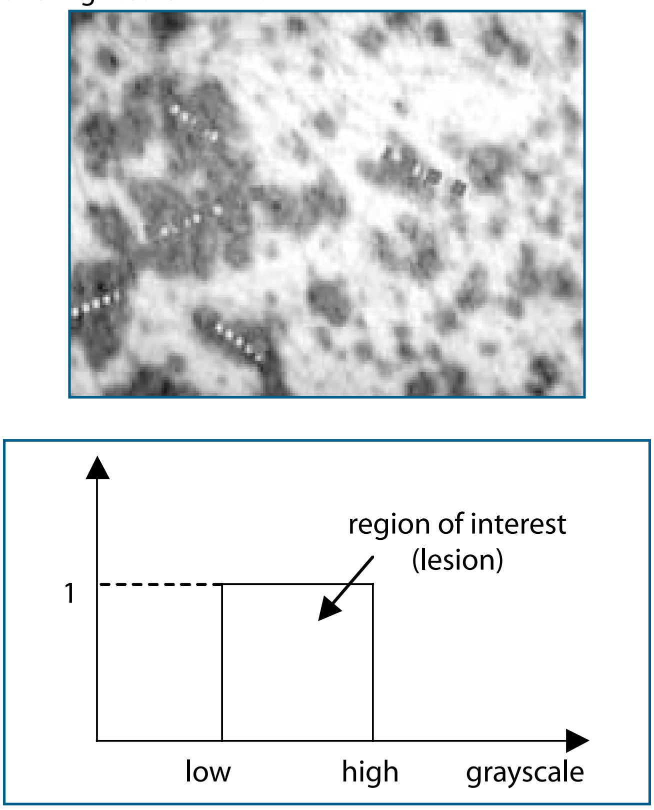


Figure 4: Determining threshold values (LOW and HIGH)

The thresholding can be summarized as below:

BW = (A >= low) & (A <= high) = 1

After the *low,high* values were specified, the thresholding was performed by *roicolor* function. The MATLAB code *BW = roicolor (h,low,high)* returned a binary image which had pixels of the value 1 for every pixel in the grayscale image that fell within the specified brightness region: [LOW, HIGH].

Another thresholding method investigated was the Otsu method that calculated the threshold value automatically [3]. This was achieved by assuming that object and background were from different maxima in the histogram. However, there was a high risk of losing information through this automatic method, explainable by the comparison to the manual method:

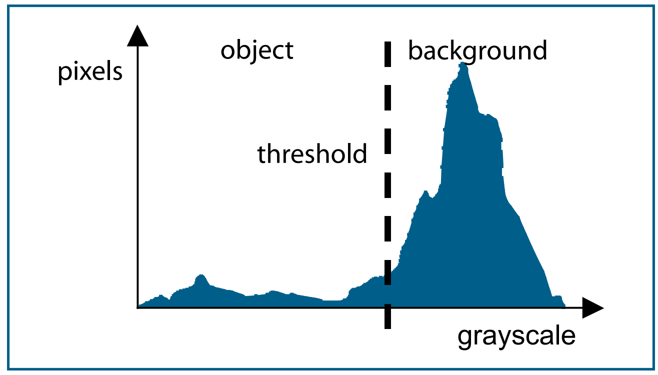


Figure 5: Automatic thresholding – Otsu method

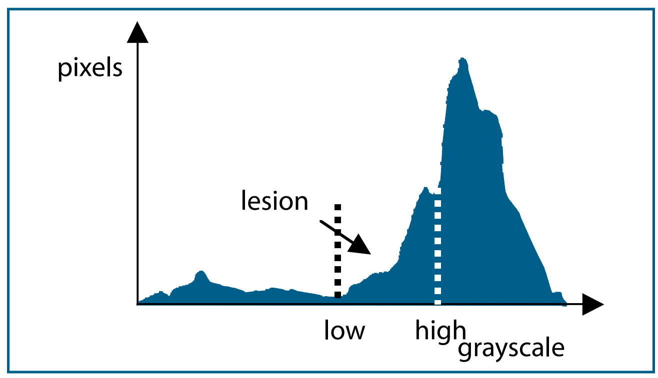


Figure 6: Manual thresholding

From Figure 5, it was seen that the Otsu method interpreted every pixel with the value of less than the threshold value of the object, while everything else is the background. However, the actual lesion area could have pixel values within the region of interest, as depicted in Figure 6. Thus, automatic thresholding by Otsu method could misinterpret object as background, resulting in segmentation errors.

The resultant images obtained by manual thresholding are shown Figure 7. It was observed that white pixels of the binary image corresponded to the lesion area. The technique was able to segment most lesion areas.

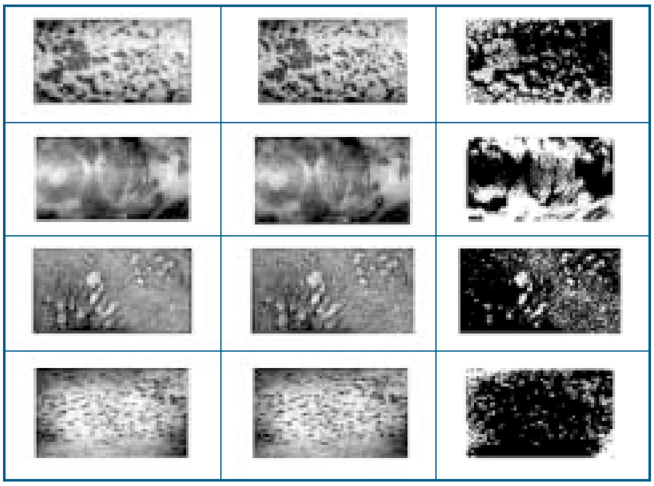


Figure 7: Resultant images after manual thresholding (left to right: original, grayscale, binary images)

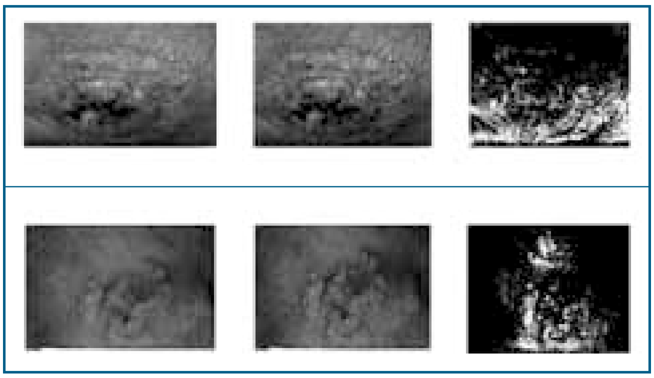


Figure 8: Images

Figure 8 shows images with lesion areas that were not segmented successfully. This was because the lesion areas and the skin around them had similar brightness intensity values. Thus, based on grayscale values they were indistinguishable from each other making segmenting by thresholding unsuitable. For this type of images, other segmentation methods should be used. For example, edge detection and background subtraction.

Morphological Operation

This step was taken if the object of interest in the threshold image was not as distinct as desired. For example, to close the gap between white pixels (to get one distinct object, if any) or o widen the gap between white pixels (to get two distinct objects, if any). The former was carried out using *'closing'* operation, and the latter using *'opening'* operation [2].

The binary images obtained were applied to the MATLAB function *bwmorph*. This function performed morphological operations on binary image, BW as follows:

BW2 = bwmorph (BW,operations)

Here, the *operations* parameter refered to *closing* and *opening*:

BW2 = bwmorph (BW,'close') or

BW2 = bwmorph (BW,'open');

Note that *'close'* performed morphological closing (dilation followed by erosion), and *'open'* implemented morphological opening (erosion followed by dilation).

ANALYSIS

Calculating the Number of Lesions

The number of lesions presented in an image was estimated by using the MATLAB *bwlabel* function. This function labeled all of the connected components in the binary image as follows:

L = bwlabel (BW,n)

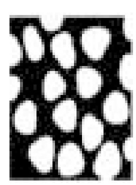
where n is the pixel-connectivity, of which 8-connectivity is most commonly used.

Estimating the % of area affected by lesions

For monitoring a disease's progress, the percentage of area affected by lesions was estimated using the *bwarea* function as follows:

total = bwarea (BW)

where *'bwarea'* estimates the area of all of the ON pixels in an image by summing each corresponding pixel in the image. Figure 9 shows the output obtained using the function.



No. of lesions = 18
Lesion area = 7946.6 pixels
% of area (lesion) = 48.5%

Figure 9: Example

Calibration of lesion area

Calibration is important in determining the actual area in terms of square centimeter for a corresponding pixel area. A line of length 1 cm was drawn (based on attached scale) on the image. By activating the *'pixval ON'* function, the number of pixels residing in a length of 1 cm was estimated by the Euclidean distance

Calibration example:

1 cm ≈ 14 pixels
Previously, the lesions' area ≈ 7946.6 pixels
Thus:

1 cm = 14 pixels
$1\ cm^2 = 14 \times 14$ pixels = 196 pixels
$y\ cm^2 = 7946.6 \div 196 = 40.54\ cm^2$
Thus, the affected area estimated in cm^2
$y \approx 40.54\ cm^2$

ANALYSIS OF RESULTS & DISCUSSION

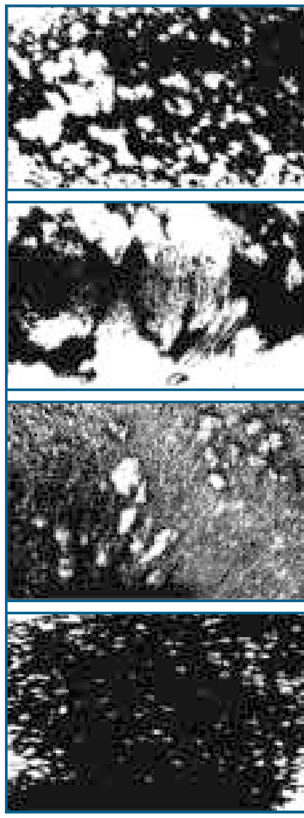
Monitoring skin diseases – estimation

The above analyses namely, calculating number of lesions and estimating percentage area affected by lesions were performed successfully on the segmented images as shown in Figure 10.

The estimation of lesions' percentage was for monitoring disease's progress, for example; either the affected area decreases or increases with time. However, for actual area calculation, calibration was needed, as images/pictures taken at different times were not necessarily taken at the same distance and angle.

Monitoring skin diseases – calibration and accuracy

The following images were calibrated to determine the actual affected area as shown in Figures 11 – 14.



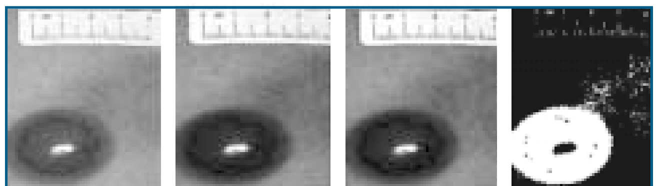
No. of Lesions = 1800
% Area (lesion) = 33.6%

No. of Lesions = 1730
% Area (lesion) = 45.4%

No. of Lesions = 549
% Area (lesion) = 16.85%

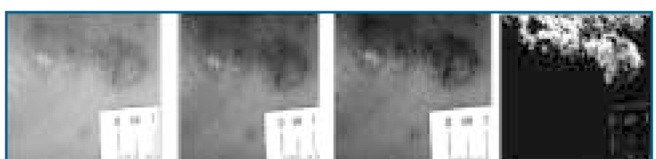
No. of Lesions = 467
% Area (lesion) = 14.77%

Figure 10: Image analysis



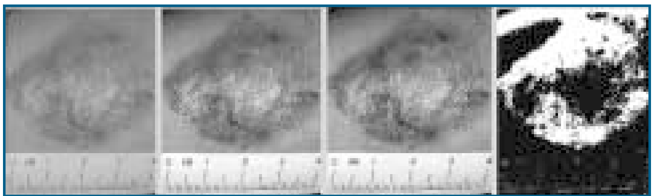
lesion area == 44592 pixels
1 cm = 66.07 pixels
$1\ cm^2 = 66.07^2$ pixels ≈ 4365 pixels
thus, actual area of lesion = 44592/4365 ≈ 10.22 cm^2

Figure 11: Calibration analysis for image #1



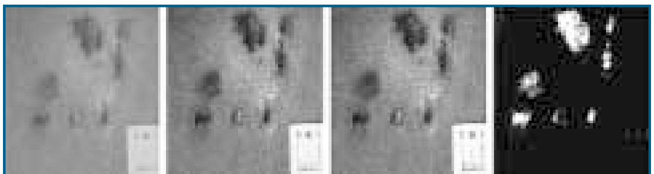
lesion area == 31837 pixels
1 cm = 138.588 pixels
$1\ cm^2 = 138.588^2$ pixels ≈ 19207pixels
thus, actual area of lesion = 31837/19207 ≈ 1.66 cm^2

Figure 12: Calibration analysis for image #2



lesion area == 84555 pixels
1 cm = 104.4 pixels
1 cm^2 = 104.4^2 pixels ≈ 10899 pixels
thus, actual area of lesion = 84555/10899 ≈ 7.76 cm^2

Figure 13: Calibration analysis for image #3



lesion area == 12611 pixels
1 cm= 80.04 pixels
1 cm^2= 80.04^2 pixels ≈ 6406 pixels
thus, actual area of lesion = 12611/6406 ≈ 1.97 cm^2

Figure 14: Calibration analysis for image #4

Discussion

It was observed from the calibration analyses that well-produced segmented image definitely increased the degree of accuracy of this calibration process. Nevertheless, the calibration result was still an estimation value since it depended on the accuracy of the thresholding process.

It should be emphasised that during image capture the photographer should ensure that the digital pictures of skin are taken in a well-lit area or by installing a lighting system which could focus on the desired skin surface uniformly.

CONCLUSION

Medical imaging can play an active role in dermatology, i.e. in disease monitoring and in aiding diagnostis. It could be deployed in a telehealthcare application with ease.

The skin disease monitoring process incorporates image processing techniques, that enabled the estimation of the number of lesions found in an image, the percentage of lesions and the lesions' area in terms of square centimeters (instead of pixels) via calibration.

It was shown that for well-defined images that resulted in effective thresholding, analysis for the monitoring of skin diseases could be performed successfully.

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He has been a Lecturer in Signal Processing and Researcher in Image Processing at Universiti Sains Malaysia (USM) since 1984. Between 1988-91, he served at University of Essex, UK initially as a Senior Research Officer in Image Processing and subsequently as a Lecturer. On his return to Malaysia, he was made Dean of the School of Electrical & Electronic Engineering at USM from 1992-96 and Associate Professor in 1994. In 1997, he became the founding Dean of the Engineering Faculty at the newly established UTP. He became the Director of Academic Studies at the university in 1999. Currently, he is the Director of Postgraduate Studies, a position he assumed in 2003.

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A SIMULATION ON THE TRANSIENT RESPONSE OF A CAPACITOR VOLTAGE TRANSFORMER USING MATLAB

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ABSTRACT

This paper presents a study on the transient response behavior of a capacitor voltage transformer based on a simulation using MATLAB. The adopted equivalent circuit was modeled in MATLAB using mathematical equations obtained through mathematical simplifications of the circuit. Based on this model, the effects of CVT components such as capacitor and ferroresonance suppression circuit, and the effects of fault type, point-on-wave and location on the CVT transient response were studied through observations on the MATLAB-generated transient responses. The ideal input voltage to the CVT was obtained from an ideal power transmission line system model in PSCAD/ EMTDC.

Keywords: *Capacitor Voltage Transformer (CVT), Ferroresonance suppression circuit (FSC), Matlab, Feroresonance*

INTRODUCTION

In power systems the primary voltage and current signals are transformed to voltages of current for metering and protection purposes. These signals are required at adequately low levels in order to suit the operation of instruments and relays. To obtain a low voltage level from a high voltage source, a wound voltage transformer is normally used to step down the primary voltage. However, as the system voltage increases, the cost of insulation makes this type of transformer inappropriate and other types of voltage sensing units are needed. The most commonly used voltage sensing unit is the CVT. CVT is commonly used in electricity distribution and transmission systems at high and extra high voltages.

Although the implementation of CVT is economical and good, it is not ideal. It loses some consistency in reproducing transient voltage variations due to the inductive, capacitive and nonlinear elements it contains. Transient response of a CVT refers to its ability to control the tendency to create irrelevant frequencies in the output. Electromagnetic voltage transformer could perform better in terms of transient response but it is again, costly.

Inconsistent transient response introduced by the CVT is mainly caused by a sudden change in the primary voltage especially when there are faults in the system. The CVT produces transient component in the secondary circuit in addition to the steady state value.

This paper was presented at Seminar Kebangsaan Sains Teknologi dan Sains Sosial 2004, Hotel Vistana, Kuantan, Pahang Darul Makmur, 31 May 2004.

The low frequency component, which tends to slow down the operation of relays, is dominant. This is due to the release of stored energy in the CVT circuit due to the burden current and the effective capacitance of the divider in resonance with the magnetizing inductance of the electromagnetic unit.

The performance of a CVT is also affected by a phenomenon called ferroresonance. It happens during certain transient conditions when the core of the tuning inductor of the intermediate transformer becomes saturated. A stable oscillation at system frequency is a result of this phenomenon. To counter this phenomenon, the CVT will usually contain a ferroresonance suppression circuit (FSC). The performance of a CVT is largely influenced by the suppression of this stable oscillation. The stable oscillation results in large distortions of voltages and currents and causes mechanical vibration of equipment.

The objectives of this project were:

1. To study the design criteria of a capacitor voltage transformer and study the effects of stack capacitance and ferroresonance on its performance.
2. To analyze the effect of CVT transient response in protection relay operations for different types of fault occurrences.
3. To simulate the transient response of CVT using MATLAB.

LITERATURE REVIEW/THEORY

CVT typically consists of coupling capacitors, compensating reactor, step-down transformer and ferroresonance suppression circuit (FSC), as depicted in Figure 1. The coupling capacitors of the CVT function as a voltage divider to step down the line voltage to an intermediate level voltage, typically 5 to 15kV. The compensating reactor cancels the coupling capacitor reactance at system frequency. This reactance cancellation prevents any phase shift between the primary and the secondary voltages at system frequency.

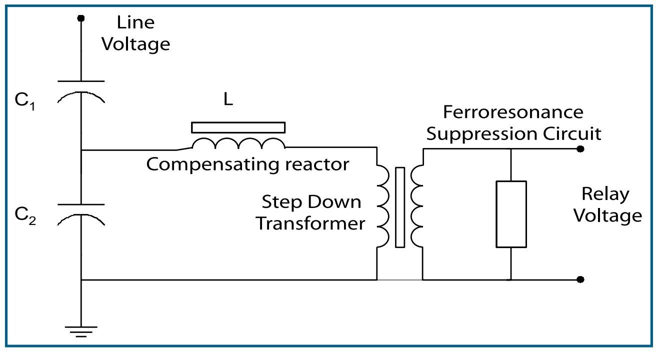

Figure 1: Typical Simplified Circuit Diagram of CVT

Theoretical studies and tests carried out with a CVT model and system protective relays showed that it is possible to study the performance of protective relays fed by capacitor voltage transformers systematically [1]. This will enable the limits of the load for this particular type of CVT to be fixed before feeding the relays. Some examples were given in [1].

The results described in [1] showed that a load represented by the parallel connection of a resistance and an inductance had a very harmful effect on the transient voltages of CVT. The amplitudes of the transient voltages were not sufficient to characterise the risk of disturbance in the performance of the relay.

Protective relays fed by CVT do not operate correctly if the secondary side voltage is not a direct replica of the primary side voltage [2]. In order to ensure correct operation of the relay, it is necessary for the secondary side voltage to be operated as accurately as possible to the primary voltage when the latter falls rapidly. The other conditions that the CVT must satisfy were given in [2].

Sometimes a phenomenon known as ferroresonance can occur in the CVT. Ferroresonance is a complicated non-linear electrical phenomenon which can lead to transformer voltages several times higher than the normal ratings. Ferroresonance occurs because the inductance in the circuit is ferromagnetic, that is, it has a core made of ferromagnetic material, usually iron, such as that of a transformer [3].

Ferroresonance in a power system can result in any or all of the following [4]:

1. High-sustained overvoltages, both phase to phase and phase to ground.
2. High sustained overcurrents.
3. High sustained levels of distortion to the current and voltage waveforms.
4. Transformer heating and excessively loud noise.
5. Electrical equipment damage (thermal or due to insulation breakdown).
6. Apparent mis-operation of protective devices.

To overcome the problem of ferroresonance a ferroresonance suppression circuit (FSC) was introduced to a CVT circuit as shown in Figure 2. A ferroresonance suppression circuit was designed to prevent sub-synchronous oscillations due to saturation of the core of a step-down transformer during overvoltage conditions. As the circuit has a non-linear transient characteristic, three methods of damping was introduced to stabilise the ferroresonance phenomenon. They were:

- Permanently connected resistive burden.
- Permanently connected tuned circuits.
- Switched damping circuits.

METHODOLOGY/PROJECT WORK

Research study

An equivalent circuit of CVT and FSC were adopted from previous studies on CVT transient response (through research study). To have an idea of the direction of the project, a research study was carried out on the factors affecting CVT transient response and also the ferroresonance phenomenon.

Implementation (Programming)

Using mathematical analysis on a CVT equivalent circuit, a CVT was modeled in MATLAB to generate its transient response towards various effects such as CVT components and various types of fault occurrences. Two models of CVT were the CVT without FSC and the CVT with FSC connected.

Analysis

Based on the transient responses of a CVT generated by MATLAB, the behavior of the CVT was analyzed. The transient responses were compared with each other and finally, the effects of this transient in protecting relay operations were analyzed.

RESULTS AND DISCUSSIONS

CVT is similar to an electromagnetic voltage transformer (VT). However, the addition of a capacitor divider circuit which consisted of a stack capacitor (C_s) and a base capacitor (C_b), distinguished the CVT with a VT. The values of the components in the CVT especially the stack capacitor influenced the ability of the CVT to produce the desired response at the secondary side of the CVT. It was desired that the secondary side of the CVT would replicate exactly the voltage at the primary. Figure 2 shows the equivalent circuit of a CVT with FSC.

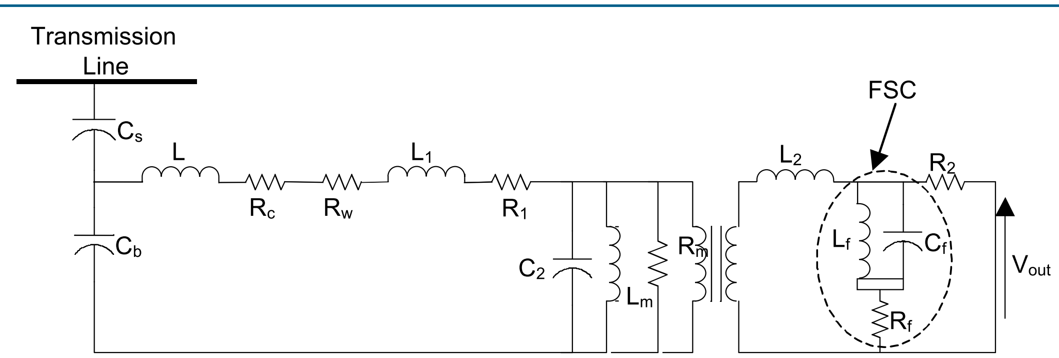

Figure 3: CVT Equivalent Circuit with FSC Connected (circled)

Table 1: CVT Component Value

Symbol	Component	Component Value
C_s	Stack Capacitance	2000 pf
C_b	Base Capacitance	0.084 _f
L	Tuning Inductance	1.056 H
R_c	Equivalent Core Resistance	2000 Ω
R_w	Winding Resistance	239 Ω
L_1	Primary Leakage Inductance	79.832 mH
R_1	Primary Resistance	1050 Ω
L_m	V.T Magnetizing Inductance	27050 H
R_m	V.T Magnetizing Reactance	5.8 MΩ
L_2	Secondary Inductance	0.168 mH
R_2	Secondary Resistance	0.162 Ω
C_2	Lumped Stray Capacitance	1060 pF
R_L	Burden resistance	103997 _
K	V.T Ratio	12kV/63.5V

Table 1 lists the components of the CVT (without FSC) and its values. The value of these components affected the CVT output at the secondary. In order for the CVT to replicate the voltage at the primary, the gain of the circuit should be unity.

Table 1 is a reduced mathematical analysis of the CVT equivalent circuit to obtain the gain function of the circuit.

Figure 3 is further simplified as shown in Figure 4. All the components refer to the intermediate voltage level. Capacitors Cs and Cb are grouped together to form a Thevenin equivalent voltage source. Refer to Figure 4.

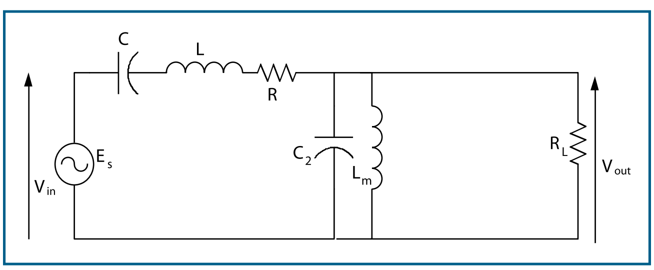

Figure 4: Simplified CVT Equivalent Circuit

- The resistor R is the total resistance of the primary, core and winding resistance.
  $R = R_1 + R_c + R_w = 1050 + 2000 + 239 =$ ***3289 Ω***

- The capacitor C is the total capacitance of the base and stack.
  $C = C_b + C_s = 0.084e\text{-}06 + 2000e\text{-}12 =$ ***86 nF***

- The inductor L is the total inductance of primary leakage inductance, tuning inductance and secondary inductance.
  $L = L_1 + L + L_2$
  $= 79.832e\text{-}03 + 1.056 + 0.168e\text{-}03 =$ ***1.136 H***

$$H(\omega) = \frac{V_{out}}{V_{in}} = \frac{Z_2 Z_3}{Z_1 Z_2 + Z_1 Z_3 + Z_2 Z_3} \qquad (1)$$

Where;

$$Z_1 = \frac{1}{j\omega C} + j\omega L + R \qquad (2)$$

$$Z_2 = \frac{j\omega L_m \times j\omega C_2}{\frac{1}{j\omega C_2} + j\omega L_m} \qquad (3)$$

$$Z_3 = R_L \qquad (4)$$

The FSC was introduced into the CVT circuit in order to eliminate the phenomenon of ferroresonance. The FSC was connected to the CVT circuit as shown in Figure 3. Table 2 shows parameters of the active ferroresonance components in the CVT circuit diagram shown in Figure 3.

Table 2: FSC Tuning Components Value

Component	Symbol	Component value
Tuning capacitance	C_f	0.285 nF
Tuning inductance	L_f	315.3 H
Tuning resistance	R_f	77379 Ω

After similar circuit simplification steps:

$$H(\omega) = \frac{V_{out}}{V_{in}} = \frac{Z_2}{Z_1 + Z_2} \qquad (5)$$

Where;

$$Z_a = R_f + \frac{j\omega L_f C_f}{L_f + C_f} \qquad (6)$$

$$Z_b = \frac{j\omega C_2 L_m}{C_2 + L_m} \qquad (7)$$

$$Z_c = \frac{Z_a Z_b}{Z_a + Z_b} \qquad (8)$$

$$Z_1 = \left(\frac{1}{j\omega C} + j\omega L + R\right) \qquad (9)$$

$$Z_2 = \frac{Z_c R_2}{Z_c + R_2} \qquad (10)$$

Effects Of Changing Capacitance Value

Figure 5 shows the transient responses of CVT with two different values of capacitance, which is the typical and four-times-larger capacitance value. Theoretically, the capacitance value associated with high capacitance CVT decreases as the CVT transient increases in magnitude. This is also depicted in Figure 6 where the transient response of a CVT with the Thevenin equivalent capacitance (which is four times the typical value) demonstrated a magnitude that is closer to the ideal VT response.

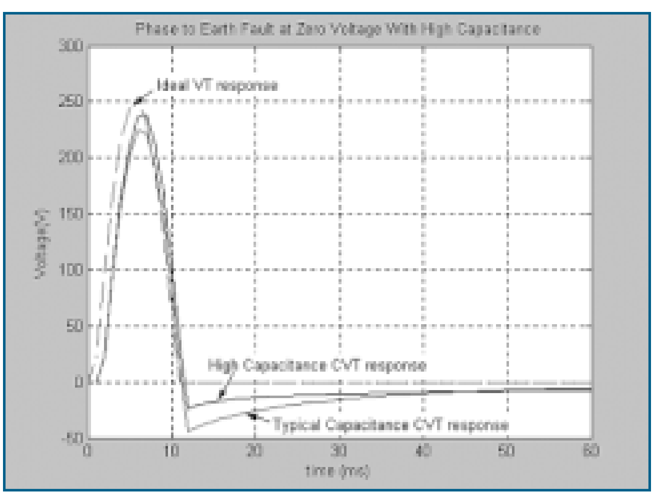

Figure 5: CVT Transient Response For Phase to Earth Fault At Zero Voltage With Varying Coupling Capacitance Value

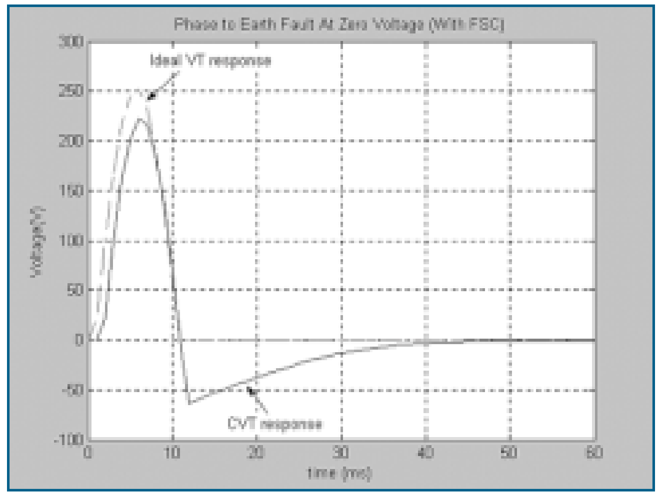

Figure 6: Phase to Earth Fault At Zero Voltage With FSC Connected

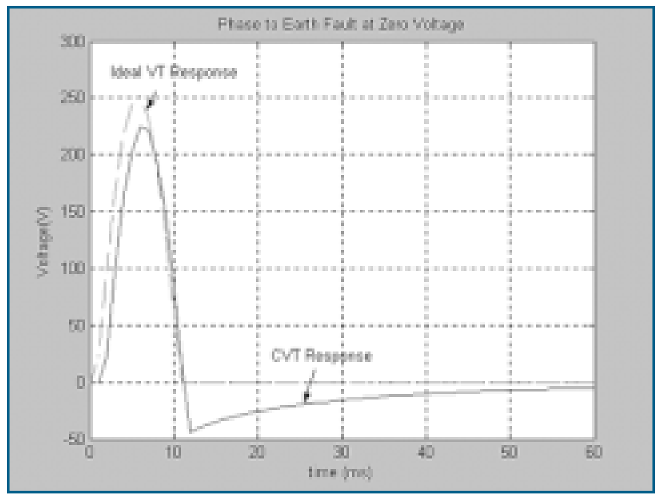

Figure 7: Phase to Earth Fault At zero Voltage Without FSC Connected

Effects of Implementation of FSC

The connection of FSC in a CVT was important to prevent stable oscillations in the output. The FSC acted like a bandpass filter and introduced extra time delay in the CVT secondary output. The energy storage elements in the FSC was found to contribute to the severity of the CVT transient. Figure 6 and Figure 7 shows CVT transient response with and without the

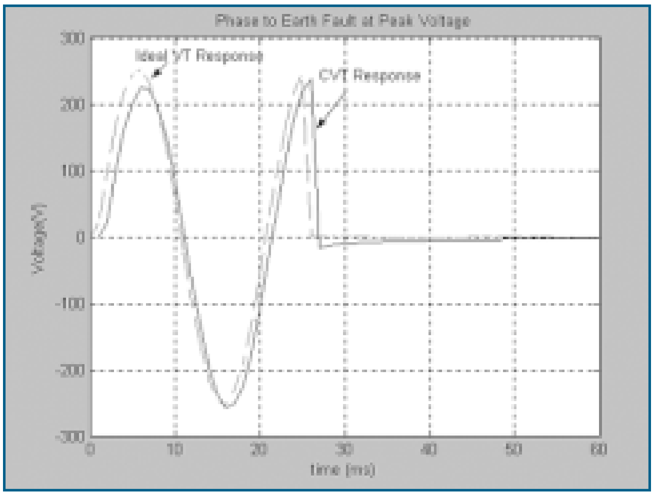

Figure 8: Phase to Earth Fault At Peak Voltage Without FSC Connected

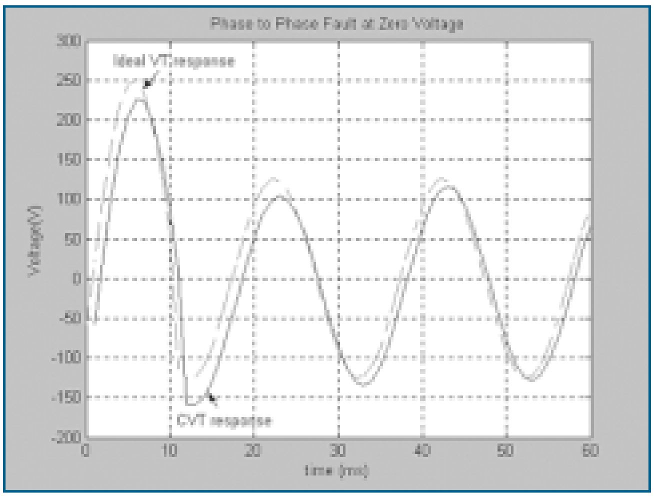

Figure 9: Phase-To-Earth Fault At Zero Voltage With FSC (Relay is 80km away from fault source)

FSC connected, respectively. Based on Figures 8 and 9, the magnitude of the output voltage at a fault occurrence was larger. However, the FSC caused the transient response of the CVT to damp faster. The transient response of the CVT with FSC during a phase to earth fault at zero voltage initiation followed the ideal VT response within 1.5 cycles after fault initiation. When fault occured at the peak voltage, the CVT transient response followed the ideal VT response within 0.5 cycles after fault initiation.

Figure 7 shows the CVT transients at zero voltage fault initiations for a phase-to-earth fault type. For comparison, the ideal VT voltage output is shown in each figure. This ideal VT response was the response that the CVT should replicate.

Effects of Fault Point-On-Wave (POW)

Based on Figure 7, the output of the CVT did not follow the ideal output voltage until approximately two cycles later. The transient response of the CVT has 'overshot' at the beginning of the fault initiation. This 'overshot' delayed the CVT to responseinclose correspondence with the ideal response.

Figure 8 shows CVT transient response for fault occurring at the peak or maximum voltage. Based on the figure, the CVT transient response shows similar behavior with the response when fault POW is at zero. The transient response of the CVT had a delay in corresponding with the ideal output voltage until after approximately one cycle later. This indicated that when fault POW was at peak voltage, the response was similar with when fault POW was at zero. This represented a better response as the overshoot introduced were of smaller magnitude and had a faster rate of restoration towards the ideal response.

Effects of Fault Type

Two types of fault studied in this project were the phase-to-earth and the phase-to-phase fault. In a power system, the more common type of fault is phase-to-ground. The transient responses plotted in this paper were with respect to phase A. During a phase-to-earth fault (Phase A to ground), the ideal voltage drops to zero immediately. Whereas during a phase-to-phase fault (Phase A and B at fault), the voltage of the phases involved reduces as the third phase voltage increases. Comparing the transient responses in Figure 7 with Figure 9, it was found that both types of fault introduced delays in reaching the steady state. It was also observed that the transient response of the CVT was closer to the ideal VT response during phase-to-phase fault compared to during phase-to-earth fault. However, when fault occured at peak voltage (graphs not shown), the difference was not so obvious.

Effects of Fault Location

The location of fault is referred to as the distance between the relay and the source of fault. The distances studied in this project were at 20 km, 80 km and 100 km.

Figure 10 shows the distance between the fault and the relay at 80 km. As the distance between the fault and the relay increased the magnitude of the fault voltage also increased and the transient response of the CVT worsened as well. The noise at the beginning of the transient is contributed by the load, which was inductive.

CONCLUSION

In high voltage power transmissions (>33kV), it would be more economical to implement capacitor voltage transformers (CVT) for protection, measurement and control compared to electromagnetic voltage transformers (VT). However, in comparison with VT, CVT was found to be not ideal and would lose some fidelity in reproducing transient voltage variations when faults occur, leading to delays or incorrect relay operations. It was also affected by the ferroresonance phenomenon where stable oscillation was produced at system frequency due to the saturation of the tuning inductor under certain conditions. This phenomenon was reduced or eliminated by implementing a ferroresonance suppression circuit at the secondary side of the transformer.

Basically, the CVT transient could be controlled by the sum of the stack capacitances, shape and parameters of the ferroresonance suppression circuits and point on wave when fault occurs.

RECOMMENDATIONS

Another factor that could be considered to control the CVT transient is the total load of the CVT. It is possible to modify the total load of the CVT so as to avoid a transient voltage of a frequency or amplitude particularly ill adapted to a given type of relay. Therefore, future research could investigate upon the performance of relays by modifying the total load of the CVT.

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DESIGNING A SOLAR THERMAL CYLINDRICAL PARABOLIC TROUGH CONCENTRATOR BY SIMULATION

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ABSTRACT

The focus on renewable energy in Malaysia gained momentum with the active involvement of the government and the private sector. This move can potentially help in diversifying the country's energy options besides relying on oil, natural gas, coal and hydropower. The scope of this paper is to look at the designing procedures of a solar thermal cylindrical parabolic trough concentrator (CPTC) by simulation. The designing effort starts off with the selection of certain parameters such as the aperture area and the diameter of the receiver to obtain the geometric concentration. Concentration ratios can be theoretically very high with the imaging concentrators of precise optical elements and continuous tracking, in the range of 10 to 40 000. A thorough analysis is necessary, where the optical precision and proper thermal analysis must be carried out to evaluate the performance of a CPTC. The results clearly showed that there must be an equilibrium achieved between the increasing thermal losses with the increasing aperture area, and the increasing optical losses with the decreasing aperture area for the optimization of the long-term performance of the CPTC.

INTRODUCTION

Improper use of fossil fuels has led to negative imbalance in the natural environment. The impact on the environment is fast surpassing the positive development brought about by the discovery of fossil fuels. One cannot deny that the exploitation of fossil fuels has brought about a better future for mankind, but if the environment is destroyed in the process then proper ways and new resources must be introduced to strike a balance. Malaysia is keen on promoting the use of renewable energy which can help in diversifying the country's energy options besides relying on oil, natural gas, coal and hydropower. The National Energy Policy introduced in 1979 aims to have an efficient, secure and environmentally sustainable supply of energy, a move which is parallel with global efforts. The development plans for using both non-renewable and renewable energy resources were taken to be the main aim and its utilization objectives outlined the need to use energy efficiently (Yap, 2002). This journey to embark on non-renewable energy technologies should be geared towards supplementing the conventional sources of energy. Since solar energy is readily available in Malaysia, it would be beneficial to fully exploit it.

This paper was presented at the International Conference on World Climate & Energy (RI03), Rio de Janeiro, Brazil, 1-5 December 2003.

The scope of this paper is to look at the design procedures of a solar thermal CPTC. It is possible to achieve a temperature around 100°C with a flat plate collector, but for power generation or industrial purposes, concentrators play a vital role. Usually for comparison purposes, concentration ratio (CR) is introduced. Increasing ratios means increasing temperatures at which energy can be delivered and also increasing requirements for precision in optical quality and positioning of optical systems. Concentration ratios can be theoretically very high with the imaging concentrators of precise optical elements and continuous tracking, in the range of 10 to 40 000.

THEORY

A solar thermal CPTC can be used to harness solar energy at rather high temperatures depending on the working fluid used. The level of concentration is restricted by the design parameters and is given as Equation (1). Equation (2) relates the CR to the acceptance half-angle and the best value is based on the sun's subtend angle of 0.54° with the highest CR at 212. Although the values look promising, the whole design process cannot be based only on these values.

$$CR = \frac{w - d_R}{\pi d_R} \quad (1)$$

$$CR = \frac{\sin \phi_R}{\pi \sin \theta_C} \quad (2)$$

There is a distinguishing; reason on the selection of a parabolic concentrator. Since the sun is very far away, the radiation rays that reach a concentrator is parallel to its axis. The parabolic curve would focus all the rays to a focal point, and a trough normally extends the shape in three dimensions to turn the focal point into a focal line. The receiver is placed concentrically along this focal line, as its axis. Eq. (3) shows the important relationship between the width and depth, and Eq. (4) is used to calculate the focal point as shown below;

$$y = \frac{d}{(0.5w)^2} x^2 \quad (3)$$

$$f = \frac{w^2}{16d} \quad (4)$$

The following Eq. (5) is used to calculate the rim angle, based on the focal point, width and depth;

$$\cos \phi_R = \frac{2f}{\sqrt{(0.5w)^2 + (d - f)^2}} - 1 \quad (5)$$

A rim angle of 90° is preferred as it gives an optimum intercept factor and allows the depth to be the focal point. The focal point, where the rim angle is set at 90° can be calculated by using the width value alone, as shown in Eq. (6).

$$f = \frac{w}{4} \quad (6)$$

The reflecting surface on the parabolic surface should have a very good specular reflectance, r where electroplated silver records a value of 0.96. Thermal analyses on the overall heat loss coefficient, convective heat transfer coefficient, collector efficiency factor and heat removal factor are performed. Finally, by the aid of meteorological data, the efficiency of the collector is determined.

METHODOLOGY

The simulation procedures were carefully developed with the design specifications that were changed and simulated using the same meteorological data (Singh & Sulaiman, 2000). The final model, together with the design specifications were then constructed mathematically. Using a preset value for the CR, the diameter d_R of the receiver was calculated using

Equation (1). The full design specifications were next processed to define the model. The parameters were the overall heat loss coefficient, U_L, convective heat transfer coefficient and heat removal factor. The processed solar insolation data were of the beam radiation I_b and diffuse radiation I_d. R_b and R_d were the ratios of total radiation on a tilted surface to the horizontal surface for beam and diffuse radiations respectively. Using these values, the absorbed solar radiation S parameter was calculated and used in the energy equation. This is important in order to obtain the correct value for Q_U, the heat gained, as it would later be used to calculate the efficiency. Efficiency calculations took into consideration diffuse radiation, while in the evaluation of S, as seen from Equation (7), only the beam component of the radiation was used.

$$S = I_b R_b (\tau\alpha)_b \left(\rho\gamma + \frac{d_R}{w - d_R} \right) \qquad (7)$$

Another efficiency ratio that was used which totally ignored the diffuse radiation is given in Equation (8) below;

$$\eta = \frac{Q_U}{(I_b R_b)(W \times L)} \qquad (8)$$

In Equation (7), γ is the intercept factor and $(\tau\alpha)_b$ is the transmittance-absorptance product for the beam radiation. An optimisation problem arose when the area of the aperture was increased due to increased thermal losses and as the area was decreased, optical losses increased. The intercept factor accounted for this problem and is defined as the fraction of the specularly reflected radiation which is intercepted by the receiver. Tracking and dispersion errors usually affects the value of γ. The equations used to evaluate these two parameters are given in Equations (9) and (10). In Equation (9), τ is the transmittance of the receiver's cover and α is the absorptance of the receiver's absorber. ρ_d is the reflectance of the cover for diffuse radiation.

$$(\tau\alpha)_b = \frac{\tau\alpha}{1 - (1 - \alpha)\rho_d} \qquad (9)$$

Equation (10) provided the value for the intercept factor γ and h obtained was based on maximum radiation. Equation (11) was used to evaluate h with σ being the standard deviation of the normally distributed radiation that was intercepted by the receiver (Magal, 1990).

$$\gamma = 1 - e^{-h^2\left(\frac{r_D}{w}\right)} \qquad (10)$$

$$h = \frac{0.5w}{\sqrt{2}\sigma} \qquad (11)$$

The software was written by using MATLAB which was designed in such a way that it is user-friendly. A snapshot of the design menu is shown in Figure 1. The following two equations show the design parameters that were used to evaluate the heat removal factor, where in equation (13), the symbol F' is the collector's efficiency factor.

$$F_R = \frac{JC_{factor}}{\pi d_R L U_L} \left[1 - e^{-\left(\frac{F' \pi d_R U_L L}{JC_{factor}} \right)} \right] \qquad (12)$$

$$F' = \left[U_L \left(\frac{1}{U_L} + \frac{d_R}{d_{Ri}} + \frac{d_R \ln\left(\frac{d_R}{d_{Ri}}\right)}{2k} \right) \right]^{-1} \qquad (13)$$

The parameter J refers to the mass flowrate of the working fluid flowing in the receiver's tube, while d_{Ri} is the inner diameter of the receiver's tube. The C_{factor} is specific heat capacity of the working fluid evaluated at the inlet fluid temperature and is found by the authors. The method to find C_{factor} can be found by evaluating heat factors such as the H_{factor} (Singh & Sulaiman, 2001) and R_{factor} (Singh & Sulaiman, 2002).

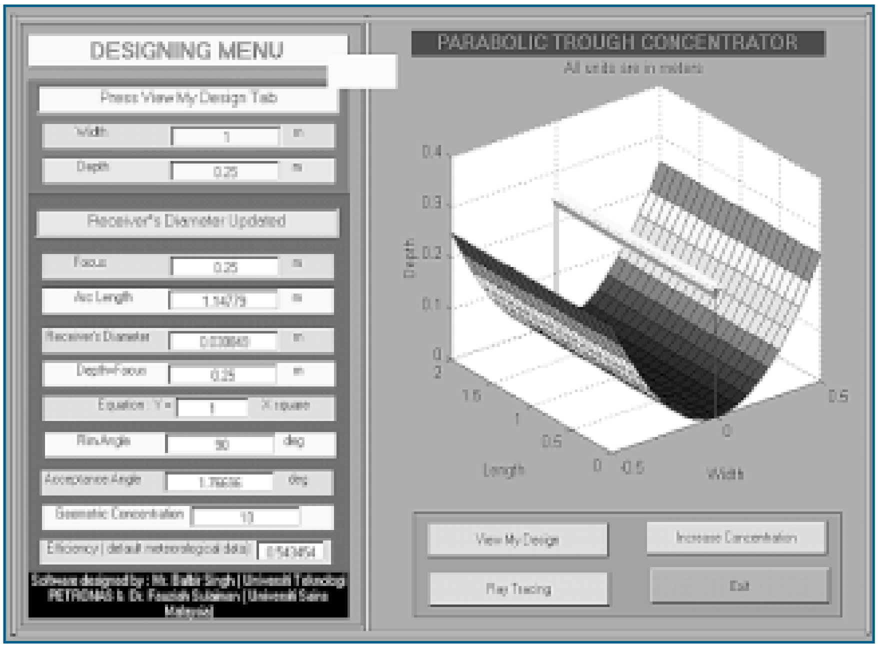

Figure 1: A snapshot of the software written in the MATLAB environment

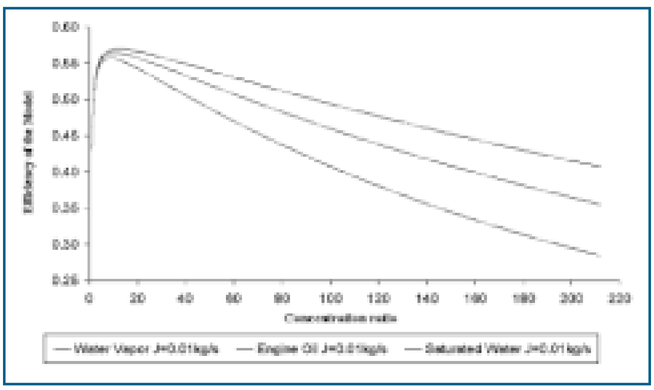

Figure 2: Graph of CPTC's model efficiency versus the concentration ratio for three different working fluids

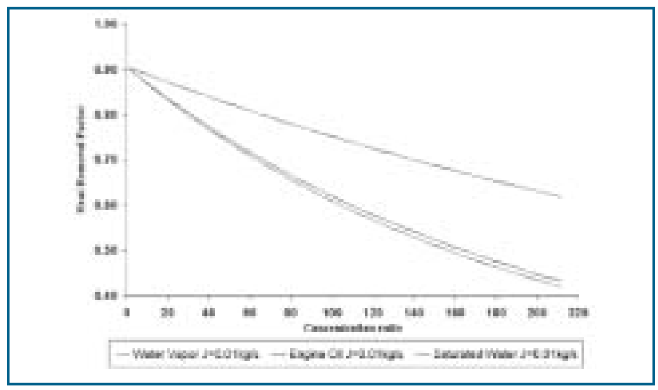

Figure 3: Graph of heat removal factor versus the concentration ratio for three different working fluids

RESULTS

The results obtained in the process of refining the model by repeating the steps had provided some interesting findings. In Figure 2, the concentration ratio was increased until it reached its maximum theoretical value of 212 for three different types of working fluid. The model's efficiency increased until the concentration ratio reached 10 for all three working fluids flowing in the receiver and then gradually decreased by at least 53 percent. The expectation is that by increasing the concentration ratio, the efficiency of the collector too will increase. However, this proved that designing the CPTC by relying solely on the CR is not sufficient.

By observing the results shown in Figure 3, there was a correlation between the decreasing efficiency and decreasing heat removal factor, as the CR increased. This meant that evaluation of the heat removal factor is very important, as it had great influence on the efficiency of the CPTC.

Eventhough efficiency decreased with increasing CR, the rate of energy gained, Q_U, actually increased. Looking at Eq. (1), if d_R is fixed at a certain value, the width w must be increased in order for the CR to increase. If d_R is held at a value of 0.03 m, then to achieve a CR of 212, the width must definitely be around 20 meters and the length if it is set to be twice of the width, would be around 40 meters. This would

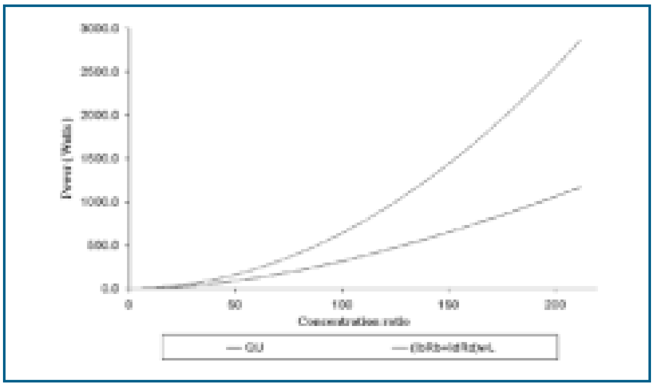

Figure 4: Graph of rate of energy gained versus the concentration ratio for efficiency

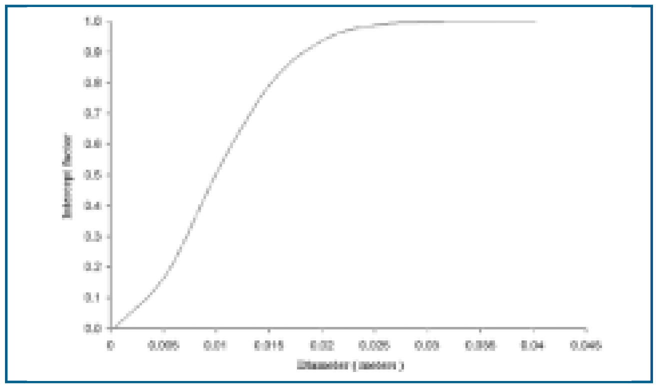

Figure 5: Graph of intercept factor versus the diameter of the receiver

make the aperture area to be around 800 m^2. Obviously, the heat gained should increase, but unfortunately, the denominator of the efficiency equation increased more than Q_U. This is shown in Figure 4, where the gap widened as the CR increased.

The diameter was held at 0.03 m so that the intercept factor g would be at a maximum value of unity as seen in Figure 5. Therefore, reducing the aperture area by reducing the d_R so as to obtain a higher CR, would cause the intercept factor g to decrease. If this happens, the amount of the absorbed solar insolation would decrease, causing Q_U to be reduced further.

CONCLUSION

This paper highlighted the processes that were necessary to evaluate the performance of a solar thermal CPTC and the use of processed data to design a simulated model using the same meteorological data. The results indicated that there would be an equilibrium achieved between the increasing thermal losses with the increasing aperture area, and the increasing optical losses with the decreasing aperture area. Hence, it was important to optimise the long-term performance of the CPTC.

The utilization of renewable energy in Malaysia should be increased as there is a global concern that the upcoming and developing nations could be faced with yet another energy crisis. As recently reported, major oil-producing countries such as the United States and OPEC have managed to block the United Nation's target to hasten a global shift towards renewable energy sources (Ball, 2002). With opposition facing the Kyoto treaty on global warming, it is expected that more damage and pollution of the environment will continue. As fossil fuels begin to exhaust, the prices of these commodities will increase manifold. Fortunately, Malaysia is working positively towards using renewable energy as seen by its approval of four renewable energy producers' licenses by the Malaysian Energy Commission recently (Yeap, 2002).

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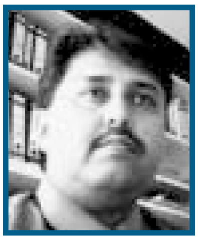

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HIGH RESOLUTION TRANSMISSION ELECTRON MICROSCOPY OF CATALYTICALLY GROWN CARBON NANOTUBES (CNTs)

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ABSTRACT

The paper reports the structural analysis of catalytically grown carbon nanotubes (CNTs), a nanostructured material using transmission electron microscopy. Here, carbon nanotubes were formed by catalytic decomposition of methane over different catalysts namely iron, cobalt and nickel. Of the many techniques which have been used to study the structures, high resolution tunneling electron microscopy (HRTEM), has undoubtedly been the most useful. While x-ray diffraction can provide more accurate crystallographic measurements, and scanning electron microscopy can give greater surface detail, only HRTEM can probe the internal structure of nanotubes, revealing details of the stacking arrangement of multiwalled tubes, the nature of defects, the structure of caps and so on. From TEM micrographs, the catalytically produced nanotubes are observed to be of the multiwalled type. Thermo gravimetric analyses (TGA) were also conducted in order to determine the degree of crystallinity of CNTs grown from different catalysts. Results of TGA revealed that the highest degree of crystalline perfection could be achieved by CNTs grown on iron followed by the ones grown on nickel and cobalt catalyst.

Keywords: *carbon nanotubes, catalyst, chemical vapour deposition, multiwalled tubes*

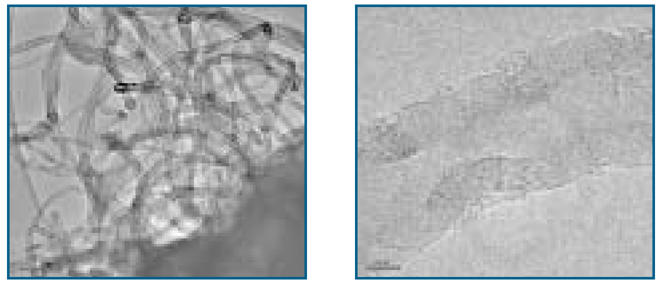
INTRODUCTION

Carbon nanotubes (CNTs) captured a considerable amount of interest ever since they were first discovered in 1991 by an electron microscopist in NEC laboratories in Japan. The remarkable mechanical and electrical properties exhibited by CNTs because of their unique structures have generated a wide range of potential applications. Thus, many research efforts have been directed to develop appropriate methodologies to grow CNTs, a prerequisite for fabrication of nanotubes based devices. Here, TEM images were used to investigate the structure dependence on the three catalysts. Although TEM is considered as one of the most powerful tools to evaluate the crystallinity of CNTs, it does not actually provide the structure information of the entire CNT as observations would be focused only on specific locations of the CNT. Structural determination using TGA systems would compensate for this drawback.

MATERIALS AND METHODS

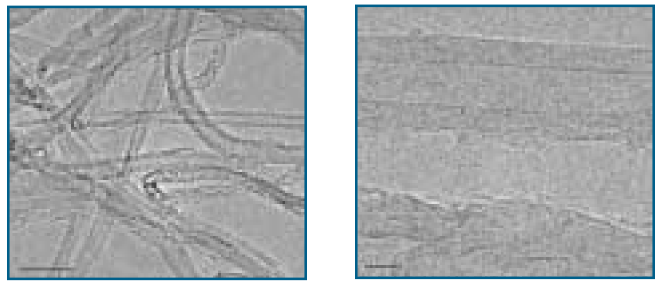
The catalytic decomposition of methane over a catalyst was carried out in a chemical vapour deposition system. Catalytic particles of iron, nickel and cobalt were prepared [8] and pretreated by etching with ammonia gas to further reduce the active

This paper was presented in the International Conference on X-rays and Related Techniques in Research and Industry (ICXRI-2004), Penang, 15 September 2004.



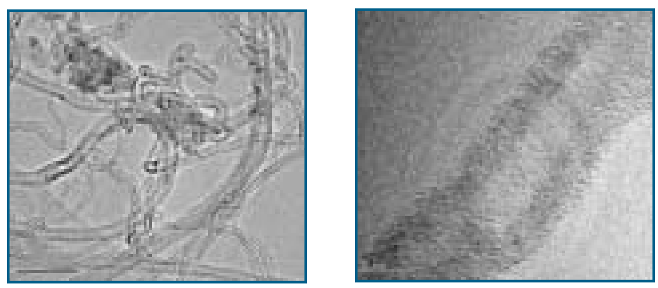
(a) (b)

Figure 1: (a) TEM images and (b) HRTEM images of CNTs grown on Ni catalyst



(a) (b)

Figure 2: (a) TEM images and (b) HRTEM images of CNTs grown on Fe catalyst



(a) (b)

Figure 3: (a) TEM images and (b) HRTEM images of CNTs grown on Co catalyst

metal particles to nano-size. The catalytic deposition of carbon on well-dispersed metal catalysts were carried out in the methane atmosphere at a flow rate of 40 sccm at 950°C. The raw products were treated with acid to purify into a fine powder. The samples were examined using TEM (Phillips Tecnai 20) operating at 200 kV. Sample preparation for TEM observation involved dispersion using the ultrasonic method. For thermogravimetric analysis, a small amount of sample was weighed and placed in the furnace and subjected to heat treatment from room temperature to 800°C with heating rate of 10°C per minute under the air ambient.

RESULTS & DISCUSSION

Figures 1, 2 and 3 depict TEM images of CNTs grown on iron, nickel, and cobalt catalysts, respectively. It was observed that CNTs grown on all three catalysts generally exhibit multiwalled structures with evenly spaced lattice fringes in almost equal number of fringes on either side of the central hollow core. The average interlayer spacings for all CNTs were found to be in the range of 0.32 nm to 0.34 nm. The smaller diameter tubes which had the largest spacings were measured and found to be in the range of 5.71 nm to 7.15 nm, depending on the morphology of the tubes which could be helical, twisted (curled) or straight shaped [8]. Analysis of HRTEM images by [6] has shown an interlayer spacing ranging from 0.34 nm to 0.39 nm.

Research work by [4] and [1,2] showed that nanotubes with diameters larger than about 1 nm can be capped in a large number of ways. Past experimental studies showed that multilayer nanotube caps could be found in a variety of morphologies with the vast majorities of the unsymmetrical type.

One interesting observation was that the nanotube cap of CNTs grown on cobalt catalysts (Figure 3), showed a asymmetrical cone structure. This commonly observed type of asymmetrical cone structure is best described by the clear image reported by [5]. Inferences about the cross-sectional shape of multiwalled tubes were made from images taken perpendicular to the tube axis because direct observations in the electron microscope proved to be extremely difficult. Studies on the influence of cap structure on the probable cross-sectional shapes [3] predicted a stronger effect on the asymmetric cone caps. It was implied that caps of this type would result in an "egg shaped" cross-section, although this effect could diminish in regions well removed from the caps.

Close examination of TEM images showed that the walls of CNTs could be used to determine the catalytic effect on the crystallinity of the grown CNTs. Figures

]1b, 2b and 3b depict the images of the wall of CNTs grown on iron, nickel and cobalt catalysts. The well-defined graphene layers of CNTs grown on the iron catalyst indicate a highly ordered crystalline structure.

The defective structure in the form of short-range layers seen in CNTs grown on nickel catalysts indicated a lower degree of crystalline perfection compared to that of iron catalysts. More defects were observed in CNTs grown on cobalt catalysts. Structural observation of TEM images indicated that the highest degree of crystalline perfection was shown by CNTs grown on iron followed by that on nickel and cobalt catalysts.

The above observations of TEM images was focused on a tiny part of a particular nanotube amongst the many nanotubes in the sample. Thus the determination of the degree of crystalline perfection based on TEM images did not reflect on the crystallinity of overall CNTs grown on the catalysts. However, with TGA, the result would reflect the crystallinity of the bulk CNTs grown on the catalysts.

The temperature programmed oxidation technique was adopted to determine the relative amounts of defective and crystalline constituents in the CNTs grown on iron, nickel and cobalt catalysts. CNTs with less crystalline structure reacted preferentially with the oxidant and lost weight at a lower temperature compared to the more highly crystalline CNTs. Plots of weight percentage against the oxidation temperature for CNTs grown on iron, nickel and cobalt is shown in Figure 4. CNTs grown on iron, nickel and cobalt catalysts started to gasify at approximately 550°C, 540°C, and 470°C, respectively. TGA plots in Figure 4 indicated that the crystallinity of the CNTs grown on Ni catalysts was slightly better than CNTs grown on nickel, with the least crystalline structure shown by CNTs grown on cobalt. This result supported the observation made by HRTEM above. Lee et al. [7] had also reported similar findings on the crystallinity of CNTs grown on iron, nickel and cobalt.

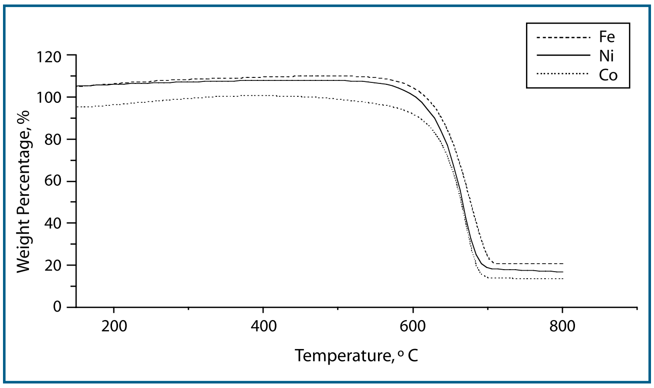


Figure 4: TGA plot of percentage weight against oxidation temperature for CNTs grown on (a) Fe (-----), (b) Ni (—) and (c) Co (·····)

Experimental studies of nanotube structures by Lee et al. were carried out using high resolution transmission electron microscopy. Images revealed the intricate structure of multiwalled nanotubes which gave a reasonable understanding of the main structural features of multiwalled nanotubes. All CNTs grown on iron, nickel and cobalt were found to be of multiwalled type with evenly spaced graphene layers.

Closer observations of HRTEM images of nanotubes could be used to determine the crystallinity of CNTs grown on different catalysts. However the finding may not be as accurate as the images obtained may not represent the bulk crystallinity of CNTs.

Another technique involving thermogravimetric analysis system is used to confirm the results. It was found that CNTs grown on iron catalysts exhibited better crystallinity compared to CNTs grown on nickel and cobalt catalysts. This implie that the degree of crystalline perfection of CNTs grown catalytically could be manipulated by the selection of the catalyst.

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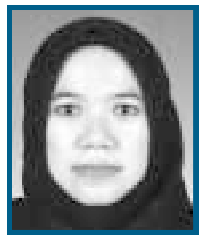

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STRUCTURAL CHARACTERIZATION OF CARBON NANOTUBES (CNTs) SYNTHESIZED BY THERMAL CHEMICAL VAPOR DEPOSITION

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ABSTRACT

The paper reports on the structural characterization of carbon nanotubes synthesized by thermal chemical vapor deposition. CNTs are produced by catalytic decomposition of methane over different catalysts namely Fe, Co and Ni. The morphology of CNTs was obtained by scanning electron microscopy (SEM) and high-resolution transmission electron microscopy (HRTEM). SEM images have shown that the morphologies of nanotubes are almost the same regardless of the catalyst used. However, some differences in the shapes of CNTs can be identified in the bulk nanotubes. Determination of the crystallinity of CNTs by HRTEM technique and thermogravimetric analysis (TGA) had produced crystalline perfection in the order of Fe > Co > Ni. This outcome is attributed to the catalyst effect on the growth rate of CNTs. It is believed that through the selective use of catalysts in the CVD method, size distribution of CNTs produced can be defined. This is a very important development of CNTs methodology as most techniques of synthesizing CNTs produced a very wide range of nanotubes sizes.

Keywords: *Carbon Nanotubes, Chemical Vapor Deposition, Multiwalled, Crystallinity*

INTRODUCTION

Since their first observation by Sumio Iijima in 1991, carbon nanotubes have captured an intense scientific interest due to their extraordinary electronic, thermal and mechanical properties. The structure of CNT can be visualized as a graphite layer rolled up into a seamless cylinder, with each end either open or capped with half a fullerene molecule. The points at which the rolled up graphite sheet is connected define the tube's diameter and chirality, which in turns, governs its properties. Its unique structural and electronic properties [1,2] have generated a tremendous amount of interest for use in a wide range of potential nanodevices [3, 4, 5].

Various methods of synthesis such as laser vaporization, pyrolysis, plasma-enhanced, arc discharge and chemical vapor deposition (CVD) have been used to grow single-walled (SWNTs) and multiwalled nanotubes (MWNTs). One serious weakness of the arc-evaporation method and of all current techniques for preparing multiwalled nanotubes is that they produce a wide range of tube sizes and structures, which could be a drawback in areas where specific tube structures are needed such as in nanoelectronics. Another application where an optimum diameter is required is the mechanical reinforcement of polymer composite. It was found that smaller diameters of MWNTs seem to provide better reinforcement [6]. Studies have shown that nanotubes

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with defined structures can be achieved by the creative use of catalysts. Although the catalytic synthesis of MWNTs has been known for many years, but the quality of nanotubes produced in this way has been rather poor. Recent work has shown that the skilful use of catalysts can lead to the formation of nanotubes that are both aligned and reasonably graphitic. Thus, there is the need for the research efforts to study appropriate catalytic methodologies and to optimise the growth parameters so as to prepare nanotubes with defined structures, which is the prerequisite for fabrication of new improved materials and nanotubes based devices.

A recent analysis of the characteristics of nanotubes grown catalytically by Lee and colleagues [7] has shown that the size distribution of nanotubes can range from 80 to 200 nm depending on the catalyst used. This was attributed to the size effect of catalyst particles on the CNT growth where before the growth of CNTs, the size distribution of the three catalysts is in the order of Fe > Co > Ni. This paper describes similar study on the structure of the nanotubes grown by CVD with the focus on the effect of the catalysts on the characteristics of nanotubes namely the diameter, shape and crystallinity. Despite similar method of synthesis adopted, we have managed to produce a narrower size distribution and much smaller diameter of nanotubes.

EXPERIMENTAL

The catalytic decomposition of methane over the catalyst was carried out using CVD system. CNTs were grown on three different catalyst particles under the same conditions. Catalytic particles of iron, nickel and cobalt were prepared [8] and pretreated by etching with NH3 gas to further reduce to nano-size particles. The catalytic deposition of carbon on well-dispersed metal catalysts was carried out in the methane atmosphere at a flow rate of 40 sccm at 950 _C. The raw products were then given the heat and acid treatment to purify them into a fine powder. Samples were examined using FESEM and TEM (Phillips Tecnai 20) operating at 200 kV. For thermo gravimetric analysis, a small amount of sample was subjected to heat treatment from room temperature to 800 _C with heating rate of 10 _C per minute under the air ambient.

RESULTS & DISCUSSION

Nanotubes when produced by CVD method will inevitably be accompanied by the side-products. Figure 1 depicts an image of unpurified nanotubes indicating the presence of nanoparticles and other graphitic debris. Examination of the final product, which had been purified, indicated that most contaminants had been removed. This is evident in Figure 2, which shows the image of CNT's grown on Co particles.

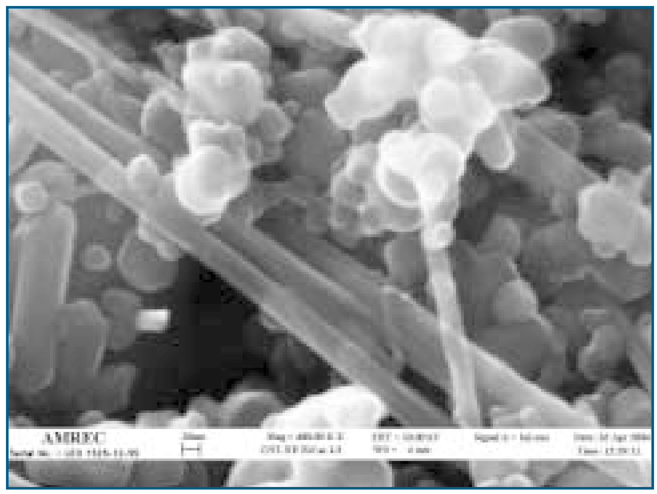


Figure 1: SEM image of unpurified CNTs

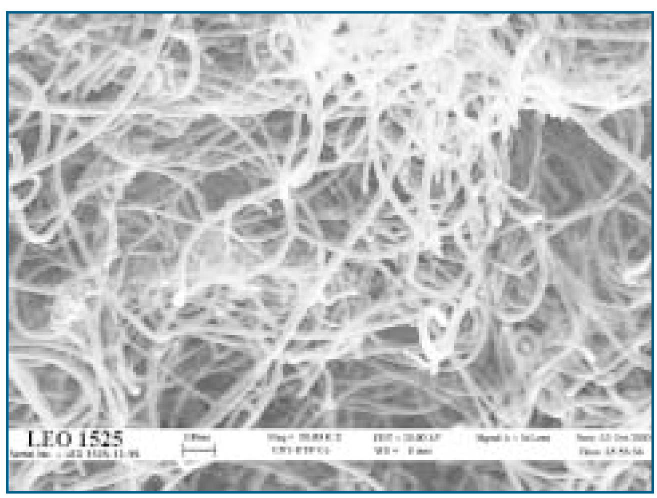


Figure 2: SEM image of CNTs grown on cobalt catalyst particles

Research work by Fujita et al [9] and Dresselhaus et al [10,11] have shown that nanotubes with diameters larger than about 1 nm can be capped in a large number of ways. Past experimental studies have in fact showed that multilayer nanotube caps can have a variety of morphologies with the vast majorities of the unsymmetrical type.

As reported in our earlier paper [11], results had indicated that CNTs grown on Fe catalyst have the largest size distribution compared to the ones on Co and Ni. Lee et al, 2002, had reported similar order in the size of CNTs grown catalytically on the same catalyst particles. This was explained by the size effect of catalyst particles on the growth of CNTs where before the growth, the size distribution of the three catalysts is in the order of Fe > Co > Ni. If we look closely at the size distribution of nanotubes produced here and the ones produced by Lee, there is a significant difference between them. As illustrated in Table 1, we have managed to produce a much smaller size distribution of nanotubes grown on all three catalysts. This is believed to be due to the longer period and higher gas flow rate of ammonia pretreatment prior to the growth of nanotubes, resulting in very much smaller nanosize catalyst particles.

Our early work [11] has also reported the distinct difference on the shape of nanotubes produced by catalytic method. Nanotubes grown on Fe particles seem to have fairly straight structure whereas a lot of curled and looped ones can be observed on CNTs

Table 1: Comparison of diameter measurements between CNTs produced here and the ones reported by Lee et al. [7]

	Fe	Co	Ni
Diameter Distribution (nm)	31-38	23-26	19-24
Diameter Distribution (Lee *et al* 2002)	80-200	80-130	90-110
Average diameter (nm)	35	25	21
Average diameter (nm) (Lee *et al* 2002)	130	110	100

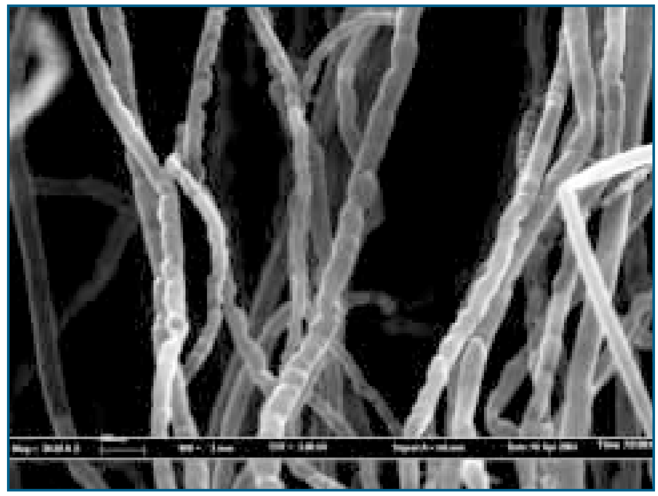


Figure 3: An example of bamboo like structure nanotubes

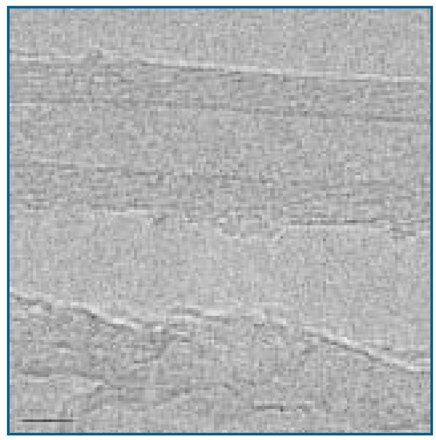
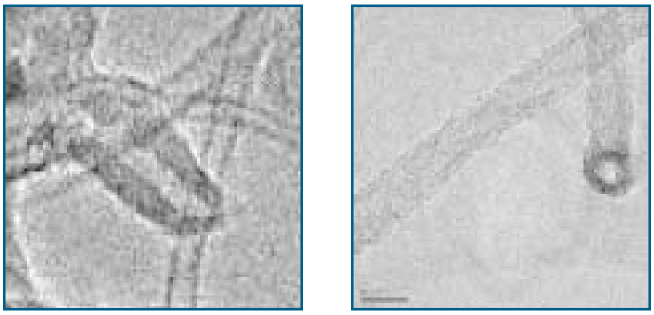


Figure 4: HRTEM image of nanotubes grown on Ni catalyst

image grown on Ni. Some helical tubes can even be identified amongst the curled ones grown on Co. Bernaerts et al [12], had also reported similar shaped nanotubes. Close observation of SEM and TEM images show that CNTs grown on all catalysts have a fairly smooth tube structure unlike the ones produced by Lee et al (2002) which seems to have a bamboo-like structure. An example of bamboo-like structure nanotubes is shown in Figure 3. No explanation was put forward as to why nanotubes come to be in this form.

In the recent study [13] we have used HRTEM to probe the internal structure of CNTs where it can reveal the stacking arrangement of multiwalled nanotubes, the presence of defects and the structure of caps. Figure 4 shows a typical HRTEM image of CNTs grown on Ni catalyst. CNTs grown on all three catalysts were



(a) (b)

Figure 5: Micrograph of (a) an asymmetric cone structure cap and (b) an open nanotube

observed to exhibit multiwalled structure with evenly spaced lattice fringes. Although most of the images observed show a closed end nanotubes of various asymmetrical shapes (one example is shown in Figure 5a), examples are sometimes observed which are completely open, with no obvious cap structure. An example is shown in Figure 5b.

CONCLUSION

Here, the morphology of carbon nanotubes grown catalytically using thermal CVD is described. CNTs produced this way have proven to be of good quality with reasonably small diameters and size range. The effect of using different catalyst particles are seen on the diameter values and shape of CNTs produced. As a direct effect of particle size of the catalyst on the growth of CNTs, the diameters were found to be in the order of Fe > Co > Ni.

HRTEM was used to probe the internal structure of nanotubes where the intricate structure of multiwalled nanotube are revealed, giving a reasonable understanding of the main structural features. All CNTs grown on Fe, Ni and Co have shown to be of multiwalled type with evenly spaced graphene layers. Closer observation of the HRTEM images of nanotubes could also be used to determine the crystallinity of CNTs grown on different catalysts. With this technique, it is found that CNTs grown on Fe catalyst exhibits better crystallinity compared to CNTs grown on Ni and Co catalyst. The finding is verified by the result of TGA conducted on the bulk CNTs. This catalytic method using CVD system has proven its capability to produce CNTs with smaller size distribution required for certain applications.

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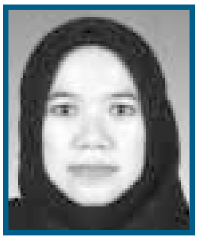

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