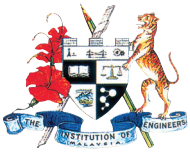

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THE INSTITUTION OF ENGINEERS, MALAYSIA
Bangunan Ingenieur, Lots 60 & 62, Jalan 52/4,
P.O.Box 223 (Jalan Sultan),
46720 Petaling Jaya, Selangor Darul Ehsan.
Tel: 03-7968 4001/4002
Fax: 03-7957 7678
E-mail: sec@iem.org.my **Homepage:** http://www.myiem.org.my

A REVIEW OF NATURAL PRODUCTS FROM PLANTS USING CARBON DIOXIDE SUPERCRITICAL FLUID EXTRACTION

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Chew-Theng Lam[1], Lee Tin Sin[1*], Soo-Tueen Bee[1], P. Siwayanan[2]

[1]Department of Chemical Engineering, Lee Kong Chian Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, Bandar Sungai Long, Jalan Sungai Long, 43000, Kajang, Selangor, Malaysia.

[2]School of Energy & Chemical Engineering, Xiamen University Malaysia, Jalan Sunsuria, Bandar Sunsuria, 43900 Sepang, Selangor, Malaysia.

**Corresponding author. Tel: +60 3 9086 0288; Fax: +60 3 9019 1989.*
Email: direct.tinsin@gmail.com (Lee Tin Sin) and direct.beest@gmail.com (Soo-Tueen Bee)

ABSTRACT

Supercritical fluid extraction (SFE) is the most effective and efficient way to extract valuable constituents from plants. SFE is the process of separating one component (the extractant) from another (the matrix) using supercritical fluids that is CO_2 as the extracting solvent. It is a well-established process for recovery of different organics, mainly nonpolar substances from various solid matrixes. CO_2 is the most common used extraction solvents for botanicals. Extraction conditions for supercritical CO_2 are above its critical temperature of 31 °C and critical pressure of 74 bar. Supercritical fluids are highly compressed gases, which have combined properties of gases and liquids in an intriguing manner. Supercritical fluids can lead to reactions which are difficult or even impossible to achieve in conventional solvents. In addition, supercritical fluid can be separated from analytes by simply releasing pressure, leaving almost no trace and yields a pure residue. The use of supercritical carbon dioxide is a simple, inexpensive, fast, effective and virtually solvent–free sample pre-treatment technique. In this research, a complete study on supercritical carbon dioxide extraction of natural products from plants is carried out to examine the principal of this method, the bioactive compounds that can be extracted and also the effect of process variables on extraction yield. Finally, SFE also has been compared with other conventional and non-conventional extraction methods in terms of selectivity, rapidity, cleanliness and possibility of manipulating the composition of the extract.

Keywords: Supercritical fluid extraction; carbon dioxide; Natural products.

1.0 INTRODUCTION

Plant extracts have been used for various purposes and in demand as alternative medicines and food preservatives. Biological properties of plant extracts such as antimicrobial and antioxidant ability gives significant importance in our daily life (Cos, *et al.,* 2006). From the analysis of World Health Organization (WHO), large population is dependent on folk medicine for their dominant healthiness demand. In Asia, the interaction of human with environment was exhibited through the use of herbal medicines in daily basis. Plants that contain substances that are able to defeat chronic and infectious diseases are always used as traditional medicine (Duraipandiyan, *et al.,* 2006). Secondary metabolites in plant material offered diverse medical properties such as antitumor, antifungal, antibacterial, anti-litholitic and antioxidant. These secondary metabolites are normally in the form of composite molecules with functional structures (Lahlou, 2013). According to the biosynthetic origins of secondary metabolites, they are able to be categorized into three major classes which are phenolic compounds, terpenoids and nitrogen-containing alkaloids.

Phenolic compounds in plant material are a group of antioxidants composed by various subclasses such as phenolic acids, stilbenes, lignans and others. In recent times, due to their potential health effects, an increased interest in extraction of phenolic compounds has arisen. Phenolic compounds contain phytonutrients with strong antioxidant properties. The principle role of antioxidants is to prevent the initiation and propagation of oxidizing chain reactions by free radicals. In consequence, it may decelerate the oxidation processes of other molecules and weaken oxidizing harm (Lobo, *et al.,* 2010). Hence, antioxidants are typically utilized on daily life as their consumption represent a central role in the avoidance of many syndromes which related to oxidative stress like cancer, cognitive and cardiovascular diseases (Uttara, *et al.,* 2009).

Essential oils have been contemplated as characteristic constituents of aromatic plants. They are composed of a group of volatile organic compounds that stimulate flavour and fragrance of a plant (Ercioglu, Velioglu and Boyaci, 2015). Furthermore, due to their comparatively safe status, their wide acknowledgement by users and exploitation for potential multi-functional use, essential oils are gaining more interest in the recent years. (Lin, *et al.,* 2009). One of the important components in essential oils is terpenoids, which are the most diverse natural compounds found in many plants. Terpenoids are biologically active and are employed for treatment of malaria, cancer, inflammation and infectious diseases. Alkaloids can be described as a group of organic particles with composite structures that consist of a heterocyclic nitrogen ring. They can

be discovered mainly in plants specifically in particular families of flowering plants. Alkaloids have been extensively utilized for various aspects in favour of their numerous pharmacological characteristics. Even though alkaloids are commonly detected in organisms, including animals and microbes, normally the higher plants also consist of different array of these compounds. Some of the alkaloids are advantageous for medicinal appliances but some others are poisonous and potentially harmful to humans (Murphy, 2017).

Extract from plants are complex mixtures of constituents and the method for extraction, sample clean up, separation and detection for each extract is distinctive. For the analysis of medicinal plants, the preliminary step is extraction since it is required to conduct the separation of intended bioactive compounds from the plants in order to isolate and carry out investigation. The main procedures for extraction include pre-washing, dehydrating of plant materials and milling to collect a homologous sample. During the process, the analyte extraction kinetics needs to be enhanced regularly and also enlarge the surface of contact between sample and solvent system so that extraction can be carried out efficiently. Some precautions and proper manners are necessary to assure that no active constituents will be damaged (Fabricant and Farnsworth, 2001).

The options for solvent system commonly relies on the particular character of bioactive compounds that being extracted. For the extraction process of bioactive compounds from plants, different solvent systems are accessible. Since bioactive compounds are thermally labile and could be varied from polar to non-polar, the applicability of the techniques of extraction need to be studied (Sasidharan, *et al.,* 2011). In general, the extraction methods used are solid–liquid extraction (SLE), solid-phase extraction (SPE) or liquid–liquid extraction (LLE). However, the latest extraction techniques include ultrasound-assisted extraction (UAE), supercritical fluid extraction (SFE) or microwave-assisted extraction (MAE), which each of these methods own certain benefits and have received a great interest for overcoming the drawbacks of conventional solvent extraction. These techniques are benefit in exclusion of extra cleaning up of sample and concentration procedures before the analysis of chromatographic, deduction in usage of organic solvent and in sample degradation, increase in selectivity of extraction, extraction performance and kinetics. Their practises for the extraction of bioactive compounds from plant materials are preferred due to the simplicity and automation of these techniques (Huie, 2002).

From the end of the 1970s, the interest in supercritical techniques and supercritical fluids used to isolate natural products are getting more and more high (Brunner, 2005). This interest is showed in the recent years in the form that large quantity of scientific reviews concerns with supercritical fluid extraction (SFE) being announced. In addition, industrial utilization of SFE has achieved an aggressive evolution in terms of patents since the early 1990s in (Schutz, 2007). In the review, the main focus is on extraction of bioactive compounds from plants using carbon dioxide as main solvent. Carbon dioxide (CO_2) with critical temperature 30.9 °C and pressure 73.8 bar, has benefits in terms of cost, less harmful to the environment and acknowledged as secure by FDA and EFSA. Besides CO_2 also has high diffusivity and adjustable solvent strength. Moreover, the characteristic of CO_2 remains as gaseous phase under room temperature and pressure makes extraction process much easier and it also offers solvent-free analytes (Herrero, *et al.,* 2006).

Supercritical fluid extraction (SFE) using carbon dioxide is an advanced technology with higher efficiency alternative i.e. short in time, high purity and lower temperature (to avoid temperature induce degration) compared to the conventional methods for example like soxhlet extraction or hydrodistillation (Manjare and Dhingra, 2019). The extraction of bioactive compounds by supercritical carbon dioxide extraction has been extensively studied due to its benefits over conventional extractions based on organic solvents. Its advantages include the consumption of non-toxic solvent that is obtainable in high purity but inexpensive and least solvent residues in final products. Additionally, SFE process can be performed at relatively low temperature, preventing degradation of heat-induced product. The capability of SFE using carbon dioxide to be conducted at low temperature is essential for sample preparation of natural products because it permits the extraction of thermal sensitive or easily oxidized compounds with the use of a non-oxidant medium (Schutz, 2007).

Comprehension of the character of plant matrix, chemical properties of bioactive compounds and also input parameters are very important since they will directly affect the efficiency of non-conventional and conventional extraction techniques. Extraction optimization is considered as one of the major aspects in SFE. By utilizing the optimum values for every process parameters, the efficiency of SFE extraction and yield of targeted bioactive compound could be significantly improved (Ruan, *et al.,* 2016). Normally, the performance of SFE is altered by various factors including process temperature, pressure, duration of extraction, existence of modifier and CO_2 flow rate.

2.0 BIOLOGICAL ACTIVE COMPOUNDS

Based on the reason of their wide range of structural variety and pharmacological activities, plants are acknowledged in various aspects especially in pharmaceutical industry. Phytochemistry defines the substantial amount of secondary metabolic compounds exist in plants. These phytochemicals are used as sources of direct pharmaceutics medium. They can be derived out of distinct parts from plants like roots, leaves, seed coat, seed, pulps, barks and flowers (Krishnananda, *et al.,* 2017).

Originally, human beings consumed plants in the interest of nutritional reason. After the exploration of their pharmaceutic abilities, this natural plants turn into an effective medicine for disease treatment and also useful for health improvement (Azmir, *et al.,* 2013). Therefore, natural sources such as extract from plants, open up a new horizon for the revelation of new medicinal agents. In most developing countries, traditional drugs and medicinal plants are used as a formal basis for the support of good health and about 80 % of the community has been noticed depends on herbal medicines. This is because plants consist a lot of chemical compounds that are suitable for chronic treatment in addition to infectious diseases. They discovered precisely more than thousands of phytochemicals are valuable and contain biological properties for example wound healing, antioxidant, anticancer, analgesic and antimicrobial (Krishnananda, *et al.,* 2017).

The comprehension regarding dynamic chemical properties of various bioactive components is the forerunner for the

development of bioactive determination from the last decade (Torssell, 1997). Subsequently of these significant technological advancements, different industries have become more concerned in bioactive compounds from natural materials such as food additives, pharmaceuticals and even on natural pesticides sectors (Azmir, *et al.,* 2013). Generally, biological active compounds exist together with some other components in plants. They can be mainly classified into two categories which are primary metabolites and secondary metabolites. Secondary metabolites can be described as metabolites that are usually formed in a stage of consequent to growth. They consist of uncommon chemical structures and also existed as combinations of mutually related members from one family group (Martin and Demain, 1978).

The generation of secondary metabolites is principally chosen by the way of assessment and the certain demand of particular species. For instance, the purpose of fragrance by flowering plants is to draw attention from insect to help them in fertilization and pollination, and synthesis of poisonous compound has been utilized against herbivores and pathogens for restraining the development of neighbouring species. In the middle of these secondary metabolites, some of the compounds are useful for biological organisms which are treated as bioactive. Hence a common explanation of bioactive compounds in plants can be defined as secondary metabolites evoking toxicological and pharmacological properties in both animals and human (Azmir, *et al.,* 2013). Plant secondary metabolites can be classified into three main categories. These three categories include phenolic compounds, nitrogen-containing compounds and terpenoids. The examples of terpenoids are sterols, plant volatiles, carotenoids, and cardiac glycosides; phenolic compounds are tannins, phenolic acid, coumarins, flavonoids, stilbenes and lignans; nitrogen-containing compounds include alkaloids, non-protein amino acids and cyanogenic glucosides (Croteau *et al.,* 2000).

2.1 Phenolic Compounds

Phenolic compounds (PCs), is the largest group of secondary metabolites in plants and they can be found ubiquitously in daily life. In other words, a huge amount of medicinal plants have been proved to be abundant in PCs. These plants involve Ginkgo biloba L., Salvia miltiorrhiza Bge., Myristica fragrans Houtt., Boehmeria nivea (L.) Gaudich. and Cimicifuga foetida L. Other than that, in our daily diets, vegetables, fruits, cereals and spices are also popular sources of PCs especially polyphenols. PCs possess a particular chemical structure composing an aromatic ring hydroxyl substituents that are able be classified into few groups. With the expanding acknowledgement of medicinal properties of PCs, they have been proved to aid in reducing the risk of various chronic disorders. The major groups of PCs include phenolic acids, tannins, flavonoids, lignans and stilbenes. As many reviews published, PCs give pharmacological properties such as anti-carcinogenic, anti-microbial, anti-inflammatory, antioxidant, estrogenrelated prevention of cancers, diabetes, cardiovascular diseases and ailments related with oxidative stress (Xu, *et al.,* 2017). Hence, these newly exposed characteristics of PCs have been utilized in the development of cosmetics, nutraceuticals foods.

Chemical structure of phenolic compounds varied from simple phenols to high molecular weight and long chain polymers such as condensed tannins (C_6–C_3–C_6)n and lignins (C_6–C_3)$_n$. Intermediate molecular weights of phenolic compounds include flavonoids (C_6–C_3–C_6) and stilbenes (C_6–C_2–C_6) (Ejaz, *et al.,* 2017). Among PCs, flavonoids represented a crucial group of compound with great importance because they can be used by human body to fight against diseases. Flavonoids are composed by 15 carbon atoms which organized in three rings (C_6–C_3–C_6) labelled as A, B, and C, respectively; where A and B are two aromatic rings, and C is a three-carbon bridge heterocyclic ring (Xu, *et al.,* 2017). They are well known to have anti-hypertensive properties. Flavonoid compounds are a type of extraordinarily efficient natural antioxidants and less harmful than synthetic antioxidants. These highly reactive molecules are normally present in biological systems and can lower the chance of degenerative diseases like cancer, heart disease or dermal disorders. Several reviews have showed that flavonoids can be consumed to avoid certain prevalent diseases like atherosclerosis, cancers and ameliorate muscle wasting (Ouédraogo, *et al.,* 2018).

PCs exert a great structural diversity and comprise a major class of plant secondary metabolites which are extensively spread in the domain of plant. Their stability alter significantly and are neither consistently distributed in the plant. This properties indeed make their extraction and isolation processes more difficult, which means that a single standardized procedure is not applicable for all kinds of phenolic compounds or plant materials. Thus, the procedures need to be amended based on the objective of the study, the targeted analytes and importantly the properties of sample (Xu, *et al.,* 2017). Basically, the amount of hydroxyl groups in PCs will affect its lipophilicity. Due to the polar region of the lipid bilayer, the interaction between phenolic compounds and lipids such as membranes of lipid cell are restricted. Phenolic compounds are normally more hydrophilic than lipophilic due to their phenolic nature. Hence, phenolic compounds can be readily separated by supercritical carbon dioxide extraction method with the aid of modifiers such as methanol, ethanol, water and etc.

2.2 Alkaloids

Alkaloids, non-protein amino acids and cyanogenic glucosides are the examples of plant secondary metabolites which contain nitrogen compound as part of their structure. They are nitrogen-containing compounds that normally modified from amino acids like tryptophan, tyrosine, aspartic acid and lysine. These compounds existed in the form of secondary metabolites in around 20 % of plant materials and presented as defensive role to defeat the attacks of herbivores and pathogen (Hegnauer, *et al.,* 1988). An alkaloid is a compound has at least one nitrogen atom in an amine-type structure. Nearly all alkaloids contain nitrogen atoms as part of a ring of atoms, which usually named as cyclic system. Alkaloids are generally categorized depending on their chemical structure. Such as, alkaloids that consist of a ring system (indole) are named as indole alkaloids. Based on this principal, the major groups of alkaloids are divided into pyrrolidines, pyridines, tropanes, pyrrolizidines, isoquinolines, indoles, quinolines, terpenoids and steroids.

Alkaloids have different physiological influences on both human being and faunas. Some famous alkaloids are strychnine, ephedrine, morphine, nicotine and quinine. Alkaloids are discovered mainly in plant materials and are exclusively popular in particular families of flowering plants. For example, all plants

from poppy family (Papaveraceae) are found to have alkaloids. The Amaryllidaceae (amaryllis), Solanaceae (nightshades) and Ranunculaceae (buttercups) are examples of other prominent alkaloid-containing families of plants.

The pharmaceutic abilities of alkaloids are relatively diverse. For example, morphine as an effective narcotic employed to reduce ache, even though its obsessive characteristics restrict its suitability for usage. Besides, codeine which is derivative from methyl ether of morphine discovered in the opium poppy, is an outstanding analgesic drug that is comparatively non-addictive. Meanwhile some other alkaloids can be acted as cardiac or respiratory stimulants. From plants of the genus Cinchona, quinidine can be obtained for treatment of arrhythmias or irregular rhythms of the heartbeat. In this aspect, lobeline that come from Lobelia inflata is harmless and thus is more useful. Besides, Ergonovine obtained from the fungus of Claviceps purpurea and ephedrine from Ephedra species can be used as blood-vessel constrictors. Ephedrine is also frequently consumed to cure the anxiety of common colds, sinusitis and bronchial asthma.

Particular techniques have been advanced for isolating valuable alkaloids. In most conditions, aqueous solutions of the alkaloids can be attained by processing plant tissue. Those alkaloids are later separated from the solution using method of extraction, which include dissolving some elements of the mixture with reagents. Dissimilar alkaloids are then can be divided and decontaminated from the mixture.

2.3 Terpenoids

Terpenoids is a subdivision of the prenyllipids (terpenes, prenylquinones and sterols), which are widespread kind of natural products and symbolize the oldest class of small molecular substances produced by plants. Terpenoids, which methyl groups are taken out or extra oxygen atoms joined can be expressed as modified terpenes. All terpenoids may be described as a group of molecules where their chemical structure is depend on a variety but definite amount of isoprene units. The biosynthesis of terpenoids begins from basis of two general five carbon (C_5) pioneers which are isopentenyl diphosphate (IPP) and dimethylallyl diphosphate (DMAPP). The two basic prenyl units are utilized precisely to compose hemiterpenes or polymerized in increased number of five carbon units through the expansion of IPP to develop prenyl diphosphates with varying lengths of chains. These prenyl diphosphates are the universal forerunners to primary terpenes that can be discover in plant materials, such as monoterpenes (C_{10}), sesquiterpenes (C_{15}), diterpenes (C_{20}), triterpenes (C_{30}), carotenoids (C_{40}) and polyprenols (C >45). Terpenoids served as the biggest and most diverse group of chemicals among the myriad compounds obtained by plants. Plants utilize terpenoid metabolites for primary activities in growth and development but also consume most of the terpenoids for protection in the abiotic and biotic environment and for more particularly chemical interactions. Generally, terpenoids from plants have been consumed by community in the respect of food, chemical industries, pharmaceutical industry and currently have been used in the development of biofuel products. Various researches have confirmed proved that this kind of compounds shows a wide spectrum of essential pharmacological features. The diverse compilation of terpenoid structures and properties have exasperated more interest for their commercial usage resulting in some with conclusively proved medical utilizations being registered as drugs on the market. Some of the terpenoids are more biologically active and are effective in healing malaria, inflammation, cancer and infectious disorders. However, several composites from this group exhibit poisonous properties lead to central nervous system manifestations and gastrointestinal problems among others.

There are different kinds of mono-, sesqui-, di-, tri-, tetra- terpene compounds have been universally reviewed. These components are discovered throughout natural sources and are found in most plants. Most of the monoterpenes are acknowledged for their impressive aromas and high volatility which are used to attract insects for pollination of flowering plants. For instance, essential oils extracted from rose, peppermint, lemon and lavender have various oxygenated monoterpenes, aliphatic and aromatic compounds that offer these oils their specially refreshing fragrance. Meanwhile, other higher molecular weight terpenes and non-aromatic terpenes can use as protective compounds by helping the plant to push away possibly harmful predators. Hydrophobicity of terpenes which allows them to cross the lipid membranes of invading cells effortlessly can be described as another protective characteristic. Even though terpenes are commonly not harmful for large organisms such as humans and animals, they can be useful against a lot of environmental threats.

Terpenes and terpenoids are the main components of essential oils which obtained from different species of medicinal plants. Essential oils are often utilized as fragrances in perfumery and substitute medicines such as aromatherapy. Artificial derivatives and variations of natural terpenes and terpenoids also largely expand the diversity of aromas which utilized in flavors used in food additives such as Vitamin A is a terpenoid. Due to the wide variety of structures that terpenes can compose, the techniques for their extraction process will vary case-by-case, mainly based on the nature properties of the targeted terpene, and quantity of the raw material and the accessibility of instruments and reagents used (Jiang, Kempinski and Chappell, 2016).

3.0 EXTRACTION TECHNIQUES

The analysis of bioactive compounds from plants mainly depends on the choice of suitable extraction technique. Extraction is the primary procedure of all medicinal herbs research, it presents an important and critical role on the outcome and final results. Extraction methods are often used as sample preparation step for analytical purposes and to strip unwanted material or obtain desired material from a product. A research carried out by Majors (1999) indicated that numerous researchers have admit the significance of sample preparation step for research project (Azmir, *et al.,* 2013).

Extraction of bioactive compounds from plant materials and their quantitative and qualitative assessment is essential for the analysis of new discovered biomolecules. These biomolecules are utilized by agrochemical and pharmaceutical industry directly or used as a lead molecule to produce more potent molecules. Extraction from the plant is a practical exercise as various solvents are used at different conditions such as pressure, temperature and duration of extraction. In addition, in the extraction process, further the separation of targeted analytes from co-extractives compounds is important. Further fractionation of extracted compounds can be accomplished on the

basis of their molecular size, acidity or polarity (Krishnananda, *et al.,* 2017).

Extraction of plant materials can be conducted by different extraction techniques. Firstly is the non-conventional methods, which have been developed during the last 50 years, is more eco-friendly since it required low usage of artificial and organic solvents in shorter process time with greater yield and quality of product. For instance, to increase overall extraction yield and selectivity of bioactive compounds, pulsed electric field, extrusion, enzyme digestion, ultrasound, supercritical fluids, accelerated solvents, ohmic heating and microwave heating have been considered as non-conventional methods. Meanwhile, for conventional extraction methods, for example Soxhlet extraction is yet studied as the reference to compare with advanced technique. Generous amount of book chapters, monograms and scientific reports be present where non-conventional methods were widely studied (Azmir, *et al.,* 2013).

To proceed with a further separation, analysis and interpretation of bioactive compounds, it is necessary to conduct a successful extraction process. Various extraction methods could be carried out in different settings for the consideration of extraction selectivity from different natural materials.

3.1 Conventional Extraction Techniques

Extraction of bioactive compounds from plant materials can be done by numerous traditional extraction methods. Most of these methods are depend on the solvating power of solvent used and the application of heat or mixing. Some common extraction methods used to collect bioactive compounds from plants are Soxhlet extraction, Maceration and Hydrodistillation.

The first Soxhlet extractor was created 1879 by a chemist from Germany Franz Ritter Von Soxhlet. This extractor was created primarily for the extraction of lipids but presently this method is not restricted only for this purpose. Soxhlet extraction has been extensively practiced for the extraction of bioactive compounds from natural sources. It is utilized as a reference method and alternatives of new extraction techniques. Typically, at first a little quantity of sample matrix is located in a thimble and then the thimble is situated in distillation flask which consists of solvent. The solution of the thimble-holder is aspirated by a siphon once it overflows. The siphon discharges the solution back into the distillation flask. This solution transfers extracted solutes into the bulk liquid. After that, solute is remain in the distillation flask whereas solvent flows back to the solid bed of sample. This procedure operates continually until the extraction is finished (Azmir, *et al.,* 2013).

Soxhlet extraction has been extensively utilized for both initial and bulk extraction. The main advantage of this method is that the sample can be extracted continuously. The solvent saturated in solubilized metabolites discharges into the flask, fresh recondensed solvent then re-extracts the material in the thimble. Soxhlet extraction use shorter process time and less solvent-consuming than others such as maceration and percolation. However, it has a main drawback which it is not suitable for thermolabile compounds or it can initiate the degradation as the extract is continually heated at the boiling point of the solvent used (Seidel, 2012).

Maceration is mainly employed in the preparation step for production of tonic long times ago. Recently, it has been developed to a well-known and inexpensive method to obtain bioactive compounds and essential oils from natural sources. For a smaller scale of maceration extraction, it commonly made up of numerous procedures. Initially, for proper mixing with solvent, crushing of plant samples into smaller particle is carried out to increase the surface area. Next is the addition of suitable solvent named as menstruum into a sealed container in maceration process. Thirdly, the solution is strained off but the solid residue is hard-pressed to recover more occluded solutions. The press out liquid and obtained strained and are then mixed together and eventually purified from contaminations by the way of filtration. In maceration, irregular shaking further extraction by two means which are enhance the diffusion and remove saturated solution from the sample surface for transporting fresh solvent to the menstruum for greater yield of extraction (Azmir, *et al.,* 2013). Maceration is applicable for both initial and bulk extraction of plant materials. However, exhaustive bulk extractions require longer processing time which takes from a few hours up to several weeks. Besides, large volumes of solvent may be consumed for this method (Seidel, 2012).

Hydrodistillation is another classical method to extract essential oils and valuable bioactive compounds from plant materials. However, organic solvent is not required in this technique and it can be carried out before the dehydration of plants. Hydrodistillation can be divided into three types which are water distillation, water and steam distillation and direct steam distillation (Vankar, 2004). For the hydrodistillation process, the first step is the introduction of the plant sample in a fixed compartment. Next, some water is added and boiled. On the other hand, for direct steam hydrodistillation, steam is inserted into the plant materials. In this method, hot water and steam is the dominant aspects to separate bioactive compounds from plant cells. The vapour mixture of oil and water is then condensed by indirect cooling of water. The condensed mixture is then flows to a separator from condenser. The separator is where bioactive compounds and oil can be extracted spontaneously from the solution (Silva *et al.,* 2005). Besides that, hydrodistillation includes three fundamental physicochemical routes which are hydrodiffusion, hydrolysis and decomposition by heat. One of the limitation of this technique is particular volatile composites may possibly be damaged in the process since this is a high temperature extraction. This weakness restricts its applicability for thermo sensitive compound extraction (Azmir, *et al.,* 2013).

3.2 Non-Conventional Extraction Techniques

The main disadvantages of conventional extraction techniques are they normally time-consuming, require expensive and high concentration solvent, involve vaporisation of large quantity of organic solvent, low selectivity of extraction and not suitable for thermo labile compounds. To overcome these drawbacks, some promising and advanced extraction methods are presented. These methods are considered as non-conventional extraction techniques. These new techniques include supercritical fluid extraction (SFE), enzyme-assisted extraction, microwave-assisted extraction (MAE), ultrasound assisted extraction (UAE), pressurized liquid extraction (PLE) and pulsed electric field assisted extraction (PEF). All these methodology are also studied as ''green techniques'' since they satisfy the criteria of the Environmental Protection Agency, USA. These rules consist of low level of harmful chemical solvent, designing nontoxic substances, safe solvents auxiliaries, intention to promote energy

efficiency, usage of renewable raw material, reduce by-products, plan to avoid degradation and so on (Azmir, *et al.,* 2013).

However, every non-conventional extraction techniques have their own significant advantages and limitations. Different extraction methods of bioactive compounds are illustrated and compared in Table 1.

Table 1: Comparison of Non-conventional Extraction Methods

Extraction Method	Advantages	Disadvantages
SLE (Microwave-assisted extraction)	Simple and easy to operate; wide adaptability.	Need to use substantial amounts of hazardous organic reagents; long extraction time; low efficiency.
UAE (Ultrasound-assisted extractions)	Simple and easy to operate; efficient; economical; wide adaptability.	Unsuitable for industrial production
MAE (Microwave-assisted extraction)	Consumes less extraction solvent and extraction time; increases the content of extracted antioxidants.	Degradation and oxidation will occus under such conditions
SFE (Supercritical fluid extraction)	Increase safety and selectivity; avoid sample oxidization in the presence of air.	Unsuitable for the extraction of polar PCs; high requirement of capital investments.
ASE (Accelerated solvent extraction)	Require small amounts of solvent; provides faster extraction processes.	The need of high temperature and pressure.
HHPE (High hydrostatic pressure extraction)	Efficient; consumes less extraction solvent and extraction time.	The need of high pressure and expensive equipment.

Microwave-assisted extraction is a technique by heating the solvents and plant tissue using microwave to increase the kinetic of extraction. This techniques commonly named as microwave extraction which combines the microwave and traditional solvent extraction. Microwaves is defined as the electromagnetic fields within the frequency range of 300 MHz to 300 GHz and are produced by two oscillating fields which are perpendicular to each other like magnetic field and electric field. The purpose of heating of dried plant material is to further reduce microscopic traces of moisture that exists in the cells of plant. Due to microwave effect, the heating up of this moisture inside the plant cell results in dehydration and produces high stress on the wall of cell. The cell wall is then pushed from inside and rupture the cell wall. Hence the exudation of active components from the ruptured cells happens and the produce of phytoconstituents increased (Krishnananda, *et al.,* 2017). MAE is acknowledged as one of the green technology since it lessen the usage of organic solvent. Some advanatges of MAE are proposed by Cravottoa et al. on 2008, which includes heating up for the extraction of bioactive compounds from plant samples in shorter time, lower thermal gradients throughout the process, smaller size of apparatus used and greater yield of extraction. This technique can extract bioactive compounds faster and a greater recovery can be achieved compared with conventional extraction techniques. MAE is a selective method to organometallic and organic compounds that are more complete (Alupului, 2012).

Pressurized Liquid Extraction (PLE) is an advanced extraction technique that make use of solvents at high pressures and temperatures used sample preparation steps for analysis by either liquid chromatography or gas chromatography. PLE is actually very much alike with Soxhlet extraction, except that the solvent used for PLE cell approaches to the supercritical region during the extraction process. This results in a more effective extractions of sample. The high temperature required in this method can increase the solubility of sample and allows greater rate of diffusion whereas high pressure ensure the solvent is always lower than its boiling point. This is because at high temperatures and pressures, solvents can penetrate into solid matrixes more easily and effectively thus lessen the use of solvent.

PLE was established to reduce time consumption and the usage of organic solvent as compared to soxhlet extraction technique. For the extraction of polar composites, this method is considered as a promising substitute method to supercritical fluid extraction. It is effective for the extraction of organic impurities from environments as well been utilized for the extraction of bioactive compounds from marine sponges (Ibanez *et al.,* 2012). The procedures of pressurized liquid extraction involves mixing of sample with sodium sulfate, loaded in the extraction cell and covered with two filtration end fittings. Then, the system will mechanically starts pressurizing and heating the samples. For PLE, the extraction pressure is always kept at a range of 1500 PSI to 3000 PSI and at a temperature of 70 ºC to 200 ºC. The extracted solution which consists of targeted analytes is now transported to an evaporation or concentration chamber where it is eventually transformed to final volume directly in a gas chromatography (GC) or liquid chromatography (LC) vessel. The vessel can formerly be moved to the analytical device for examination process. With the advantages of low volume solvent requirements, PLE provides a more practical and environment-friendly substitute method to conventional approaches. This method is the most suitable way for rapid and reproducible initial extraction of a large amount of samples (Seidel, 2012).

4.0 SUPERCRITICAL FLUID EXTRACTION TECHNIQUE (SFE)

Nowsaday, a dramatically growing of attention has been noted for supercritical fluids as a substitute solvents involved in the extraction of bioactive compounds from natural sources. The primary cause for this attention was the feasibility of conducting extraction processes at temperature close to ambient using supercritical fluid extraction, thereby avoiding the targeted components from inducing in thermal damage. After numerous researches and development, SFE is probably can be acknowledged as a well-established technique for extraction and separation of compounds. Furthermore, the design and operating principles of SFE are completely been understood, thus it is able to apply in the extraction of medicinal and aromatic plants (MAPs) commercially (Karale, *et al.,* 2011). The utilization of supercritical fluid intended for extraction begun with its innovation by Hannay and Hogarth on 1879, and Zosel who

published a patent with title of decaffeination of coffee via SFE technique. Ever since this starting point, supercritical fluid technique has drawn extensive attention and it was favourably used various industries especially in pharmaceutical, food analysis, environmental and polymer sectors.

Efficiency of extraction for any technique mostly relies on the appropriate selection of solvents (Cowan, 1999). The most important factor for solvent choice is the polarity of targeted bioactive compounds. Besides that, there are some other factors that should be considered in the selection of solvents for successful extraction such as molecular attractive force between solute and solvent, mass transfer, usage of modifier, environmentally friendly, human toxicity and commercial feasibility. (Azmir, *et al.,* 2013).

Some commonly solvents includes aliphatic and chlorinated hydrocarbons, esters and lower alcohols are used for extraction of particular bioactive compounds. Plants are complex matrices which containing an extent of secondary metabolites with different polarities and functional groups in it. Even though water is frequently employed as extracting solvent in lots of traditional procedures, organic solvents of different polarities are mostly chosen for new methods of extraction to exploit the varying solubilities of plant components (Seidel, 2012).

4.1 Supercritical Fluids (SFs)

Supercritical fluids (SFs) is a substance at supercritical condition, or defined as a dense gas which is a fluid at pressure and temperature above its critical point to a particular level. To achieve supercritical phase, the reduced temperature, Tr (T/TC) should not more than value of 1.3, meanwhile the reduced pressure, Pr (P/PC) is unlimited range and could be as high as allowed by technical restrictions. Under appropriate situations, any substance can achieve its supercritical phase. Nevertheless, only fluid with critical temperature around ambient temperature are suitable to be utilized as a substitute solvents for the extraction of bioactive compounds (Karale, *et al.,* 2011).

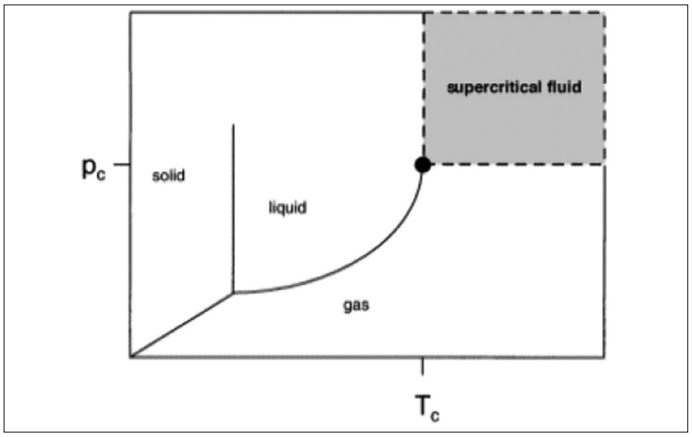

Figure 1: Phase diagram of a single substance (Karale, et al., 2011)

Figure 1 shows phase change of any substance by controlling its temperature and pressure. A graph of the solubility parameter for CO_2 against pressure is similar to that with parameter of density against pressure. The plot indicates that power of solvation for a supercritical fluid is directly connected to its density of fluid. The applicability of consuming supercritical fluids as extracting solvents is related to their fluid density. Once a fluid reaches critical phases, its density becomes nearer to that of in liquid phase. It is also acknowledged that expansion coefficient and compressibility of the fluid will become higher once it reaches critical point and thus even small alteration in the operating parameters can obviously change the density as well as the solvent power of supercritical fluid. Another attractive characteristic of supercritical fluids is that its behaviour lie between liquids and gases. Supercritical fluid possess densities like liquids, whereas the diffusivities and viscosities are more similar to gases. Therefore, a supercritical fluid is able to diffuse through a solid sample matrix more rapidly than a liquid, but still have a solvent ability to extract the solute from the solid sample matrix (Karale, *et al.,* 2011). The phase diagram for a pure compound at supercritical conditions is shown in Table 2.

Table 2: Critical Parameters for Selected Substances (Capuzzo, Maffei and Occhipinti, 2013)

Substance	T_c (°C)	P_c (bar)	ρ_c (g/cm^3)
Ar	-122.3	48.5	0.53
CH_4	-82.5	46.4	0.16
C_2H_6	32.4	48.8	0.20
C_2F_6	19.9	30.6	0.62
CHF_3	26.2	48.5	0.62
CO_2	31.1	73.8	0.47
C_2H_4	10.0	51.2	0.22
SF_6	45.6	37.2	0.73
NH_3	132.5	112.8	0.24
MeOH	240.6	79.9	0.27
EtOH	243.5	63.8	0.28
C_6H_6	289.0	48.9	0.30
H_2O	374.2	220.5	0.32

Supercritical fluids like methanol, ethane, pentane, propanol, ammonia, trifluoromethane and water are often employed in extraction process. Ghafoor *et al.* (2010), have developed SFE to extract phenolic compounds from grape seeds and the extract products obtained are examined, including gallic acid, protocatechuic acid and p-hydroxybenzoic acid. In the comparison with other extraction techniques, SFE utilize lower volume of hazardous organic reagents with shorter duration of extraction, increase selectivity and safety, and can prevent sample from oxidization in the existence of air. Anyhow, the main drawback of this process is the necessity of high capital investment cost (Xu, *et al.,* 2017). There are numerous compounds that applicable in supercritical techniques, however the most frequently used of solvent is supercritical carbon dioxide (SC-CO_2). Carbon dioxide (CO_2) is expressed as a perfect solvent used for SFE. One of the reason is that the critical temperature of CO_2 which is 31 ˚C, is near to ambient temperature and its low critical pressure of 74 bar allows the accessibility to be operated at moderate pressures, usually in the range of 100 bar to 450 bar. From the point of view of nutraceutical, food and pharmaceutical applications, SC-CO_2 is an ideal solvent since it is less hazardous, non-flammable, not expensive and ready to be separated from final product. It is more ecological friendly and acknowledged as safe by EFSA and FDA. In addition, SFE with SC-CO_2 using a non-oxidant medium is able to be conducted at low temperatures, which permits the extraction of temperature sensitive or easily oxidized compounds which is very essential for food and natural goods sample preparation (Karale, *et al.,* 2011).

On the other hand, the main limitation of CO_2 is its mild polarity that allows it only for extraction of lipid and non-polar compounds, but inappropriate for most of the pharmaceuticals compounds. Due to its mild-polar properties, it not suitable to be utilized for dissolution of polar molecules. However, this drawback of low polarity of CO_2 can be overcome completely by the addition of organic modifier (co-solvents) (Ghafoor, *et al.,* 2010). Generally only a little quantity of modifier is sufficient as helpful to increase the polarity of carbon dioxide significantly. For instance, only 0.5 ml of dichloromethane is needed to improve the efficiency of extraction which is same for 4 hours by hydrodistillation. The characteristics of sample matrix and targeted analytes and the reference experimental data are major basis for selection of the suitable modifier (Azmir, *et al.,* 2013). Besides, the milder processing conditions would leads to complication of system thermodynamics and increased capital costs (Karale, *et al.,* 2011).

In addition to CO_2, other supercritical solvents have been evaluated for agronomic applications. There are some reports about the choice of nitrous oxide (N_2O) as an extraction fluid. The chemical properties of this fluid make N_2O more suited for the extraction of polar compounds. However, in the presence of a high organic content, the gas can cause violent explosions. This drawback strongly limits its use. Even water was investigated as a possible supercritical fluid but, unlike CO_2, the high critical temperature and pressure together with the corrosive nature of H_2O under these conditions, has limited its practical applications. Even so, water was used in some cases as a co-solvent for the extraction of more polar compounds from aromatic plants. The presence of water as pretreatment of plant material or added to CO_2 at supercritical and subcritical state as a co-solvent has shown to influence the qualitative and quantitative composition of the extract. In addition, ethane, propane and dimethyl ether have been used as supercritical solvents for the extraction of bioactive compounds from plants. Beside critical points that are comparable with CO_2, these solvents have higher polarizability than CO_2, resulting in a stronger interaction with the more polar compounds and co-solvents. However, experimental results show that SC-CO_2 offers a wider versatility for the fractionation of extracted compounds using different operative pressures in the extractors or separators (Capuzzo *et al.,* 2013).

4.2 Mechanism of Supercritical Fluid Extraction

Supercritical fluid extraction has been practiced to a thousands of solid sample matrices. However, the extract or the extracted solid sample itself can be the final product. The advantage of consuming supercritical fluids in extraction technology is the simplicity of purification of the extracted products from supercritical fluid solvent. This separation process can be carried out by simple expansion. Moreover, supercritical fluids possess liquid-like density but they also have excellent mass transfer behaviour as contrasted with liquid solvents. This is due to their low surface tension and high diffusivity which allows diffusion into the permeable structure of solid sample matrix more easily to liberate the solute (Karale, *et al.,* 2011).

Extraction of solutes from solid matrices can be carried out by four different mechanisms. Firstly, the process is just a simple dissolution of solute into solvent that would not dissolve the solid matrix, when there are no connections between solute and the solid matrix. On the other hand, if interactions between the solute and solid matrix solute exists, the extraction process is labelled as desorption. The adsorption isotherm of the solute on the solid matrix with existence of solvent defines the equilibrium. Solids extraction process such as regeneration of activated carbon fall in this classification. The third mechanism is the swelling of solid matrix by solvent and extraction of the targeted solute by the first two mechanisms. The fourth mechanism of extraction is called reactive extraction, where the insoluble solute reacts with the solvent and the reaction products are soluble hence extractable (Mohamed *et al.,* 2008).

Extraction is usually complied with additional separation procedure which the extracted solute is separated from the solvent. One more considerable respect in supercritical fluid extraction involve to the interactions between solvent and solute. Typically the solid and solute interactions will define the simplicity of extraction, for example the intensity of the adsorption isotherm is defined by relations of adsorbent and the adsorbate. On the other hand, when supercritical fluids are employed, relations between the solute and solvent effect the adsorption properties because of large negative partial molar volumes and partial molar enthalpies in supercritical fluids (Karale, *et al.,* 2011). Generally, a fundamental SFE system consists of a few equipment such as a CO_2 mobile tank, a pump needed to pressurize the gas, container for modifier, an oven that attached with the extraction cell, a regulator to keep high pressure during whole process and a collecting chamber. Generally, various type of meters like flow meter or gas meter might be also equipped to the system for controlling. A schematic drawing of SFE equipment is shown in Figure 2.

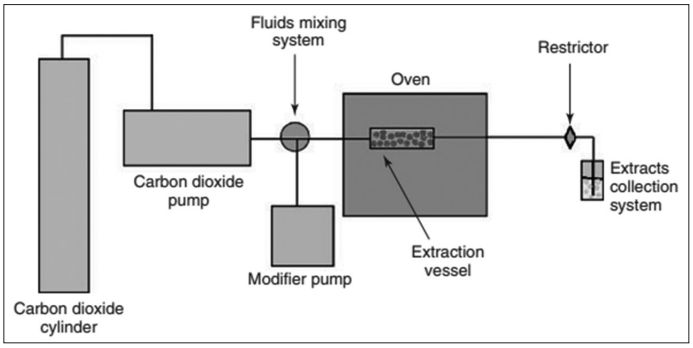

Figure 2: A Schematic Diagram of SFE System (Pourmortazavi, Rahimi-Nasrabadi & Mirsadeghi, 2014)

A common procedure for batch extraction are as follows. Firstly, natural resource feed is introduced in the extraction tank. To ensure that the extraction carried out at desired conditions, the tank is attached with temperature regulators and pressure control device at both ends of the tank. The extraction tank is then pressurized with a particular fluid with the assist of pumps. The pump is also required for the circulation of fluid. After that, the fluid and solubilized mixtures moved from the tank to separator. The salvation power of the fluid is reduced by elevating the temperature or lowering the pressure of supercritical fluid extractor. The final extract product is then collected through a valve placed at the bottom of the separator (Karale, *et al.,* 2011).

SFE procedure could be carried out by two principal modes of static and dynamic. In the static extraction, sample matrix is exposed to a fixed amount of SC-CO_2 for a definite time. In contrast, during the dynamic extraction, fresh CO_2 continuously passes through the sample matrix. In the most of

SFE experiments, a combination of both static and dynamic modes is employed. At first, a static mode is used to allow the penetration of SC-CO_2 to the plant matrix and solubilize the analytes, followed by a dynamic mode that sweeps the analytes from the extraction vessel, through the restrictor and into the collection system. After passing CO_2 and analytes through the restrictor, the CO_2 decompresses to the atmospheric pressure and loses its SCF properties such as solvating power. The analytes therefore are released into the trapping system (Pourmortazavi, Rahimi-Nasrabadi and Mirsadeghi, 2014).

5.0 EFFECT OF PROCESS PARAMETERS

The consumption of bioactive components in various commercial industries for example like pharmaceutical, chemical and food sectors represents the demand of the most suitable and typical technique to extract bioactive compounds from plant materials. Other than conventional methods, multiple advanced techniques have been identified but still not a process has been standardized for extracting different types of bioactive compounds from plant materials. The effectiveness of both non-conventional and conventional extraction methods are generally rely on the major process variables, comprehension about chemical properties of bioactive compounds, nature of plant matrix and previous experimental data (Azmir, *et al.,* 2013).

The first procedure in the SC-CO_2 extraction is to optimize the experimental settings to achieve a satisfactory extraction of the targeted analytes and prevent the co-extraction of other unwanted components. For the development of SC-CO_2 extraction technique, as various process variables possibly influence the extraction efficiency, the optimization of the operating settings is an important stage. The successful extraction of bioactive compounds from plant materials depend on various parameters of SFE and basically these parameter can be modified (Raverchon and Marco, 2006). Process parameter must be measured accurately in order to maximize advantages from this method. The main variables affecting the effectiveness of extraction are temperature, pressure, solubility of solute, extraction time, flow rate of CO_2 solvent and existence of modifier (Ibanez *et al.,* 2012).

Various parameters such as pressure, temperature, CO_2 flow rate and extraction time could affect the solubility of an analyte molecule in the CO_2 phase (Aghel *et al.,* 2004). The pressure and temperature of SCF influence the density of the fluid that determines the number of interactions between CO_2 and molecules of the analytes. Increasing these interactions provide enough cohesive forces between analyte molecules and SCF to conquer binding forces between analyte and sample matrix. In other words, the analyte molecules solubilized in the SCF. Therefore, the value of target molecules solubility in SC-CO_2 is dependent on the molecular weight of analyte compound and the level of interactions between SC-CO_2 and analyte molecules. On the other hand, the kinetics of SFE from plants matrices is variable due to the effect of various parameters on the extraction process. Commonly, the extraction of the first fraction of analytes is limited by their solubilities in fluid phase and the extraction rate of the rest analytes is limited by diffusion process. Meanwhile, the phase equilibrium is dependent on the interactions between analytes and the solid matrix (Pourmortazavi, Rahimi-Nasrabadi and Mirsadeghi, 2014).

5.1 Temperature

Figure 3 shows the typical extraction profiles from solid materials. In the plot, the extractor yield, which is the amount of targeted components extracted with respect to the overall quantity of components in the solid matrix, is constructed versus duration of extraction. From the profile, the higher the temperature, the steeper the plot. It is mainly consists of two parts. First, is a straight line corresponding to the extraction of the compounds readily extracted by supercritical CO_2 solvent and secondly an asymptotic curve describing the extraction of the part involved solid matrix. For the first situation, the extraction rate is restricted by solubility; meanwhile in the second case, the success of SFE is limited by mass transport (diffusion) properties. The consequence of process temperature are also defined in Figure 3 (Karale, *et al.,* 2011).

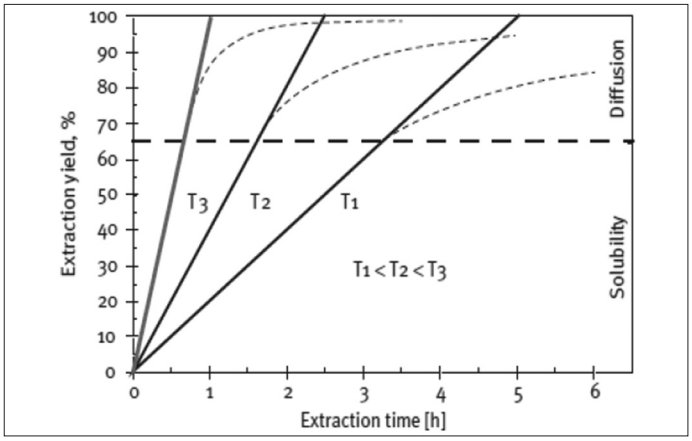

Figure 3: Extraction yield versus time at different temperatures (Karale, et al., 2011)

In view of considering consequence of temperature towards solubility of solid materials, there are two dissimilar effects. First is the improvement in solid volatility with increased temperature, results an increment in vapour pressure and secondly is the decline of density in solvent with higher temperature. The enhancement of solubility by temperature is reliant on which effect is more dominant. Higher process temperature causing a reduction in extraction rate by the reason of fluctuation in the solvent density and resultant diversity in solubility of solvent. However, a greater extraction rate can be accomplished by increasing process temperature in the case of solubility but under the situation that the limiting factor is not supercritical fluid (Karale, *et al.,* 2011).

A report published by Patil, *et al.,* in 2014 was aimed to study the flavonoids extraction process of wedelolactone from Wedelia calendulacea. by employing supercritical carbon dioxide extraction method. Wedelia calendulacea can be utilized as a treatment for numerous ailments. W. calendulacea is thought to own characteristics of main active constituent of flavonoids which is wedelolactone. Wedelolactone exhibits variety biological activities including antitumor, anti-inflammatory, antiosteoporotic, antivenom and hepatoprotective effects. In the report, the effect of extraction temperature on the extraction yield of wedelolactone was examined. As consider to the consequence of temperature on solid compounds solubility, there are relatively two distinctive impacts will be exposed. Firstly is the increase in solid volatility which leading to vapour pressure rise and another is lower solvent density in

response to increased temperature. The increase of solubility by temperature is relying on which factor is dominant. In the study, the consequence of temperature on extraction yield at three different values which are 40 °C, 60 °C and 80 °C, was examined to advance the extraction process. From the result, it shows that the yield of wedelolactone was reduced with the increased of extraction temperature from 40 °C to 80 °C and the optimum yield of wedelolactone was collected at the condition of temperature 40 °C. This consequence of temperature may be caused by decrease in density of solvent and thus leads to a reduction solutes solubility in the supercritical fluid.

5.2 Pressure

Generally, the yield of targeted analytes with SC-CO_2 extraction is affected by extraction time, temperature, pressure, temperature and modifier. Elevated pressure can increase the density of fluid. Furthermore, the solubility of solid composites in supercritical fluid possibly will be also affected by the repulsive interaction of solute and fluid. It is proved that the solubility of supercritical CO_2 is influenced by its vapour pressure and density. Under constant temperature, the solutes solubility increases with respect to increment in density of supercritical CO_2 at higher pressures when the solubility of solutes is dominated mainly by density instead of vapour pressure. However, because of the decreased density of supercritical CO_2, the dissolving power will decrease at higher temperature under constant pressure (Al-Hamimi *et al.,* 2016).

The repulsive interaction between solute and fluid becomes stronger as pressure continues to increase. When pressure achieves a particular level for some complexes, the repulsive interaction of solute and fluid turn out to be stronger than the increase in the solubility which resulted from higher solvent density. Under this condition, the compounds solubility declines and hence leads to a reduction in extraction yield. The solubility of solute in supercritical fluid rely upon complicated balance among few aspects including density of fluid, solute vapour pressure and the repulsive interaction of solute and fluid which are limited by pressure and temperature. Normally, the density of fluid increase with elevated process pressure and hence varying the solubility of solute. At high pressure, a yield of volatile fractions and lower yield of non-volatile fractions can be attained. However, insignificant increment in recovery will be observed under higher pressure or flow rate than a certain value of pressure that guarantees high solubility of analyte in supercritical fluid (Barroso *et al.,* 2011). dl-Tetrahydropalmatine (dl-THP) is an alkaloid which frequently appear in plant. It has been intensively investigated due to its medicall properties. From the report that published by Liu, *et al.,* (2008), dl-THP in Corydalis yanhusuo was extracted through supercritical carbon dioxide extraction method. Four factors which are the dynamic duration of extraction, process temperature, pressure and various modifiers used in the extraction were studied. By using ANOVA, the impacts of the process variables on the dl-THP yield were studied.

In the study, three different pressures of SFE which are 200 bar, 300 bar and 400 bar were performed for analysis of the impacts of pressure on dl-THP yield. The mean yield of alkaloids varied from 1.07 mg/g at 200 bar to 1.02 mg/g at 400 bar, and this represents that the dl-THP yield was affected insignificantly by pressure. The difference of yield is about 0.05 mg between 200 bar and 400 bar. It is noticed that the effect of pressure is smaller than temperature on the yield of dl-THP when the preferred modifiers are used. The yield of the compound extracted does not improve with increasing pressure from 200 bar to 400 bar. From the study it showed that every variable showed an effect on the dl-THP yield in the specific limits.

5.3 Duration of Extraction

Extraction time is expressed as one of the dominant causes for exhausted extraction and is a critical index for determination of extraction effectiveness. The influence of extraction time must be considered in order to attain an optimum extraction yield. This is because shorter extraction time might lead to unfinished extraction but longer extraction time possibly will be time and solvent wasting. For SFE, the extraction time is usually less than 2 hours. The total extraction duration is actually counted from two stages which are static extraction and dynamic extraction. A example of the kinetics of the extraction practice at conditions of 40 °C and 90 bar and is shown in Figure 4. In the experiment, a dynamic extraction method was used which the extraction time is started from a duration of static pre-treatment with no CO_2 flow followed by a dynamic time which the flow rate of CO_2 is fixed. To examine the influence of dynamic extraction time on extraction efficiency of the natural sources, other variables must remained constant throughout the experiment. The dynamic extraction employing three different periods which include 20 minutes, 30 minutes and 60 minutes was carried out with 10 minutes of static pre-treatment. Figure 4 indicates that longer dynamic extraction time would improve the final extraction yield. However, the dependence between recovery and extraction duration gradually becomes flat. Hence a dynamic extraction time of 30 minutes was selection in following extractions. From the study, it can be concluded that the optimum time for experiment was 10 minutes for static extraction and 30 minutes for dynamic extraction (Herzi *et al.,* 2013).

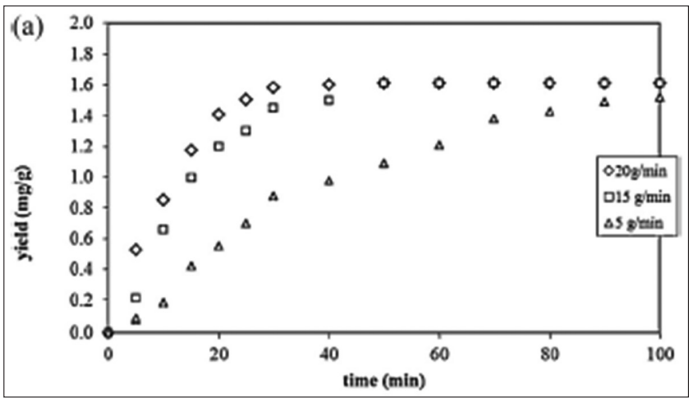

Figure 4: Extraction yield at different solvent flow rates as a function of the extraction time (Herzi et al., 2013)

5.4 Existence of Modifiers

The union between economic feasibility and safety are acquiring more consideration and indeed, safer and less harmful solvents that are easy to remove or recover, are gaining in popularity. More than 90% of supercritical fluid extractions have been performed with carbon dioxide as supercritical solvent because of the abovementioned practical reasons. Supercritical carbon dioxide (SC-CO_2) has a polarity comparable to liquid pentane and therefore, it is compatible for the solubilization of

lipophilic compounds such as lipids and essential oils. However, this low polarity index makes SC-CO_2 hardly suitable for the extraction of polar compounds. To overcome this restriction, practical approaches involve the use of polar co-solvents (Capuzzo *et al.,* 2013).

Another typical exercise in SFE is to modify the supercritical fluid polarity and enhance their solvating power towards targeted analytes by using polar modifiers. For instance, the addition of comparatively low percentages of methanol which in the range from 1 % to 10 %, to carbon dioxide enlarges its extraction array to comprise analytes of high polarity. Based on the nature of solid matrix and the attractive forces of the targeted analyte, the modifier may effects the efficiency of extraction by few methods. Firstly, it increases the solubility of analytes in the supercritical fluid as a consequence of interactions between analyte and modifier in the fluid stage. Secondly, modifier can be used to promote desorption of analytes. The particles of polar modifiers allows interactions with the sample and compete with analyte for the active sites in the solid matrix. Lastly, it distorts the diffusion between solid matrix and analyte, thus further diffusion of solvent into the matrix by swelling (Casas *et al.,* 2007).

The effect of modifiers can be observed from the review published by Liu *et al.,* (2008). In the experiment, different types of modifiers including ethanol, methanol and 1,2-propanediol were employed to examine the influence of modifiers on final extraction yield of dl-THP. It can be seen in Figure 5 that the extraction yield is affected by different modifiers. The extraction yield fluctuates from 0.990 mg/g to 1.088 mg/g when 1,2-propanediol was used instead of ethanol. The extraction yield collected was highest when employing 1,2-propanediol as modifier with supercritical CO_2.

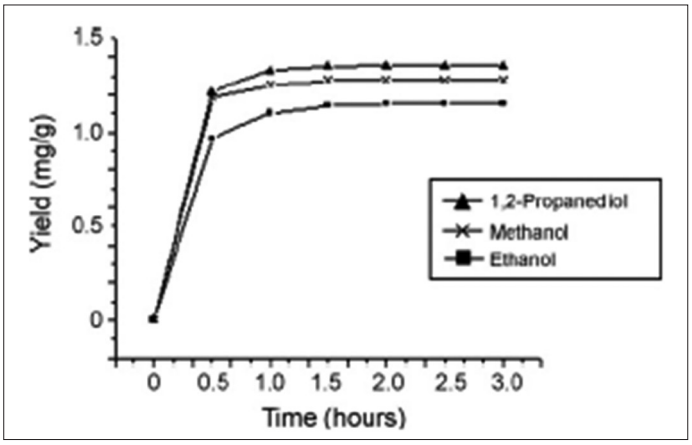

Figure 5: The cumulative yield of dl-THP using different modifiers (Liu et al., 2008)

5.5 Flow Rate of Solvent

Figure 6 was created to indicate the influence of solvent flow rate as a process variable. It represents that extraction yield increases with greater dioxide flow rate of supercritical carbon until it reaches the highest point and then declines with further increase in the flow rate. The outcomes are described as a trade-off between a diffusion process and a thermodynamic equilibrium condition. The interface gas phase concentration of the solute is a function of the mass transfer coefficient or flow rate of solvent, whereas the equilibrium state is always preferred by both high rate of diffusion and long residence time. At lower solvent flow rates, the resistance of mass transfer restricts the quantity of solute transfered into the bulk solvent and then supercritical carbon dioxide discharges from extractor unsaturated. By way of higher flow rate, resistance of mass transfer declines continuously till the leaving solvent is saturated and the equilibrium to be reached and hereafter the optimum extraction yield is achieved (Kumoro and Hasan, 2007).

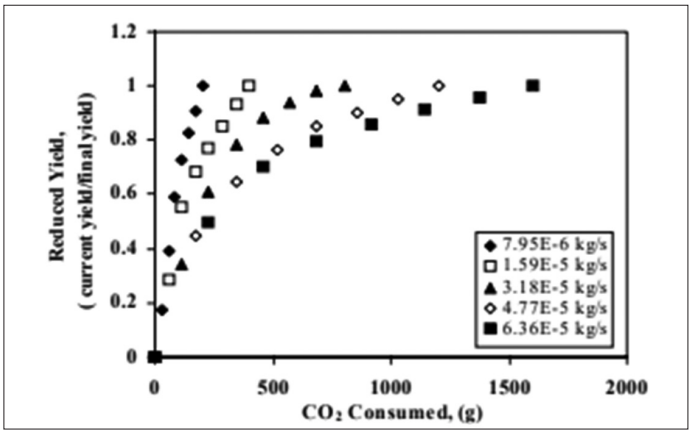

Figure 6: Effect of solvent flow rate on extraction yield as a function of CO_2 consumed (Kumoro and Hasan, 2007)

However, further increase of the solvent flow rate will decrease the residence time affecting the system to diverge from equilibrium and the solvent discharges from extractor unsaturated regardless of the high rate of mass transfer. This is caused by the quantity of solvent which is excess enters to the cellular structure of the samples, just bypassed the extractable samples (Saldana *et al.,* 2002). This performance showed the existence of a mass transfer resistance which is probably intra particle diffusion or an external film resistance. Hence in a semi batch supercritical fluid extraction, the optimal flow rate of solvent needs to be evaluated a priori. However, it should be noticed that the situation of optimal solvent flow rate be governed by the nature of the solvent – solute system, the geometry of the extractor and process temperature and pressure (Kumoro and Hasan, 2007).

In the work of Kumoro and Hasan (2007), a study to examine the consequence of flow rate of solvent towards the extraction rate was conducted and a few experiments was carried out at conditions of 313 K and 10 MPa, whereas the flow rate of supercritical CO_2 was adjusted from 7.95×10^{-6} kg/s to 6.36×10^{-5} kg/s. From Figure 6, it presented that the extraction yield improved with increment of solvent flow rate from 7.95×10^{-6} kg/s to 3.18×10^{-5} kg/s. However further increase of solvent flow rate limited the extraction yield. Consequently, an optimal flow rate of 3.18×10^{-5} kg/s was achieved for the system in experiment.

6.0 ADVANTAGES OF SUPERCRITICAL FLUID EXTRACTION

The advantages of using supercritical fluids for the extraction of bioactive compounds can be understood considering following points (Lang and wai, 2001):

i. Supercritical fluid has a higher diffusion coefficient and lower viscosity and surface tension than a liquid solvent, leading to more penetration to sample matrix and favourable mass transfer.

ii. Extraction time can be reduced substantially by SFE in compared with conventional methods.
iii. The repeated reflux of supercritical fluid to the sample provides complete extraction.
iv. The selectivity of supercritical fluid is higher than liquid solvent as its solvation power can be tunable.
v. The separation of solute from solvent can easily be bypassed by depressurization of supercritical fluid, which will save time.
vi. SFE is operated at room temperature so it is an ideal method for thermo labile compound extraction.
vii. Small amount of sample can be extracted compared with solvent extraction methods which will save time.
viii. SFE uses little amount of organic solvent and considered as environment friendly.
ix. The recycling and reuse of supercritical fluid is possible and thus minimizing waste generation.
x. SFE scale can be arranged on specific purpose from few milligram samples in laboratory to tons of sample in industries.

7.0 APPLICATIONS OF SUPERCRITICAL FLUID EXTRACTION

Among the different extraction techniques used at analytical and preparative scale, supercritical fluid extraction (SFE) is one of the most used. From a simple literature search, it can be easily deduced the impact of SFE as sample preparation technique for the analysis of target compounds from natural products and foods. It is worth to mention that SFE has been also widely used in this field for process development, which is to extract target (bioactive or valuable) compounds from different matrices. Even though these processes usually offer clear advantages over traditional ones, the main drawback for industrial scale use is the lack of realistic economic studies. In this context, some papers have been published lately dealing with the assessment of the industrial economical feasibility of some developed processes, such as essential oil extraction from rosemary, fennel and anise and brewery spent grain management (C.G. Pereira, *et. Al.,* 2007). Therefore, SFE can be regarded as a possible tool not only from a laboratory point of view but also for the natural products and food industries.

Probably, the most extended use of SFE is in the food field. A high variety of samples, type of materials, target compounds and procedures have been published in the last years. A relatively new group of applications that have been recently developed which includes the extraction and fractionation of carbohydrates by SFE. The SFE technique is using supercritical CO_2 as the best option for this group of compounds due to the low polarity of carbon dioxide. SFE has been also used to remove unwanted compounds from other matrices. For example, supercritical CO_2 with water as co-solvent has been employed to selectively extract caffeine from green tea while avoiding the extraction of antioxidants from the matrix.

SFE has been widely used to value food industry by-products. These products are generated during food manufacturing and normally do not have any commercial value. By-products extraction allows the removal of valuable or interesting compounds that otherwise cannot be utilized. Industrial activities generate a large variety of byproducts and wastes ranging from manure to packing residuals. Strong research is focused in the development of new technologies and new uses for these materials in order to reduce their environmental impact. New processes are being developed to recover components producing high added value products. Mainly SFE has been tested for the extraction of lipids and lipophilic components (Herrero *et al.,* 2010).

Proprietary pharmaceutical product development is driven by continuous innovations in drug discovery, drug polymorph preparation, dosage form design and process engineering while meeting rigorous regulatory standards. Innovations in all these areas are feasible with the application of technologies utilizing supercritical fluids. Pharmaceutical companies are more and more urged to develop production processes with very low environmental impact, in particular to reduce the use of volatile organic compounds in medicine manufacturing as well as to avoid residues in the finished product. Other benefits of supercritical fluid technologies, apart from their mass transfer related properties, are linked to the reduced complexity of the process which stems from a diminution of the number of steps as well as to the improved process understanding and control. In general terms, the main use of supercritical fluids in pharmaceutics deals with the extraction of bioactive compounds from a mixture (purification from reactions, quantification of active enantiomer, extraction from natural matrices) or with the extraction of the matrix. In this case, crystallization and particle formation have undergone an enormous development in recent years (Herrero *et al.,* 2010).

The interest of SFE not only as an analytical tool but also for process development is discussed. It seems clear that SFE has an enormous interests nowadays and the of applications of SFE, including not only its use as sample preparation technique but also new and recent advances in different areas such as food science, pharmaceutical and environmental science.

8.0 SUMMARY AND FUTURE WORKS

It is necessary for the scientist and chemist to establish a simpler and a more efficient extraction method for the extraction of chemical components from different parts of the plants since the advanced invention of medicinal drugs and its application in the treatment of various diseases is getting more developed. The supercritical fluids like CO_2 under elevated pressure is able to provide more well-organized, efficient and appropriate technique for extraction of natural sources for coming future without losing the capability and activity of a medical drugs. The increasing demand of extracts for bioactive compounds of plants promotes continuous study for convenient extraction methods. Nonetheless, most of these techniques rely on different mechanisms and extraction improvement is developed from various processes. Therefore, comprehension about every aspect of extraction process is very important. Incorporation of hybrid methods should also be examined in consideration of plant material properties and selection of compounds. However, there are still deficient of complete experimental data in certain existing extraction methods. Appropriate selection of methods also give significant effects on the analysis of extraction effectiveness.

From another point of view, the increasing commercial significance of bioactive compounds and commodities full in these bioactive compounds may contribute to discover more

advanced extraction techniques in future. Proper calculation of production costs which includes both capital and operating cost, should be accomplished in order to exploit supercritical fluid extraction technique at the scale of industrial level. In addition, the respective effects of the various process parameters which can influence the efficiency of SFE and also amount of extraction yield of targeted analytes is discussed in this project. SFE efficiencies are not only affected by experimental process parameters such as temperature, pressure (density), extraction time and modifier used but also by sample variables, extraction vessel variables and collection variables. However, a single standardized procedure is not applicable for all types of bioactive compounds from plant. Therefore, the procedures must be optimized case by case depending on the property of target analytes and nature of solid sample.

In conclusion, supercritical fluid technology has provides important advances for the extraction of bioactive compounds from natural sources compared to conventional extraction methods. Even if this technique is struggling with the limitation of cost–effectiveness factors in the event of low volume products, it is overcoming this drawback day-to-day and promising commercial benefits. Based on this study, it can be concluded that supercritical fluid extraction is recognized as one the favourable method for the extraction of the bioactive compounds from plant materials. ■

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ABBREVIATION

CO_2	Carbon dioxide
dl-THP	dl-Tetrahydropalmatine
EFSA	European Food Safety Authority
FDA	Food and Drug Administration
GC	Gas chromatography
LC	Liquid chromatography
LLE	Liquid–liquid extraction
MAE	Microwave-assisted extraction
MAPs	Medicinal and aromatic plants
N_2O	Nitrous oxide
P	Pressure
PC	Critical pressure
Pr	Reduced pressure
PEF	Pulsed electric field assisted extraction
PLE	Pressurized liquid extraction
SC- CO_2	Supercritical carbon dioxide
SFE	Supercritical fluid extraction
SFs	Supercritical fluids
SLE	Solid–liquid extraction
SPE	Solid-phase extraction
T	Temperature
TC	Critical temperature
Tr	Reduced temperature
UAE	Ultrasound-assisted extraction
WHO	World Health Organization

PROFILES

LAM CHEW THENG is a Bachelor of Chemical Engineering (Honours) graduate from Universiti Tunku Abdul Rahman.

LEE TIN SIN is a professional engineer and associate professor of Universiti Tunku Abdul Rahman.
Email address: direct.tinsin@gmail.com

BEE SOO TUEEN is a professional engineer and associate professor of Universiti Tunku Abdul Rahman.
Email address: direct.beest@gmail.com

PARTHIBAN A/L SIWAYANAN is a profesional engineer and associate professor of Xiamen University Malaysia.
Email address: parthiban.siwayanan@xmu.edu.my

IMPROVING CREATIVITY IN ENGINEERING UNDERGRADUATE STUDENTS IN PRIVATE INSTITUTION OF HIGHER LEARNING IN MALAYSIA – A PILOT STUDY

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Chua Yaw Long[1,2], Balamuralithara Balakrishnan[2], Koh Yit Yan[3], Chai Voon Chiet[4]

[1]Universiti Tenaga Nasional, Malaysia, Jalan Ikram-Uniten, 43000 Kajang, Selangor, Malaysia
Email: chuayl@uniten.edu.my; Tel: +60 3 8921 2020

[2]Fakulti Seni, Komputeran dan Industri Kreatif, Universiti Pendidikan Sultan Idris, 35900 Tanjong Malim, Perak Darul Ridzuan, Malaysia
Email: balab@fskik.upsi.edu.my; Tel: +60 5 4505482

[3]Faculty of Engineering and Built Environment, University of Newcastle, Singapore
6 Temasek Boulevard, #10-02/03, Suntec Tower 4, Singapore 038986
Email: yityan.koh@newcastle.edu.au; Tel: +65 6221 3306

[4]Heriot-Watt University Malaysia, No 1, Jalan Venna P5/2, Precinct 5, 62200 Putrajaya, Malaysia
Email: v.chai@hw.ac.uk

ABSTRACT

Creativity is an essential factor when it comes down to engineering designs. Creativity and engineering complement each other to provide useful and yet eye-opening solutions to anyone's every-day problems. Recent research conducted had indicated that creativity, which happens to be one of the vital skills for the engineers in the 21st Century that can be taught and learnt, has reduced significantly over the years. Thus, there is a need for engineering educators to address this reduction issue by introducing creative thinking as a skill to be acquired by the current generation of engineering undergraduates. This research paper presents the outcome of research conducted to improve and enhance the creativity level of local engineering undergraduates at a private institution of higher learning. Such enhancement is done through a Creative Thinking Module that features few proposed creative thinking tools such as Brainsketching, Concept Maps and Morphological Analysis. The Torrance Test of Creative Thinking Figural Forms was applied to measure the creativity level of respondents in this research. A pilot study had been conducted in a local private university, and results indicated improvement in the creative ability of the students upon completion of the Creative Thinking Module.

Keywords: Creativity, Creative Thinking Module, Torrance Test of Creative Thinking, Engineering Design.

1.0 INTRODUCTION

Creativity is the capability of a person to come up with new objects or new designs (Wang, 2007). It is one of the critical skills in a knowledge-based society in coping with problems (Terkowsky & Haertel, 2013). Unfortunately, education system and providers around the world, Malaysia inclusive, are not supportive enough in the development of creativity learning (Brand, Hendy, & Harrison, 2015; Robinson, 2013; Terkowsky & Haertel, 2013; Haertel, Terkowsky, & Jahnke, 2012; Daud, Omar, Turiman, & Osman, 2012; Beghetto, 2010; Kazerounian & Foley, 2007). The education system relied heavily on cognitive learning (Chin, Thien and Chew, 2019) resulting students more exam-based-oriented in the tertiary study that does not meet the proficiency requirement in creative thinking and problem-solving skills upon a graduate.

Malaysian engineering graduates are often reported to be equally competent in terms of knowledge when compared to graduates from overseas universities. Nonetheless, researches have shown that Malaysian graduates are lacking in terms of many other skills in communication and presentation and also when it comes to creative thinking and being innovative (Soon & Quek, 2013, Selvaraj, Anbalagan, & Azlin, 2014). Research had also indicated that Malaysian graduates do not meet the proficiency requirement in creative thinking and problem-solving skills when in job place (Safarin, Md, Khair, & Yahya, 2013). Research activities related to creativity in particular for engineering design courses are also not well documented, developed or established to date causing Malaysian norms for local engineering students are not available for better validity of the results obtained. Comparison can hence only taken with the USA norms developed by Torrance (1966, 1990) (Afida, Aini, Mohd, & Rosadah, 2012; Torrance, 1966; Torrance, 1990).

The learning of creative thinking skills is vital and should begin when the students are still at school (Romeike, 2006). In this case, for engineering undergraduate students taking engineering design module, it is an appropriate time to enhance their creative thinking skill. Apart from this, the current engineering curricula also face various challenges when it comes to introducing creativity education to engineering programmes.

The planning, implementation and evaluation of programmes to meet the requirements set out by the Engineering Accreditation Council Malaysia, also present a large number of difficulties. The curriculum planners face difficulties in planning and coordination, including curriculum structure administration, Continuous Quality Improvement (CQI) cycle, programmes review in the achievement of programme outcomes (PO), course outcomes (CO) and programme educational objectives (PEO) and weighting of different subjects. There are also situations where programmes coordinators will encounter problems in resources allocation, mainly when it involves different departments.

In addition, as outlined in the Engineering Accreditation Manual (EAC 2020) that "*The curriculum shall also provide students with ample opportunities for analytical, critical, constructive, and creative thinking, and evidence-based decision making in dealing with complex engineering problems*", and it has become evident that the engineering program providers will need to consider the inclusion of the creative thinking elements in the course designs.

Despite the requirement of the inclusion of creative thinking elements in the courses, to date, there are still limited works of literature that present the review, effectiveness and suggestions towards the inclusion of creative thinking elements in the conduct of courses. Creative thinking has hence not been given sufficient attention in the engineering programmes to be a single module in the engineering programme.

Educators also need to take the trouble to cater for students that come from different backgrounds. The course coordinator many a time need to spend more time searching for suitable teaching staff from within and outside of the department.

Serious attention should be given to reduce the Creative Thinking and Problem-Solving skills proficiency gap for better employability of our engineering graduates. Based on such problem statement mentioned above, this research is established to achieve the objective to assess the effectiveness of the Creative Thinking Skills for Conceptual Engineering Design module developed by the researcher in improving engineering undergraduates' creativity.

In the quest to achieve the developed country status, Malaysian engineers have a role to play that cannot be ignored. The National Education Blue Print 2015-2025 (Higher Education) had laid a solid foundation for the Malaysian IHLs to educate and train the next generation of Malaysia Engineers to be able to improve the living environment. To achieve this, engineers require not only technical knowledge and skills but also creativity and innovation to cater to the needs of the future generation. Fostering the engineering students' creativity ought to be during their undergraduate education. By understanding the state of creativity in engineering undergraduate students, steps can be taken to address any deficiencies through appropriate training and counselling.

This research provides the understanding of the current state of creativity of local undergraduate students taking engineering design module. The research then moves another step further in providing an alternative solution to foster and improve the students' creativity without compromising the current engineering programme structure. The effect of the proposed alternative solution is then studied and analysed.

2.0 DEFINING CREATIVITY

Creativity is not something that is gifted to selected few, but rather a skill that can be acquired (Rhodes, 1961). This set of skill can be learned by providing a properly design curriculum that comprises the following elements for learning:

1) A real-world problem that the students are tasked to solve.
2) Components that involve interactive learning activities amongst students and educators, and
3) Provide students with the opportunity to explore other options for solutions, as mentioned by the constructivism theory.

Creativity also involves the development of tangible solutions to problems. Engineers applied their knowledge and skills to solve problems driven by the needs and changes, and these solutions often take the form of tangible artefact. After all, engineering has the most room for improvement in supporting creative skills development (Shanna, Erika, & Colleen, 2014).

Illustrated in Figure 1, creativity can be categorised into four major types (Rhodes, 1961), naming:

a. Process
b. Product
c. Person, and
d. Press

For this research, only Process component is investigated, and thus explanations only the Process component is be presented in the subsequent topics. The Person component is the personality aspect of teachers, while the Press component refers to the environment and the infrastructure that aid creative teaching. The assessment of both components requires a certified psychologist, and hence it is out of the scope of current research. On the other hand, The Product component refers to the works of art, inventions or publications as a result of creativity, since this paper focused on the students. Hence, this component is also excluded in the current study and is addressed in other researches.

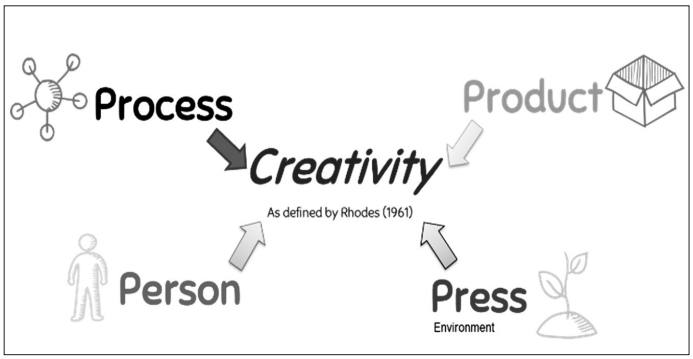

Figure 1. The 4 P's in Creativity as described by Rhodes (1961)

In this study, creativity is defined based on Torrance's (1974) definition:

"a process of becoming sensitive to problems, deficiencies, gaps in knowledge, missing elements, disharmonies, and so on; identifying the difficult; searching for solutions, making guesses or formulating hypotheses about deficiencies; testing and retesting hypotheses and possibly modifying and retesting them, and finally communicating the results."

From the employer survey data as well as research activity and analysis conducted by various organisations, it is clear that creativity is one of the essential tools that engineers are required to be equipped with in order to survive in the 21st-century workplace (Casner-Lotto & Benner, 2006). Engineers are directly involved with the business of innovation as their job scopes are to design, to innovate and to solve problems.

Hence, it is understood that the Process is the procedures adopted by the Person to develop the Product. Hence, it is also the thought process used by the Person instead of the methodology. The thought process here can be viewed as twofold – convergent thinking and divergent thinking. While convergent focuses on obtaining a concrete solution to a problem through analyses, judgements and decision-making, which is out of the relation of creativity, and hence the divergent thinking, which is explained in the following section, is the governing thinking process of the creative thinking.

3.0 DIVERGENT THINKING

Divergent thinking involves producing multiple or a variety of answers or solutions to problems through processes like shifting perspective on currently available information by viewing it in a new way, or even to the point of transforming it, through unexpected combinations of elements usually not regarded as belonging together. The answer that is derived may be something that had never existed. These processes definitely will assist the engineers in developing variability in their products or solutions, thus creativity. Table 1 lists the various characteristics of divergent thinking.

Table 1: Characteristics of Divergent Thinking

Typical Process	Typical Results
• Being unconventional • Seeing the known in a new light • Combining the disparate • Producing multiple answers • Shifting perspective • Transforming the known • Seeing new possibilities	• Alternative or multiple solutions • Deviation from the usual • A surprising answer • New lines or attack or ways of doing things • Opening up exciting or risky possibilities

Divergent thinking involves unique processes and strategies or thinking tactics for processing information that is favourable to the generation of variability. These thinking tactics involve Constructing Remote Associates, Building Unusual Categories, Building Broad Networks, and Accommodation Rather than Assimilation.

3.0 CREATIVE THINKING SKILLS FOR CONCEPTUAL ENGINEERING DESIGN MODULE

The Creative Thinking Skills for Conceptual Engineering Design Module developed utilised learning materials available related Creative Thinking in general as a foundation. They modified to cater to the needs of engineering design. As creative thinking skills are applicable in many fields such as poetry, language, arts and others, the content to be applied in this research will be simplified and focused in areas applicable to engineering design only.

As illustrated in Figure 2, seven creative thinking skills were selected and incorporated into the module developed, namely Brain Sketching, Mind Map, Attribute Listing, Functional Decomposition, Morphology Diagram, SCAMPER, and Synetics.

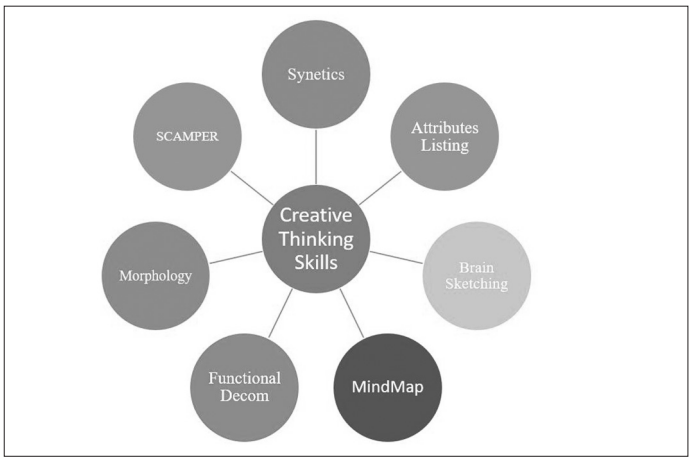

Figure 2. Content of Creative Thinking Skills for Conceptual Engineering Design Module (Chua, 2019)

4.0 TORRANCE TEST OF CREATIVE THINKING FOR DIVERGENT THINKING ASSESSMENT

In order to assess divergent thinking among students, tests have been designed and evaluated to observe divergent thinking behaviour and other problem-solving skills among students. Among these tests, the Torrance Test of Creative Thinking, which has its reliability and validity proven (Almeida, 2008; Kim, 2011) is used.

From the definition of creativity by Torrance (1974), one of the most prominent tools to measure creativity, Torrance Test of Creative Thinking (TTCT), has been adopted to be the instrument for gaining a measure of creativity as a process in this research. TTCT consists of four tests of divergent thinking and other problem-solving skills, which are scored on four scales, which are Fluency, Abstractness of Title, Originality and Elaboration. For the interest of this research, the Torrance Test of Creative Thinking (TTCT) Figural Form A and Figural Form B are adopted. The TTCT-Figural forms A and B consist of three subtests which compose a drawing, finish a drawing and compose a different drawing parting from parallel lines (Torrance, 1974). Form A is a line-based form, while Form B is a circle-based form. Both forms are aligned to assess four critical cognitive processes of creativity (Almeida, 2008):

- **Figural Fluency** or number of relevant responses. It is the ability of the respondents to produce a large number of figural images. It is a simple count of the number of different relevant responses.
- **Figural Originality** entails considering novelty responses, not familiar and unusual, but relevant. It is the ability of the

respondents to produce statistically infrequent, uncommon or unique responses that require creative strength. It is the sum of the points given for each response based on the normative list in the manual. Bonus credit is given for combining two or more figures into a single image.

- **Figural Elaboration** as referred to the number of details used to extend a response. It is the respondents' ability to develop, embroider, embellish, carry out and elaborate ideas. It is the number of details other than the initial, bare minimum responses.
- **Abstractness of Titles**. It is referred to a variety of categories or shifts in responses. Relates to the respondents' ability in synthesising and organising processes of thinking, ability to capture the essence of the information involved, to know what is important, enabling the viewer to see the picture more deeply and richly.

In this research, Figural Form A was used to assess the current creativity level of the respondents. The Figural Form B was employed after the implementation of module developed during the pilot study. The combination of both forms assesses the figural creativity among engineering students in the study.

5.0 RESEARCH HYPOTHESES

The implementation of Creative Thinking Module aims to improve students' divergent thinking skills. Through the module, students learn to different skills to implement creative solutions towards problems. Such divergent thinking skills are then assessed through four major items in TTCT. Therefore, this paper suggests looking into the following hypothesis:

H1. The Creative Thinking Module improves the Figural Fluency of respondents significantly.
H2. The Creative Thinking Module improves the Figural Originality of respondents significantly.
H3. The Creative Thinking Module improves the Figural Elaboration of respondents significantly.
H4. The Creative Thinking Module improves the Abstractness of Title of respondents significantly.

6.0 METHODOLOGY

This study employed the Pre-Test and Post-Test method. The creativity level of the students was determined first using the Torrance Test of Creative Thinking Figural Form A. The respondents then underwent a workshop using the module developed. After the completion of the workshop, the creativity of the respondents was later re-evaluated using Torrance Test of Creativity Figural Form B. Paired Sample T-Test is used to analyse the score of TTCT Figural Form A and Form B.

The selection of sample size is made based on the formula suggested by Bonnett (2012) on the determination of sample size to ensure the reliability for the selected size.

$$n = \frac{\left\{\frac{2k}{(k-1)}\right\}\left(z_{\alpha/2}+z_{\beta}\right)^2}{ln\left(\tilde{\delta}\right)^2+2}, \qquad (1)$$

where n is the sample size, k is the number of components in the scale, $z\alpha/2$ and $z\beta$ are points on the standard normal distribution exceeded with probability $\alpha/2$ and β, $\tilde{\delta} = (1-\rho_k)(1-\tilde{\rho}_k)$ with ρ_k and $\tilde{\rho}_k$ are coefficient alpha and its estimator, respectively.

Based on the equation, to obtain a Cronbach alpha value of 0.7 and above, with the items in the TTCT Figural Forms, a sample size of 33 is suggested. With the inclusion of the potential 5% dropout rate, which is unlikely in this research as all students were briefed and understood on the module, the optimum sample size for this research is 35 people. This number of sample size is also supported by some studies, where sample size for the pilot study requires 10% of the total sample size of a more extensive parent study, or even as small as 10 to 30 participants (Hill, 1998; Isaac and Michael, 1995; Julious, 2005).

With the above-mentioned suggested sample, 35 respondents from 3rd-year Mechanical Engineering students at Inti International University located in Nilai, Negeri Sembilan Malaysia, are selected to participate in this pilot study. Students in this pilot study attended a 2-day workshop on Creative Thinking in October 2019. They filled the TTCT Figural Form A and TTCT Figural Form B before and after the workshop, respectively. The T-test was conducted to analyse the results.

7.0 RESULTS AND DISCUSSIONS

Various hypotheses and null hypotheses were established. A total of four hypotheses were established.

7.1 Figural Fluency

The first hypothesis looks into the effect of the module in improving the Figural Fluency of the respondents. Table 2 illustrates the results of Pre-Test and Post-Test using Paired Sample T-Test.

Research Hypothesis 1:
There is significant difference in the Figural Fluency Scores between Pre-Test and Post-Test.

Null Hypothesis 1:
There is no significant difference in the Figural Fluency Scores between Pre-Test and Post-Test.

Table 2: Figural Fluency Paired Sample T-Test Results

T-Test: Paired Two Sample for Means		
	POST_FL	**PRE_FL**
Mean	37.23	19.2
Variance	110.71	49.4
Observations	35.00	35
Pearson Correlation	0.35	
Hypothesized Mean Difference	0.00	
Df	34.00	
t Stat	10.25	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.69	
P(T<=t) two-tail	0.00	
t Critical two-tail	2.03	

The mean of Figural Fluency for Pre-Test is 19.2 while mean for Post-Test is 37.23. According to Chua (2013), if the significant (2-tail) value is smaller than .05, the result is significant. The Paired Sample T-Test result shown in Table 2 indicated that the research result is significant ($t = 10.25$, $p < 0.05$). The null

hypothesis is rejected, and thus the module improved Figural Fluency of the respondents significantly.

7.2 Figural Originality

The second hypothesis developed to look into the effect of the module in improving the Figural Originality of the respondents. Table 3 illustrates the results of Pre-Test and Post-Test using Paired Sample T-Test.

Research Hypothesis 2:
There is significant difference in the Figural Originality Scores between Pre-Test and Post-Test.

Null Hypothesis 2:
There is no significant difference in the Figural Originality Scores between Pre-Test and Post-Test.

Table 3: Figural Originality Paired Sample T-Test Results

T-Test: Paired Two Sample for Means		
	POST_OR	**PRE_OR**
Mean	16.03	12.69
Variance	46.21	35.81
Observations	35.00	35
Pearson Correlation	0.27	
Hypothesized Mean Difference	0.00	
Df	34.00	
t Stat	2.54	
P(T<=t) one-tail	0.01	
t Critical one-tail	1.69	
P(T<=t) two-tail	0.02	
t Critical two-tail	2.03	

The mean of Figural Originality for Pre-Test is 12.69 while mean for Post-Test is 16.03. According to Chua (2013), if the significant (2-tail) value is smaller than .05, the result is significant. The Paired Sample T-Test result shown in Table 3 indicated that the research result is significant ($t = 2.54$, $p < 0.05$). The null hypothesis is rejected, and thus the module had improved Figural Originality of the respondents significantly.

7.3 Figural Elaboration

The third hypothesis was established to investigate the effect of the module in improving the Figural Elaboration of the respondents. Table 4 illustrates the results of Pre-Test and Post-Test using Paired Sample T-Test.

Research Hypothesis 3:
There is significant difference in the Figural Elaboration Scores between Pre-Test and Post-Test.

Null Hypothesis 3:
There is no significant difference in the Figural Elaboration Scores between Pre-Test and Post-Test.

Table 4: Figural Elaboration Paired Sample T-Test Results

T-Test: Paired Two Sample for Means		
	POST_EL	**PRE_EL**
Mean	5.63	4.20
Variance	10.18	3.46
Observations	35.00	35.00
Pearson Correlation	0.65	
Hypothesized Mean Difference	0.00	
Df	34.00	
t Stat	3.46	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.69	
P(T<=t) two-tail	0.00	
t Critical two-tail	2.03	

The mean of Figural Elaboration for Pre-Test is 4.2 while the mean for Post-Test is 5.63. According to Chua (2013), if the significant (2-tail) value is smaller than .05, the result is significant. The paired sample T-Test result shown in Table 4 indicated that the research result is significant ($t = 3.46$, $p < 0.05$). The null hypothesis is rejected, and thus the module had successfully improved Figural Elaboration of the respondents significantly.

7.4 Abstractness of Titles

The fourth hypothesis was instituted to analyse the effect of the module in improving the Abstractness of the title of the respondents. Table 5 illustrates the results of Pre-Test and Post-Test using Paired Sample T-Test.

Research Hypothesis 4:
There is significant difference in the Abstractness of Title Scores between Pre-Test and Post-Test.

Null Hypothesis 4:
There is no significant difference in the Abstractness of Title Scores between Pre-Test and Post-Test.

Table 5 Abstractness of Titles Paired Sample T-Test Results

T-Test: Paired Two Sample for Means		
	PRE_AB	**POST_AB**
Mean	3.46	5.06
Variance	10.49	31.35
Observations	35.00	35.00
Pearson Correlation	0.32	
Hypothesized Mean Difference	0.00	
df	34.00	
t Stat	-1.72	
P(T<=t) one-tail	0.05	
t Critical one-tail	1.69	
P(T<=t) two-tail	0.09	
t Critical two-tail	2.03	

The mean of Abstractness of Titles for Pre-Test is 5.06 while mean for Post-Test is 3.46. According to Chua (2013), if the significant (2-tail) value is smaller than .05, the result is significant. The paired sample T-Test result shown in Table 5 indicated that the research result is not significant ($t = -1.72$, $p > 0.05$). The null hypothesis is accepted. The module, in this case, does not improve the Abstractness of Titles of the respondents significantly.

7.5 Figural Creativity

Table 6 illustrates the sum of means of all elements of Figural Creativity for Pre-Test and Post-Test values. Based on the results obtained, the respondents had shown a significant improvement in almost all aspects. Nonetheless, the improvement was not shown in the Abstractness of Title. However, the overall creativity of the respondents had increased.

Table 6: Figural Creativity – Sum of Means of Pre-Test and Post-Test Value

Elements	Post-Test	Pre-Test
Fluency	37.23	19.2
Originality	16.03	12.69
Elaboration	5.63	4.2
Abstractness of Title	3.46	5.06
Figural Creativity	62.35	41.15

The conduct of the Creative Thinking module May assist students to improve their ability to produce a large number of figural images which are unique and able to elaborate from such production. However, students' ability to synthesise and organise the data is still yet to be observed through this analysis. The education system in Malaysia, which is biased towards the examination, has trained students from a young age to focus on the examination to obtain a good result. In addition, they have also been focusing on providing a standard answer that meets the examiner's requirements to ensure that they gain marks in an examination. Besides, the education system also focuses on individual achievements rather than team performance. Hence, there are not many chances that students would acquire interactive skills, leading to improvements in creative skills.

The results also show that the implementation of a Creative Thinking Module will help students to improve their creative thinking abilities, which is much needed in the engineering designs. There are courses in the engineering programmes that require creative thinking backgrounds, such as Mechanical Design, Computer-Aided Design, Process Design, and Structural Analysis and Design, as outlined in the EAC (2020) Manual. Hence, it is indispensable to research into the effectiveness and appropriateness of the incorporation of such module into the conduct of engineering programme to ensure that those students can step up their performance in such design courses with the provision of more creative ideas in their designs.

Institutions of Higher Education in Malaysia has now shifted their focus of the conduct of engineering program with the inclusion of the engineering complexity (EAC, 2020). Such idea consists of challenging students with specialised skills required to suggest engineered solutions to some open-ended problems or even non-engineering-based problems that are faced by people every day. Such a solution of problems may also require various communication channels and techniques to ensure that people who are not expert in engineering will be able to understand and make use of the solution to address their needs. Given this, creative thinking skills become an essential skill that students will need to have as part of the professional skills to be integrated into the engineering workplace.

In order to ensure that the creative thinking skill is well developed, a series of topics could be considered to be included in the courses after the completion of Creative Thinking Module to observe students' creative skills.

7.6 Sustainable Engineering

Sustainable engineering relates to the design of operating systems that does not compromise the natural environment and not depleting the materials for future generations. It is a discipline that addresses all aspects of engineering and should be treated as an interdisciplinary approach. The inclusion of the creative skills makes engineers rethink their design from the other angle that is not only sustainable but also making the design stands out from other standard engineering designs. Of course, with the successful implementation of such idea, the Institution of Higher Education may also consider offering a postgraduate programme that combines both creativity and sustainable design as one program that would further encourage the inclusion of creativity in engineering designs. For instance, the Creative Sustainability Master's Programme offered by Aalto University, Finland, is a good example that includes both creativity and sustainable in the engineering design that also demonstrates the interdisciplinary inclusion.

7.7 Complexity in Engineering

The complexity is defined as "the measure of uncertainty in achieving the functional requirements of a system within their specified design range" (Suh, 2005). The solution towards the complexity of engineering requires both technical knowledge and creativity, where the ideas proposed would sometimes be based on the engineering theories but needed to be presented in a manner that can address the current need of the society. Sheard and Mostashari (2011) described that the attributes of complexity include non-linearity, adaptivity, decentralisations, openness, and multi-scale. These attributes make the systems to be perceived as being uncertain; difficult to understand; unpredictable; uncontrollable; unstable; unrepairable; unmaintainable and costly; having unclear cause and effect, and taking too long to build. Hence, the inclusion of creativity in the solutions is essential to solving the problem. One example where the Complexity in Engineering is included in the curriculum design is the offer of the course Engineering Complexity in the Bachelor of Engineering program in the University of Newcastle, Australia to integrate professional skills with technical skills in the engineering designs.

8.0 CONCLUSION

In this research, the researcher developed a Creative Thinking Skills for Conceptual Engineering Designs to address the issue of decline in Creativity that had been reported by other researchers regarding the capability of local engineering graduates. Based on the findings above, it can be concluded that Engineering undergraduate students can be trained or educated to be more creative when it comes to deriving various relevant design of products or solutions.

However, the research findings also indicated that the current engineering education system has not been successful in improving the ability of the undergraduate engineering student to have the ability to capture the essence of information involved. The current engineering education needs to be able to educate these future engineers to be able to identify the critical information needed, to be able to present to his/her audience more creatively and effectively. The educators must also be aware that they need to generate engineers who can come up with abstract designs or solution that will most likely bring about

revolutionary changes. More attention should be given in this aspect so that the students can acquire this set of skill while still in university.

The Ministry of Education of Malaysia implemented the Primary School Standard Curriculum (Kurikulum Standard Sekolah Rendah (KSSR)) and Secondary School Standard Curriculum or Kurikulum Standard Sekolah Menengah (KSSM) in 2017. Such implementation stresses balanced knowledge and skills, including creating thinking, innovation, problem-solving and leadership. With such implementation, it is hoped that, when these students enter university in the future, they will have equipped with a better creative thinking skill that can cope with the design courses in the university. ■

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PROFILES

BALAMURALITHARA BALAKRISHNAN is currently an Associate Professor in Sultan Idris Education University, Malaysia. His research interest is in Engineering Education, Education Technology and Creativity in Education.
Email address: balab@fskik.upsi.edu.my

Ir. CHAI VOON-CHIET graduated from University of Salford, Universiti Teknologi Malaysia and Universiti Kebangsaan Malaysia. He is currently working as Assistant Professor in EGIS, Heriot-Watt University Malaysia. His research interest is in Engineering Education.
Email address: v.chai@hw.ac.uk

Ir. CHUA YAW LONG graduated from Universiti Putra Malaysia and University of Sheffield. He is currently a lecturer in the Mechanical Engineering Department, College of Engineering, Universiti Tenaga Nasional. Apart from his research in renewable energy, he is also active in research related to engineering education.

He currently serves as a Committee Member of IEM Engineering Education Technical Division and Chair of IEM STEM Promotion Sub Committee. Apart from this he also holds various positions in the Institution of Mechanical Engineers (IMechE) of United Kingdom. He is currently the Vice Chair of International Young Members Committee, South East Asia Region Young Member Representative and also a Committee Member of IMechE Malaysia Branch. He is passionate about engineering education and creativity in education.
Email address: chuayl@uniten.edu.my

KOH YIT YAN graduated from the University of Leeds, specializing in Engineering Fluid Mechanics. Despite his main research area in Mechanical Engineering, which includes the mathematical modelling of fluid flow with the aid of the supercomputer, he also completed a module on Teaching and Learning in Higher Education, which emphasizes pedagogy, learning, and assessment. In addition to his research in the areas of teaching and learning, he has also been invited as speaker and trainer in seminars and workshops related to teaching and learning, sharing best practices in teaching and learning with fellow colleagues and students.

Koh Yit Yan is currently also the Hononary Secretary of the South East Asia Association of Institution of Research (SEAAIR) and the Young Member Representative of Institution of Mechanical Engineers (IMechE) Singapore Branch.
Email address: yityan.koh@newcastle.edu.au

A NOVEL COAXIAL FED PATCH ANTENNAS AT TVWS BAND CHANNELS 24 AND 28 FOR RURAL WIRELESS COMMUNICATION

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Yi Lung Then[1], Yi Yu Yap[2], Chamath Kalanaka Vithanawasam[3]

[1,2,3]Faculty of Engineering, Computing and Science,
Swinburne University of Technology Sarawak Campus,
93350 Kuching, Sarawak, Malaysia
Email: ythen@swinburne.edu.my[1]

ABSTRACT

Microstrip patch antennas are useful for wireless communication as the technology is continuously evolving. Contacting types of microstrip patch antennas, coaxial-probe feeding, will be discussed and designed for the applications of television white space (TVWS). As the digital switchover in many countries is completed or nearly completed, TVWS is desired to be utilized for good purposes. One of them is to provide Internet access. Coaxial-probe fed single-layer single-patch microstrip patch antennas which are directional antennas, are proposed to provide wireless communication in rural areas by broadcasting hotspots. CST Microwave Studio is used to design and simulate the proposed antennas. To widen the bandwidth of the first proposed antenna, improvements are made and can be observed in the rectangular patch antenna with modified U-slots and E-shaped rectangular patch antenna. Both coaxial fed microstrip patch antennas are in good measurements and feasible to cater to the applications of TVWS at the respective channels which are Channel 24 and Channel 28.

1.0 INTRODUCTION

The element of microstrip patch antenna consists of a metal patch placed above a larger ground plane where the patch is printed on a microwave substrate material with different permittivity. Different methods to couple power into or out of microstrip antenna can be categorized into contacting and non-contacting; the former are coaxial and microstrip line feed where the connection to transmission line is direct whereas the latter transfers power between feedline and radiating patch by using electromagnetic field coupling [1]. In this paper, microstrip patch antenna with coaxial-probe feeding will be discussed. Usually, the coaxial probe has a characteristic impedance of 50 Ohms. The inner conductor of the coaxial connector extends from the ground to the patch passing through the substrate whereas the outer conductor extends from the ground up to the substrate. Fabrication is easier using coaxial feed method and it produces low spurious radiation. In addition, the feed can be placed at any suitable position in the patch to match the input impedance. Nonetheless, modelling is difficult as drilling a hole in the substrate is inevitable and the connector juts outside the ground plane [2].

The presence of wireless communication is inevitable in today's world. One of the Sustainable Development Goals proposed by the United Nations is to build resilient infrastructure where information and communication technology is essential. However, digital divide between rural and urban regions remains an issue throughout the world. A statistic in 2018 showed that globally, 3.9 billion people, or 51.2 per cent of individuals are online but 80 per cent of individuals in the least-developed countries have no access to the Internet [3]. This may be due to the high cost of infrastructure deployment as well as low population density in rural areas.

To fill the gap, television white space (TVWS) can be utilized. TVWS is the inactive or unused space exploited between actively used spectrums in very high frequency (VHF) or ultra-high frequency (UHF) spectrum where its frequency spans from 470 MHz to 790 MHz [4]. It is assigned for terrestrial television (TV) broadcasting and is usually underutilized [5]. Plenty of white spaces are available to be discovered, notably in rural areas as a result of lesser TV stations and lower population density [6]. Moreover, most of the developed and developing countries have either completed or are in the process of switching TV stations from analogue to digital transmission. In Malaysia, the digital switchover (DSO) is completed [7]. As the spectrum efficiency of digital TV is higher, the digital switchover will free up most of the TV bands and regulators can reassign these spectra for other wireless purposes with the certain requirements met. The main objective of this paper is to design and simulate the coaxial-probe fed microstrip patch antennas with reflection coefficient of less than -10 dB which resonated in the frequency range of 470 MHz to 790 MHz for TVWS applications which is to provide wireless communication in rural areas by broadcasting hotspot.

2.0 LITERATURE REVIEW

2.1 Microstrip Patch Antenna

With the advancement of wireless communication systems, microstrip patch antenna is commonly used and has becoming one of the vital elements in the system. It is known for its compact structure, low profile, ease of fabrication, simple geometry and compatibility with monolithic microwave integrated circuits (MMIC) designs [8, 9].

However, there are some disadvantages such as surface wave excitation and narrow bandwidth. Besides, the physical size of microstrip patch antennas is rather large at VHF and UHF spectrum where the TV white space frequencies are located. To increase the bandwidth while minimizing the size of the antenna, slots can be cut on the patch, shorting pins can be used, parasitic patches can be added, and thicker substrates can be used [10].

Microstrip patch antennas have been widely designed and implemented for the higher frequencies such as L-band, S-band and C band which is approximately 1 GHz to 8 GHz. However, design of microstrip patch antenna that operates at UHF band for the usage of TVWS applications is scarce. One of the studies proposed a U-shaped monopole antenna with meandering technique for TVWS application where the gain measured was 2.2 dBi and 3.7 dBi at 500 MHz and 798 MHz respectively with impedance bandwidth of 57% [11].

2.2 Coaxial-Probe Feeding

2.2.1 U-Shaped Slot Patch Antenna

In terms of slot resonator, U-slot patch antenna is commonly designed and implemented to enhance bandwidth. Originally, a U-shaped slot on a rectangular patch of single-layer single-patch microstrip antenna with air substrate was designed to achieve impedance bandwidth of 10% to 40% [12]. Compared to the usage of parasitic patches, either stacked geometry or coplanar geometry, U-shaped slot will neither increase the thickness of the antenna nor the lateral size of the antenna. Unlike the addition of dissipative loads such as resistors, U-shaped slot will not reduce the bandwidth efficiency and gain of the single-layer single-patch antenna [13]. Numerous other U-shaped slot patch antennas can be observed in the literature as well [14; 17].

2.2.2 E-Shaped Patch Antenna

Like cutting a U-slot on the radiating patch of a microstrip antenna, E-shaped patch antenna is also commonly designed and implemented to enhance bandwidth. E-shaped patch can be illustrated as two parallel slots which are incorporated into the patch of a microstrip antenna. An E-shaped patch antenna has been fabricated which increased the bandwidth of the design by more than 30% [18]. The microstrip antenna is coaxially fed and operates at frequencies of 1.9 GHz and 2.4 GHz. The E-shaped patch antenna has a simpler structure compared to the U-slot microstrip patch antenna as the length, width and position of the slots are easier to regulate in order to achieve satisfactory performances.

2.3 Television White Space

TVWS has started to be vitalized in terms of its implementation in both rural and urban regions globally. Companies such as Microsoft and Google have been actively advancing TVWS technology and testing its related applications [19]. Microsoft acts as a consultant by running different projects in Singapore, UK, and parts of Africa whereas Google focuses on vertical market applications in urban and rural areas such as Tanzania and Kenya respectively.

In terms of Internet access, several studies have mentioned the high cost of deploying and maintaining infrastructure of wireless systems in the higher bands, thus TVWS can play an important role by providing cost-effective solutions [19; 21]. Especially in sparsely populated regions, providing broadband access can be challenging due to the low average revenue per user, high energy cost and geographic accessibility problems. Number of base stations deployed over an explicit service area is reduced and the mobility is increased as TVWS has lower path loss, longer transmission range and higher penetration capabilities compared to the higher frequencies. Low-cost Internet access in 5G environment for rural regions can be accomplished with the usage of TWVS spectrum [22]. By using TVWS in metropolitan areas, more powerful public Internet access with larger coverage and boosted download speeds can be accomplished [23].

3.0 METHODOLOGY

3.1 Antenna Configuration

The rectangular single-layer single-patch microstrip patch antennas are designed and simulated on a glass-reinforced epoxy laminate material named Flame Retardant-4 (FR-4). It is a cost-effective composite material which is commonly used in the fabrication of printed circuit boards [24]. In this work, a 1.6 mm thick FR-4 substrate with a dielectric constant of 4.7 and a loss tangent of 0.0025 is adapted. To feed the proposed antenna, a 50 SMA connector, where the insulator is made of Teflon and has an outer diameter of 3.2 mm and inner diameter of 0.4 mm, is connected to the proposed antenna.

3.2 Antenna Design

3.2.1 Rectangular Patch Antenna with Modified U-Slots

With resonant frequency of 498 MHz, the parameters are obtained and tabulated in Table 1.

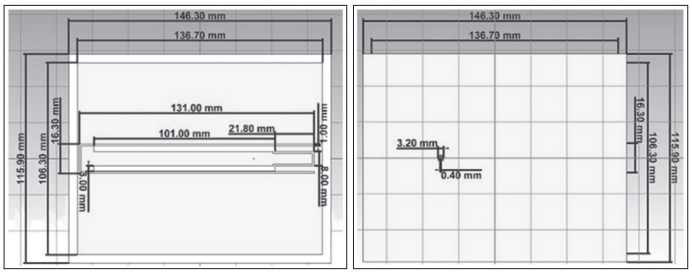
Table 1: Parameters of rectangular patch antenna with modified U-slots

Parameters	Values
Width of patch (mm)	136.7
Effective dielectric constant of substrate	4.582
Effective length of patch (mm)	107.8
Length extension, Δ (mm)	0.74
Actual length of patch (mm)	106.3
Position of probe feeding (mm)	30
Width of ground plane (mm)	146.3
Length of ground plane (mm)	115.9

With the parameters, design of the antenna is simulated in CST Microwave Studio as shown in Fig. 1.

3.2.2 E-Shaped Rectangular Patch Antenna

With resonant frequency of 530 MHz, the parameters are obtained and tabulated in Table 2. With the parameters, design of the antenna is simulated in CST Microwave Studio as illustrated in Fig. 2.

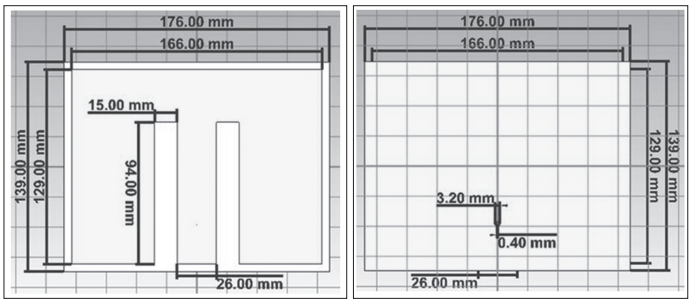


(a) *(b)*

Figure 1: Configuration of rectangular patch antenna with modified U-slots: (a) top view (b) bottom view

Table 2: Parameters of E-shaped rectangular patch antenna

Parameters	Values
Width of patch (mm)	166
Effective dielectric constant of substrate	4.602
Effective length of patch (mm)	130.95
Length extension, Δ (mm)	0.74
Actual length of patch (mm)	129
Position of probe feeding (mm)	26
Width of ground plane (mm)	176
Length of ground plane (mm)	139



(a) *(b)*

Figure 2: Configuration of E-shaped rectangular patch antenna: (a) top view (b) bottom view

4.0 RESULTS AND DISCUSSIONS

Simulation results for both rectangular patch antennas in terms of reflection coefficient, bandwidth, voltage standing wave ratio (VSWR), gain and far-field pattern are analyzed.

4.1 Rectangular Patch Antenna with Modified U-Slots

Reflection coefficient of -13.36 dB is obtained at resonant frequency of 496.8 MHz as illustrated in Fig. 3. The bandwidth of the antenna is 9.97 MHz measured from 491.72 MHz to 501.68 MHz. The bandwidth obtained is in good measurement as the frequency range of TVWS channel in Malaysia is only 8 MHz and the assigned frequency of Channel 24 is ranging from 494 MHz to 502 MHz. Besides, VSWR obtained at resonant frequency is less than 2 which is 1.55 as shown in Fig. 4.

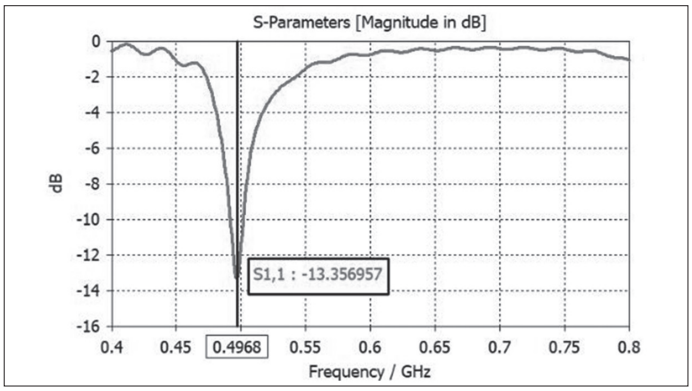


Figure 3: Simulated reflection coefficient of rectangular patch antenna with modified U-slots

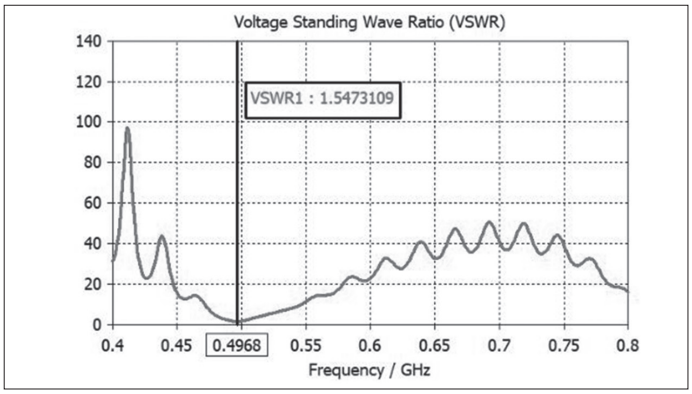
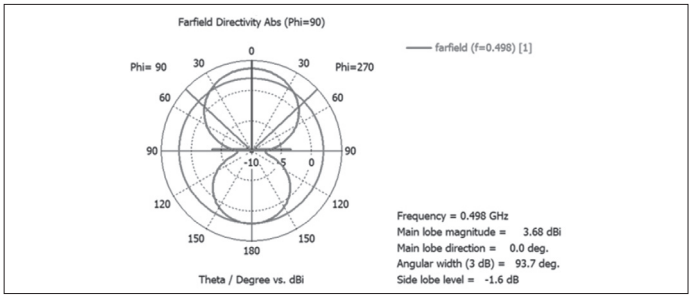
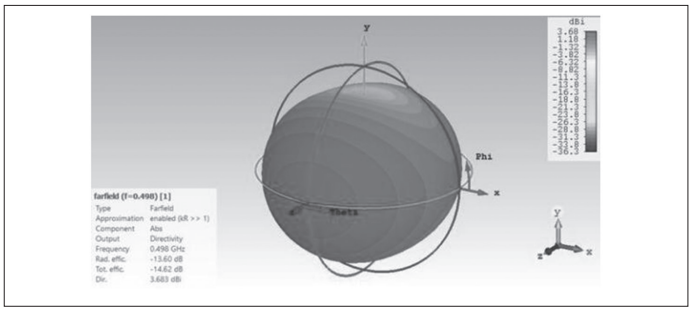


Figure 4: Simulated VSWR of rectangular patch antenna with modified U-slots

The gain obtained at resonant frequency of 498 MHz is 3.68 dBi and it can be observed that the antenna is a directional antenna. The polar form and 3-dimensional form of far-field patterns are illustrated in Fig. 5.



(a)



(b)

Figure 5: Simulated far-field patterns of rectangular patch antenna with modified U-slots: (a) polar form (b) 3-dimensional form

The simulation results obtained were in good measurement. The reflection coefficient and bandwidth are enhanced by cutting the modified U-slots on the rectangular patch. The proposed antenna can be used to cater to TVWS Channel 24 where the assigned frequency is 498 MHz.

4.2 E-shaped Rectangular Patch Antenna

Fig. 6 depicts that the reflection coefficient is -49.91 dB at resonant frequency of 529.6 MHz. The bandwidth of the antenna is 9.22 MHz measured from 525.02 MHz to 534.24 MHz. The bandwidth obtained is in good measurement as it fulfills the bandwidth requirement of TVWS channel in Malaysia which is 8 MHz. Furthermore, the antenna resonates within the assigned frequency of Channel 28 which is ranging from 526 MHz to 534 MHz. Moreover, VSWR obtained at resonant frequency is approximately equal to 1 which is 1.01 as shown in Fig. 7.

The antenna is a directional antenna and the gain obtained at resonant frequency of 530 MHz is 4 dBi. Fig. 5 illustrates the polar form and 3-dimensional form of far-field patterns.

The simulation results obtained for the E-shaped rectangular patch antenna are desirable amongst the other two proposed antennas. The E-shaped patch antenna is enhanced through bandwidth enhancement method which is adding two parallel slots on the patch. The E-shaped patch antenna can be used to cater to TVWS Channel 28 where the assigned frequency is 530 MHz as it fulfilled the bandwidth requirement and resonated at the assigned frequency.

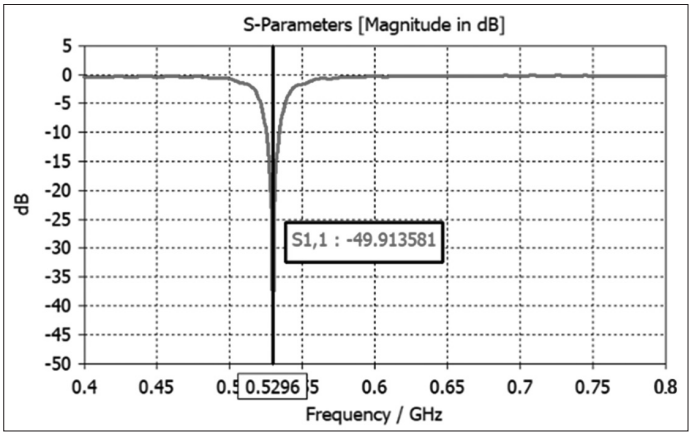


Figure 6: Simulated reflection coefficient of E-shaped rectangular patch antenna

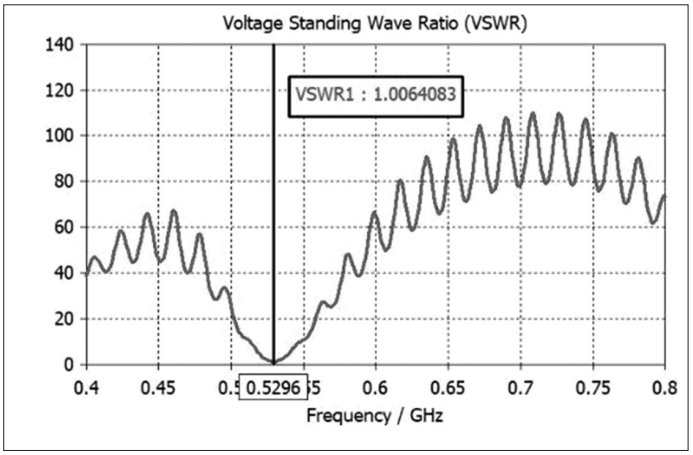
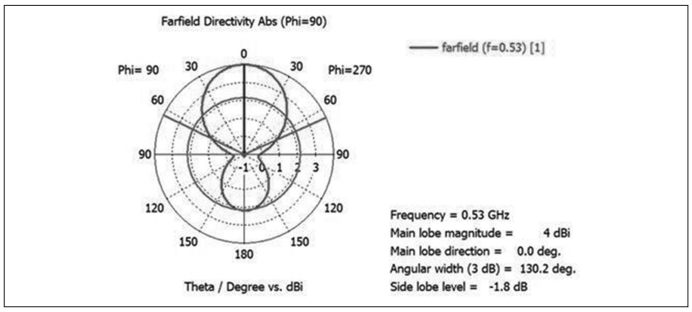
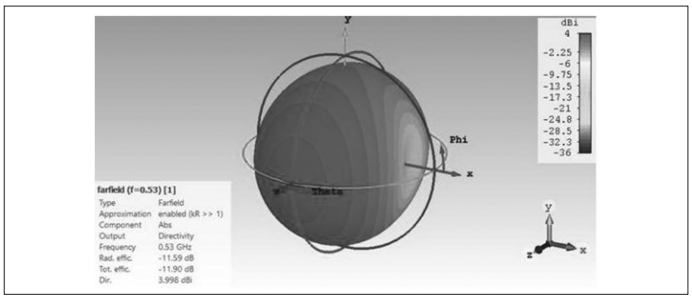


Figure 7: Simulated VSWR of E-shaped rectangular patch antenna



(a)



(b)

Figure 8: Simulated far-field patterns of E-shaped rectangular patch antenna: (a) polar form (b) 3-dimensional form

4.3 Gain Comparison of Antennas

The two antennas display a satisfactory reflection coefficient targeting the respective channels. The rectangular patch antenna with the modified U-slots successfully caters to the bandwidth for Channel 24 and the E-shaped rectangular patch antenna caters to the bandwidth for Channel 28. When using these antennas in a practical scenario after fabrication, one antenna can be used at a time, ideally at the client station, where either Channel 24 or 28 can be used for the connection depending on the antenna. Both antennas are directional, and there should ideally be no movement of the client station after a connection has been established. The E-shaped rectangular patch antenna, having a slightly higher gain of 4 dBi will have a stronger chance of connecting at longer distances in comparison to the U-slot antenna, with its lower gain of 3.68 dBi. This will not, however, be a significant difference, and both antennas should be able to connect effectively at close ranges.

5.0 CONCLUSION AND RECOMMENDATIONS

It is vital to research on coaxial fed microstrip patch antennas for the application of TVWS with the constant evolving of technology and the lack of Internet access for rural communities. Coaxial feeding is desired since it is easy to fabricate and produces low spurious radiation. Moreover, to match the input impedance, the feed can be placed at any desired position in the patch. All in all, this paper is to propose a single-layer single-patch coaxial-probe fed microstrip patch antenna to provide wireless communication in the rural area by broadcasting hotspot. The proposed antennas' design and simulations have been carried out and desirable results are obtained and the

feasibility of the proposed antenna is proven. Both coaxial fed microstrip patch antennas are in good measurements and feasible to cater to the application of TVWS at the respective channels which are Channel 24 and Channel 28. ■

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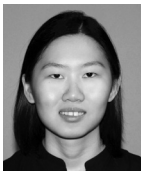
PROFILES

DR YI LUNG THEN is a registered chartered engineer with Engineering Council, UK. He is currently lecturing in Swinburne University of Technology Sarawak. He is the founder of IEEE Sarawak SIGHT and Chair for Humanitarian Technology in IEEE Sarawak Subsection since year 2018. His research areas involve wireless connectivity, sensors and instrumentation, and microwave propagation.
Email address: ythen@swinburne.edu.my



YI YU YAP obtained her Bachelor of Engineering (Honours) from Swinburne University of Technology Sarawak Campus in 2020, majoring in Electrical and Electronics Engineering. Her research interests include antennas and wireless connectivity.
Email address: yiyuyap@outlook.com

CHAMATH KALANAKA VITHANAWASAM received his Bachelor of Engineering (Honours) in Electrical and Electronic engineering from Swinburne University of Technology Sarawak Campus in 2018 and is currently a master's candidate in the same university. His research work includes microwave engineering, rural connectivity and antenna and wave propagation.
Email address: chamathkv@yahoo.com

INFILLING STREAMFLOW DATA USING HEC-HMS

(Date received: 17.03.2019/Date accepted: 18.12.2020)

Kee An Hong[1], Jer Lang Hong[1], Izihan bin Ibrahim[2], Nur Wajihah bt. Abd. Hakim[2]

[1]Hong & Associates

[2]International Islamic University Malaysia

ABSTRACT

A set of quality control streamflow data is always required in the planning, design and management of water resources projects. Although every effort has been made by the authority in the collection of complete and continuous hydrological data such as rainfall and streamflow, gaps and incomplete data sets with inadequate length are always encountered, as is always the case. These can be due to faulty field instruments, the occurrence of natural disasters and other reasons. Over the years, various techniques have been developed to infill the missing data, especially the streamflow data. These techniques include regression analysis ,rainfall runoff modelling and the use of artificial neural networks(ANN) data driven models. In this study, the HEC-HMS model is used to simulate long term daily streamflow of Sg Melaka. The process involved using recorded flow and rainfall data of 1989-1992 to calibrate the model and the model validation using records of 1985-1986. Results show that the model can be used to estimate the flows of Sg Melaka once properly calibrated. This is also shown in the results of flow duration curves. From this study, it can be concluded that missing flows of Sg Melaka can be infilled using the HEC-HMS moel and daily rainfall records in the basin. Streamflow records can be extended if complete rainfall records are available for periods where no streamflow records are available.

Keywords: Infill, streamflow, HEC-HMS, calibration, validation, sensitivity, performance criteria.

1.0 INTRODUCTION

Quality control streamflow data is always required in the planning, design and management of water resources projects. Although every effort has been made by the authority in the collection of complete and continuous hydrological data such as rainfall and streamflow, gaps and incomplete data sets with inadequate length are always encountered, as is always the case. These can be due to faulty field instruments, the occurrence of natural disasters and other reasons. Over the years, various techniques have been developed to infill the missing hydrological data, especially the streamflow data. These techniques include regression analysis, rainfall runoff modelling and the use of artificial neural networks (ANN) data driven models.

As available streamflow data with adequate length is of great importance in hydrological analysis and missing values cannot be ignored if the data available is limited, gaps should be infilled where possible using the available techniques and existing streamflow and hydrometric data. Streamflow data can also be extended if long term hydrometric data such as rainfall are available. In this study, we use HEC-HMS, a rainfall runoff model developed by the US army Corps of Engineers [1], to infill the missing streamflow data of Sg. Melaka as a case study. HEC-HMS has been widely applied throughout the continents for long term rainfall runoff simulation studies. Examples are Sweden and Nepal [2], Brazil [3], India [4], Kenya [5], India [6], Kenya [7], Sweden [8], Sri Lanka [9], Eastern Europe [10].

2.0 MATERIALS AND METHODS

2.1 The Study Area

The Sg Melaka basin is shown in Figure 1. The basin area is 350 km^2. The maximum breadth and width of the basin are 26 km and 14km. The basin is of low lying and undulating hills in the south and mountainous country in the north border. A small area in the south is below 15 m contour line.

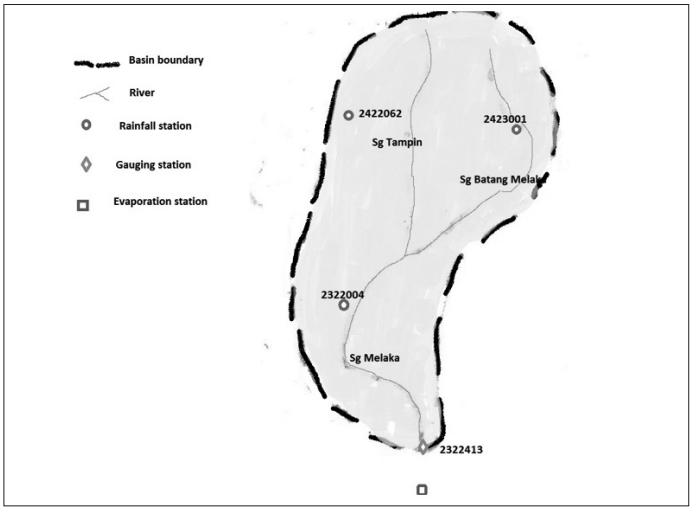


Figure 1: The Melaka Basin

The main river Sg Melaka and its major tributary, the Sg Batang Melaka rise to the hill in the north. The two rivers meander through low lying and undulating land on their way to the sea. The low-lying area is cultivated with palm oil whilst the upper basin is covered with lallang and forest. The soil cover of the basin is basically coarse and sandy clay.

2.2 Hydrological Data

The Melaka basin was chosen as a case study as there are three rainfall stations quite evenly distributed in the basin with long and rather continuous records. In this context, the mean basin rainfall can be estimated with accuracy. For simplicity mean catchment rainfall is taken as the mean of the three stations. There is a streamflow record with over 50 years although intermittent missing records exist. Years with complete records are available and can be used for HEC-HMS modelling. The evaporation station is located at Melaka Airport and the potential monthly evaporation values have been estimated [11]. Details of the data available are listed in Table 1. The data were examined carefully for consistency and the streamflow and rainfall data for the period 1/1/1989 to 31/1/1992 were used for model calibration and the period 1/1/1985 to 31/12/1986 were used for model validation. As daily evaporation data for these periods consist some gaps, the mean monthly potential evaporation (forest evaporation) presented in Water Resources Publication No 5 [11] were used in this study. The monthly forest evaporation values of Melaka Airport are shown in Table 2.

Table 1: Hydrological data of Melaka basin

	Station name	Station ID	Period of recods
Rainfall	St. Thomas School	2422062	1948- to date
	Ladang Tebolang	2423001	1953- to date
	JKR Alor Gajah	2322004	1948- to date
Streamflow	Sg Melaka at Pantai Belimbing	2322413	1960- to date
Evaporation	Melaka Airport	0210	1960-to date

Table 2: Forest evaporation, Melaka Airport, mm

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Evaporation	128	126	141	137	128	119	119	122	124	123	115	111

2.3 Methodology

HEC-HMS is useful in analyzing urban flooding, flood frequency, flood warning system planning, and in long term streamflow simulations. HEC-HMS calculates runoff using the key components of the model. Components can be chosen by users for specific needs for particular basins. In the long term streamflow simulations of Melaka basin, we choose six main components of HEC-HMS. These are: meteorology, interception, surface detention, infiltration, direct runoff, and baseflow.

Methods used in the key components to estimate model parameters of HEC-HMS in long term streamflow simulations are:

Meteorology- This involves the input of daily streamflow, rainfall and monthly potential evaporation data.

Simple canopy – This method is chosen for its simplicity due to a lack of available data defining the canopy. The model parameters are initial storage and maximum storage in canopy.

Deficit-constant soil loss method – The deficit-constant method provides the ability to simulate soil moisture characteristics using easily derived and calibrated parameters. The parameters are initial deficit-which represents initial condition of the soil layer, and it is the amount of water to saturate the soil layer, maximum deficit-which is the maximum amount of water the soil layer can hold, constant loss-which is the percolation rate of the soil layer.

Snyder unit hydrograph transformation method – The parameters for this method are fairly easy to calibrate, this method has shown to be very effective in representing the timing and shape of flow hydrographs through varying magnitudes and volumes of floods. The parameters are standard lag which is the time between the centre of mass of rainfall and the peak of the hydrograph, and peaking coefficient which determines the peak rate of runoff.

Exponent recession baseflow method-Parameters for this method such as initial discharge, recession constant and threshold can be estimated from hydrograph records and generally satisfactory parameters can be obtained through calibration. Initial discharge is the baseflow at the beginning of the simulation. Recession constant is the rate at which baseflow recedes between storm events. Threshold ratio is the ratio to the peak flow at which the baseflow is reset.

The computation process can be readily summarised as a flow diagram as shown in Figure 2.

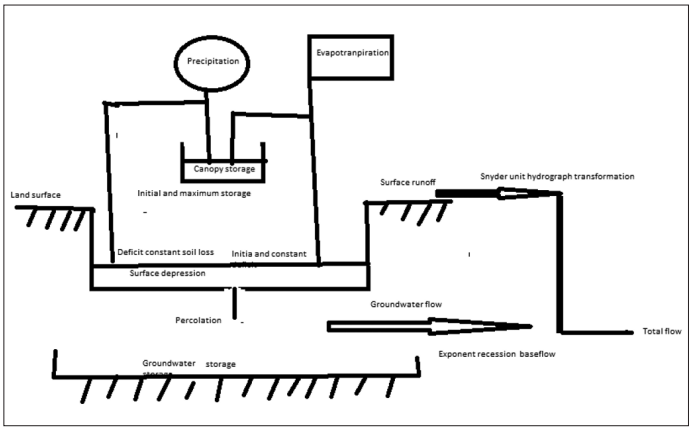


Figure 2: Representation of the HEC-HMS components in long term rainfall runoff simulation

In the HEC-HMS model, the precipitation represents the average catchment precipitation, which can be estimated using arithmetic mean, Thiessen polygon, isohyetal and inverse distance squared method. Evaporation as modelled in the program includes vaporization of water directly from the soil and vegetative surface, and transpiration combined and estimating as an average volume. The varying monthly evapotranspiration values can be input into the model. The deficit constant loss model tracked the moisture deficit continuously, and was computed as the initial abstraction volume less precipitation volume plus recovery volume during the precipitation free period. The recovery rate can be estimated as the sum of the evaporation rate and percolation rate, or some fraction thereof.

The soil moisture model is represented by a series of storage layers. Rate of inflow to or outflow from and the capacities of the

layers control; the volume of water lost or added to the storage components. Current storage contents are calculated during the simulation and vary continuously both during and between storms.

The storage layers are:

Canopy storage - Precipitation is the only inflow into this layer. Precipitation fills the canopy storage and when this storage is filled, precipitation will be available for other storages. Water in canopy is removed by evaporation.

Surface storage - Surface depression storage is the water held by surface depression. Inflow into this storage comes from precipitation not captured by canopy and in excess of infiltration rate. Outflow from this storage can be due to infiltration or evaporation. Once the volume of surface interception is exceeded, this excess water contributes to surface runoff.

Soil storage - The soil storage represents water stored in the layer of soil. Inflow is infiltration from the surface.

Ground water storage - Ground water layer is the horizontal interflow processes. Water percolates into the groundwater storage from the soil profile.

Direct runoff is modelled using the unit hydrograph (UH) method. In this study, we use the Snyder UH. Snyder [12] selected the lag, peak flow and the time base as parameters for the UH.

The relationships are:

$$t_p = 5.5t_r \quad (1)$$

Where t_p is the standard catchment lag in hours
And t_r is the rainfall duration in hours

$$t_{pR} = t_p - \frac{t_r - t_R}{4} \quad (2)$$

Where t_R =duration of desired UH
t_{pR} = lag of desired UH
The peak of standard UH in terms of catchment area and lag is:

$$\frac{U_p}{A} = C\frac{C_p}{t_p} \quad (3)$$

Where Up peak of standard UH
A= catchment area
Cp= UH peaking coefficient
C= conversion factor
For other durations, the UH peak is:

$$\frac{U_{pR}}{A} = \frac{CC_p}{t_{pR}} \quad (4)$$

The tp and Cp can be calibrated using HEC HMS

The exponential recession baseflow model derived the k value using the following formula:

$$Q_t = Q_0 k^t \quad (5)$$

Where Qo= initial baseflow
Qt= baseflow after t time unit
K is a decaying coefficient

2.4 Model Performance Criteria

In this study, the model performance was evaluated following the guidelines developed by Moriasi *et. al* [13] for a monthly time step based on model evaluation statistics. The statistical measures are:

$$\text{PBIAS} = \frac{\sum_1^n (Y_{io} - Y_{is})}{\sum_1^n (Y_{io})} * 100 \quad (6)$$

$$\text{RSR} = \frac{\sqrt{\sum_1^n (Y_{io} - Y_{is})^2}}{\sqrt{\sum_1^n (Y_{io} - Y_{om})^2}} \quad (7)$$

$$\text{NSE} = 1 - \frac{\sum_1^n (Y_{io} - Y_{is})^2}{\sum_1^n (Y_{io} - Y_{om})^2} \quad (8)$$

Where Y_{io} is the ith observed monthly flows, Y_{is} is the ith simulated monthly flows and

Y_{om} is the mean of observed monthly flows

PBIAS is the percent bias

RSR is root mean square error-observation standard deviation ratio

NSE is Nash-Suteliffe efficiency

The recommended criteria of Moriasi *et. al* are shown in Table 3.

Table 3: General performance ratings for NSE and PBIAS, RSR for a monthly time step (from Moriasi et al., 2007)

Performance rating	NSE	PBIAS	RSR
Very good	0.75 < NSE ≤ 1.00	PBIAS < ±10%	0.00<=0.50
Good	0.65 < NSE ≤ 0.75	±10% ≤ PBIAS < ±15%	0.50<RSR<=0.60
Satisfactory	0.50 < NSE ≤ 0.65	±15% ≤ PBIAS < ±25%	0.60<RSR <=0.70
Unsatisfactory	NSE ≤ 0.50	PBIAS ≥ ±25%	RSR>0.70

3.0 RESULTS AND DISCUSSION

A model is considered reliable only when it can estimate streamflow comparable to observed flow with accuracy. The rainfall runoff model for the Melaka basin was calibrated and validated using recorded flows for different periods. Initial model parameters were obtained by using optimization procedures of HEC-HMS. For the present study, statistical parameters such as NSE, PIAS and RVR are used to evaluate the performance of the HEC-HMS model. The 1989-1992 hydrological data were used to calibrate the model and after the model is calibrated, a different set of data(1985-86) were used to evaluate the accuracy of the model.

3.1 Calibration Results

The 1989 -1992 daily streamflow and rainfall records and the monthly forest evaporation data (Table 2) were used for HEC-HMS to obtain the model parameters of the Melaka basin. The sensitivity analysis was carried out to determine the important parameters which needed to be precisely estimated to make accurate prediction of basin flows. Thus, the model was run with initial parameter values for a simulation run. From the results, model parameter values were adjusted and trial runs were repeated with new parameters. When a good performance statistical measure like NSE is reached, a sensitivity test was

carried out to test the performance of the model by changing the parameters one at a time while keeping the others unchanged. This was done until the best fit parameters are obtained. Checks are also made at the same time through graphical inspections. For the calibration runs, the best fit parameters obtained through optimization for the Melaka basin are shown in Table 4.

Results are shown graphically in Figure 3.

It can be seen from the graph that the recorded flows have been modelled quite correctly for most of the time except for some high flows and the low flows in early 1991. The statistical performance measures are shown in Table 5. Referring to the rating table of Moriasi for statistical measures, the performance of the model is satisfactory.

Table 4: Model parameter values for Melaka basin

Parameter	Optimised value
Deficit and constant-constant rate	0.38
Deficit and constant deficit	0.1
Deficit and constant-Maximum deficit	1.35
Recession –initial discharge	1.62
Recession-ratio to peak	0.1
Recession-recession constant	0.97
Simple canopy – initial storage	0
Simple canopy-maximum storage	4.7
Simple surface-initial storage	0
Simple surface=maximum storage	4.8
Snyder unit hydrograph-peaking coefficient	0.46
Snyder unit hydrograph –standard lag	56

Table 5: Performance of the calibration model based on PBIAS, NSE, and RSR, for a monthly time step

Calibration period	PBIAS	NSE	RVR
1/1/1989 - 31/12/1992	-2.54	0.62	0.62

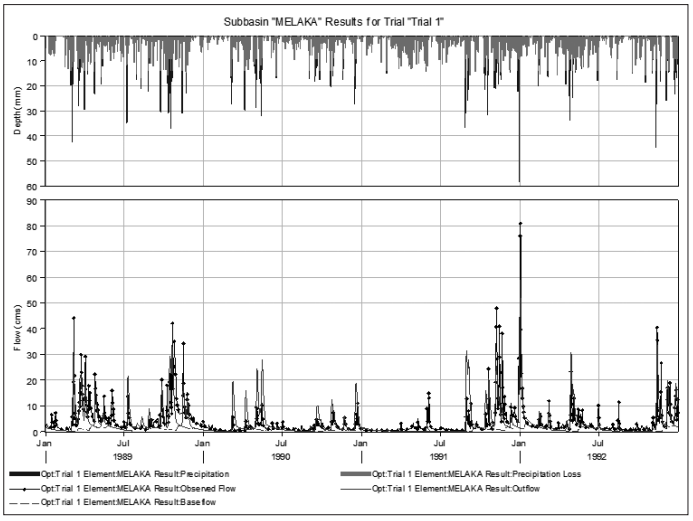


Figure 3: Observed and simulated flows, 1989-1992, Melaka at Pantai Belimbing

3.2 Validation Results

Using the derived parameters of the calibration runs, a validation run was performed adopting daily rainfall of 1985-1986 and the mean monthly forest evaporation. The model performance statistical measures are shown in Table 6. Results are also shown in Figure 4. From Figure 4, it can be seen that except for some high flows and the flows in April – May 1986, the model is generally able to reproduce the observed flows. The model also gives satisfactorily statistical parameters such as PBIAS, NES and RSR when applied to simulate the 1985-1986 data.

Table 6: Performance of the validation model based on PBIAS, NSE, and RSR, for a monthly time step

Validation	PBIAS	NSE	RVR
1/1/1985 - 31/12/1986	19.5	0.56	0.67

3.3 Comparison of Flow Duration Curves

The observed and predicted daily flows for 1985-86 were used to derive the flow duration curves as presented in Figure 5. From the curves shown in Figure 5, it is clear that the model is able to predict the observed flows well except for some medium flows.

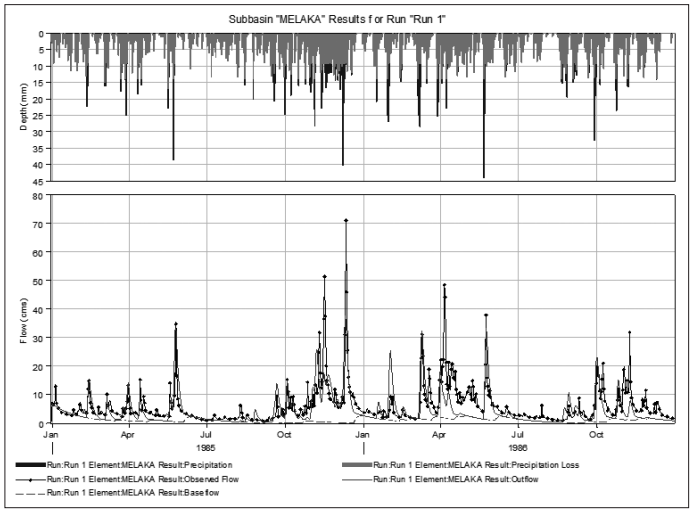


Figure 4: Observed and simulated flows, 1985-1986, Melaka at Pantai Belimbing

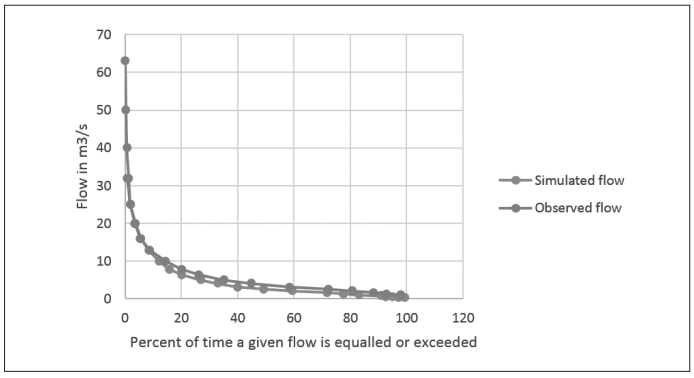


Figure 5: Flow duration curves for observed and predicted flows, 1985-86

In the study for Sava catchment [10] in Eastern Europe, data from 30 gauging stations were used to calibrate and validate the HEC-HMS model and the model evaluation statistics derived using monthly data obtained were as follows:

Type of run	PIAS	NSE
Calibration	-0.5-0.5	0.66-0.89
Validation	-20-18	0.28-0.86

Our study shows that compared to the results obtained elsewhere, satisfactory results were obtained using HEC –HMS in modelling the data of Melaka basin. In the absence of detailed field data such as soil and evaporation, the conceptual model has been used successful in estimating streamflow from rainfall data.

4.0 CONCLUSION

In this study, the HEC-HMS model is used to simulate long term daily streamflow of Sg Melaka. The process involved using recorded flow and rainfall data of 1989-1992 to calibrate the model and the model validation using records of 1985-1986. Results show that the model can be used to estimate the flows of Sg Melaka once properly calibrated. This is also shown in the results of flow duration curves. From this study, it can be concluded that missing flows of Sg Melaka can be infilled using the HEC-HMS model and daily rainfall records in the basin. Streamflow records can be extended if complete rainfall records are available for periods where no streamflow records are available.

5.0 ACKNOWLEDGEMENT

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PROFILES

HONG KEE AN is a professional Engineer major in hydrological analysis, design and modeling. He received his B. Sc. degree in Agricultural Engineering from National Taiwan University in 1971 and the M. Eng. degree in Water Science from Asian Institute of Technology in 1973. He is the author of the book "River routing using HEC-HMS Excel solver and neural designer". He is a Fellow of the Institution of Engineers, Malaysia and is listed in Who's Who in Engineering published by the American Association of Engineering Societies.
Email address: keeanhong@yahoo.co.uk

DAVID HONG JER LANG is currently the principal architect of SNS Sdn Bhd. He received his B. Sc degree in computer science from Nottingham University in 2005 and the Ph. D. degree from Monash University in 2010.He is the co-author of the book "River routing using HEC-HMS Excel Solver and neural designer". David Hong is listed in Who's Who in the World.
Email address: jerlanghong@gmail.com

IZIHAN BIN IBRAHIM is a civil Engineering graduate and he obtained a Master's degree from Imperial College UK in Engineering Hydrology. He was a lecturer of university Kebangsaan for 3 years before he joined HYDEC, a consulting Engineering firm. He is presently a lecturer in International Islamic University and he is also a Director of Rho 1, a consulting firm in Hydrology and hydraulics.
Email address: izihan@gmail.com

NUR WAJIHAH obtained her B.SC. in Civil Engineering from UNIMAS in 2017. She is a hydrologist of RHO 1 Consultant for the past 3 years and is now pursuing a Master's degree at International Islamic University, Malaysia.
Email address: nurwajihah94@gmail.com

A STUDY ON THE ASSESSMENT OF THE REQUIREMENT OF MARINE SERVICE VESSELS FOR MONGLA PORT WITH RESPECT TO FUTURE DEMAND AND IMO GUIDELINES

(Date received: 16.09.2020/Date accepted: 14.12.2020)

Dr M Reaz H Khondoker, PEng and K Rasel Hasan

ABSTRACT

The objective of the study is to assess the future requirement of marine service vessels for Mongla Port Authority (MPA) to meet the increasing demand and to improve the performance of the port for carrying out the mandated responsibilities of different marine services to incoming and outgoing ships as an international maritime port under IMO guidelines. The growing international trade in Bangladesh impacted largely in the maritime activity of the country. It is seen that the growth rate of the cargo and container volume of imports and exports at Mongla port is increasing day by day. However, there are only 32 (thirty two) marine service vessels, out of which 19 (nineteen) vessels are more than 30 years old, 12 (twelve) vessels are less than 15 years of age and one vessel is between 15 to 30 years. Therefore, MPA lacks far behind to provide different marine services due to inadequate and very old marine service vessels. In view of the same, a study has been carried out which comprises the assessment of the requirements of different necessary marine service vessels with respect to increasing traffic demand as well as IMO guidelines to provide essential marine services to various incoming and outgoing ships. Consequently, a procurement plan has been suggested which depicts the number and type of marine service vessels to be procured by 2020 and by 2030 to enable MPA to be developed as a modern maritime port and fulfill the responsibility as the south-western gateway of the country as well as a regional hub supporting transit facilities to India, Nepal and Bhutan.

1.0 BACKGROUND

Bangladesh is showing an average 6% growth in the gross domestic product (GDP) for last decade with a total GDP of 302.57 billion USD in 2019 [1]. The share of international trade is 35% of total GDP in 2017 [2]. The export share is dominated by the readymade garment sector which is 84% of the total export of 40.53 billion USD in 2018-19 [3]. With a population of 167 million, the country's import is also getting larger and larger day by day. The total import for the year 2018-19 is 68.10 billion USD [4]. The country has a higher maritime dependency for international trade. The share of maritime trade is 94.44% for import and 98.99% for export of the total import and export of the country in 2018-19 [4]. And for the maritime trade the country completely depends on the Chittagong Port, which handles more than 90% of the total trade of the country [5] and [6]. Even though Mongla is the second largest seaport of the country, it is hugely suffering to penetrate more market share. Taken into consideration of the trade prospects of the country as well as development of the south-western part of the country, the Government emphasizes on the development of the Mongla Port recently.

In 1950s Mongla Port became operational as an Anchorage Port at the confluence of Passur River and Mongla Nulla about 45 km south of Khulna Metropolitan city. Anchorage was started over Joymonirgoal to Digraj, which has been shifted to Herbaria. A feasibility study for construction of shore based port facilities on the bank of Passur River was done by an American firm, Fedric R. Harris and Pak Techno Consultant, in the 1967-68 and Hedco, the Netherlands, studied approach to Passur River from Bay of Bengal. On the basis of their recommendation of the 1st phase of Master plan, about 2068.80 acres of land were acquired at the east bank of Passur River. About 5 km long riverbank along the waterfront from Mongla River confluence to Digraj was used to build up land based port operation facilities. Different port oriented government and private enterprises were allotted about 3 km of waterfront. Out of 2068.80 acres of land, Mongla Port Authority in its own jurisdiction utilized 1046.88 acres of land for construction of different port based facilities. In view of expansion of the business of Mongla Port, about 255.41 acres of lands were allocated to BEPZA (Bangladesh Export Processing Zone Authority), 315.15 acres to BEZA (Bangladesh Economic Zone Authority) and 346.34 acres to different govt. and non-govt. organizations. A number of different port facilities have been developed based on the Master plan and since 1950, Chalna Port started to function as Government Directorate and in May 1977, the directorate was concerted to an autonomous organization called Chalna Port Authority. The Chalna Port Authority was again renamed as "Mongla Port Authority" on 8th March 1987 [7].

To accelerate and develop Mongla Port, government has taken different initiatives recently such as construction of Padma Bridge at Mawa point, establishment of Khulna-Mongla railway link, supply of gas through pipe line, construction of Khan Jahan Ali airport, establishment of 1320 MW coal based power plant at Rampal and Special Economic Zone at Mongla Port area, etc. The above projects are expected to be completed by 2018-20. After completion of the Padma Bridge, an opportunity will be generated up for Dhaka based export and import cargos especially for ready-made garments. Moreover, after establishment of coal based power plant at Rampal, minimum 45.00 lac ton coal would

likely to be imported through Mongla Port annually as raw materials of the plant. On the other hand, Special Economic Zone will create a new horizon for imports and exports. Consequently, the uses of Mongla port will be increased enormously.

To meet up these additional demands efficiently and effectively, Mongla port has to commence different types of strategic plans which will play a vibrant role in the national economy facilitating sea borne import and export trade of the country and the region as well [8]. Port provides amenities and services to the international shipping lines and other concerned agencies providing port facilities with capacity of handling about 70,00,000 tons general cargo/break bulk and 4,00,000 TEUs container. It has 5(five) jetty berths, sheds, open space, cargo handling equipment and safe navigable channel for day and night shipping. Total 34 (thirty four) nos. ships can take berth in jetty and anchorage i.e., in the port at a time. With the completion of Rupsa and Paksey bridges, transport network with northern area has been elevated and uninterrupted. Resultantly port bound cargo of western part of Jamuna River and transit cargo from Nepal and Bhutan as well as India can find a good demand of handling through Mongla Port. After completion of Padma bridge, it is anticipated that Mongla Port will get a new turn in handling of Dhaka bound export-import cargo in promoting international trade and business of the country and the region as well. In the study report entitled "Bangladesh: Port and Logistics Efficiency Improvement" conducted by ADB [9], a projection of the utilization of port facilities have been conducted where it is shown that even though in case of the maritime trade the share of Chittagong port is 90% and Mongla is 10% at present. However, it is estimated in the same report that there will be 50% share of Chittagong port and 40% that of Mongla port in 2040.

It is, therefore, seen that to cope up with the growing demand of cargo handling at Mongla Port, further development is an inevitable necessity. In view of the same in order to improve the performance of the port and to meet the increasing demand, different proposals for development of the port as well as procurement of different types of marine service vessels for carrying out the mandated responsibilities of Mongla port (Figure-2) as an international maritime port under IMO guidelines as well as providing required marine services to incoming and outgoing vessels in the port are being studied.

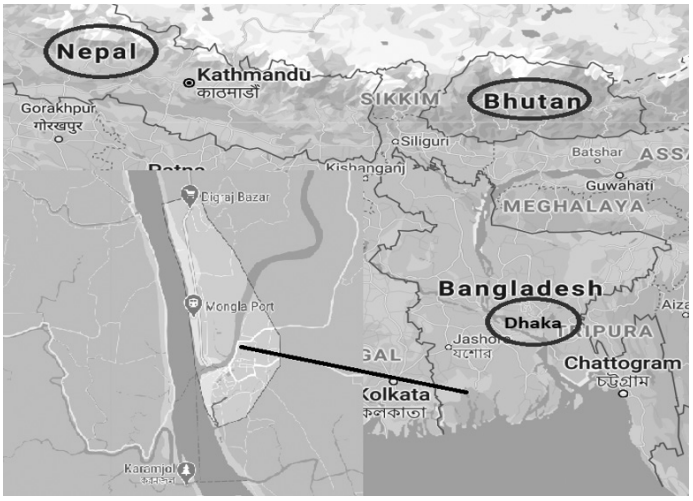

Figure 1: The Location of Mongla Port and its Possible Hinterlands

2.0 METHODOLOGY

The main objective of the reseach is to indentify the numbers and types of marine service vessels for enhancing the operational performance and reach the optimum utiliztion of the Mongla port. That is also to reduce the incredible pressure on the Chittagong Port and reduce the risk for the country of depending high on a single port. In order to achieve the object of the research the trade and traffic prospects of the country and Mongla port have been analysed. The findings of the previous studies along with the port performance statistics have been investigated. The present status of the marine service vessel fleet is examined technically and classified according to their suitability to provide the required marine services. Comparing the trade and traffic prospects of the country and the port with the marine service fleet requirement a conclusion on the required number of vessels have been drawn. A procurement plan has also been suggested to procure the marine service vessels in different phases considering the trade and traffic pattern. In oder to decide the types of marine service vessels mainly different international rugulations, policy and guidelines are taken into consideration which are mostly IMO regulations and guidelines which is highlighted in Section 3 and World Bank Port Reform Toolkit 2007 [10].

3.0 IMO GUIDELINES FOR MARITIME PORT RELATED TO MARINE SERVICES

IMO is the United Nations' specialized agency responsible for safety and security of shipping and the prevention of marine pollution by ships. The national maritime administration of different countries of the world has many tasks according to the IMO conventions, also has many responsibilities toward the ships rising its flag or entering its ports which are; flag state control, port state control, search and rescue, pollution prevention and navigational services, etc.

IMO Convention does give the organization a mandate to regulate in ports and some current IMO regulations do indeed extend to port operations, such as surrounding security, waste reception facilities, etc. However, there are many opportunities to further explore and enhance the cooperation between shipping, ports and the logistics industries. A port sector that can streamline procedures and remove barriers to trade, embrace new technologies and treat safety, security and reputation as both desirable and marketable, will be a major driver towards stability and sustainable development and support the achievement of the U.N. sustainable development goals.

It is evident that more dialogue with ports and more involvement from port-related stakeholders at IMO were necessary, particularly with advancements in automation and digitalization. Ports are becoming increasingly relevant in actions to combat climate change and reduce shipping emissions, including supply of low-emission fuels for ships, port call optimization and just-in-time operations and moves towards sustainable onshore power supply, requiring port infrastructure and information exchange.

IMO has also developed and adopted international collision regulations and global standards for seafarers, as well as international conventions and codes relating to search and rescue, the facilitation of international maritime traffic, load lines, the

carriage of dangerous goods and tonnage measurement. The Maritime Safety Committee (MSC) is IMO's senior technical body on safety-related matters. It is aided in its work by a number of Sub-Committees. The following safety related issues, which are on the other hand guidelines for port activities are important to mention;

- Code for Safe Practice for the Safe Loading and Unloading of Bulk Carriers (BLU Code);
- Recommendations on the Safe Transport of Dangerous Cargoes and related Activities in Port Areas;
- The adequate protection of any sea port from fire, explosion or other similar incidents is essential to the continued wellbeing of the country. To assure such protection, adequate marine disaster response capability should be available and utilized under well-conceived disaster contingency plans of the port. The harbor master must develop this Marine Firefighting plan in consultation with the local fire and emergency response agencies and organizations to encourage coordinated planning and exercising.
- IMO has always paid great attention to the improvement of navigational safety whether the ship is in movement or anchored in port and harbor. SOLAS covers various aspects of ship safety, including construction, fire protection, life-saving appliances, radio-communications, safety of navigation, the carriage of cargoes and safety measures for high speed craft.
- Implementation of maritime search and rescue to be implemented by flag state, port state or coastal state.
- Pilots with local knowledge have been employed on board ships for centuries to guide vessels into or out of port safely. Qualified pilots are usually employed by the local port or maritime administration and provide their services to ships for a fee, calculated in relation to the ship's tonnage, draught or other criteria.
- Within SOLAS's [11] chapter XI-2 on Special Measures to enhance maritime security is the International Ship and Port Facility Security (ISPS) Code, which is a mandatory instrument for all countries, party to the Convention.
- Currently, the agenda of IMO's Facilitation and Maritime Safety Committees is the issue of adequate anti-cyber security practices, which may be used to protect and enhance the resilience of cyber systems supporting the operations of ports, vessels, marine facilities and other elements of the maritime transportation system.
- IMO is continuously pursuing a pro-active approach to enhance implementation and enforcement, both by flag and port states, including a pro-active action plan to ensure that shore-based reception facilities for ship generated waste keep up with international regulatory requirements.
- IMO has recognized that provision of reception facilities is crucial for effective MARPOL [12] implementation and the IMO Marine Environment Protection Committee (MEPC) has strongly encouraged member states, particularly those Parties to MARPOL as port states, to fulfill their treaty obligations on providing adequate reception facilities.

From the above review, it is well understood that IMO has formulated different regulations and codes through different sub-committees in order to ensure safety and security of the ships during their movement through waterways and during their berthing in the port harbors. The rules and regulations for protection of environment and mitigation of pollutions both in waterways and in port areas have also been formulated by the concerned sub-committees and well defined in SOLAS [11], which has been first accepted in 1973 and amended and extended in different years. Therefore, the maritime port authorities have huge responsibilities to follow the relevant rules, regulations and code of conduct and develop necessary facilities to provide different designated marine services including tugboat service, water supply, fuel supply, emergency medical service, mooring service, navigational aids, hydrographic survey, waterway maintenance and dredging, etc. in order to ensure safe navigation and operation, safety and security of the vessels and environmental protection of the nature under their jurisdictions.

4.0 MARINE SERVICES OF MONGLA PORT

As mentioned earlier, there are a number of responsibilities to be fulfilled by a sea port in order to ensure safety, security and environmental protection to the ships, water and other areas of the port according to IMO and UNCLOS regulations and guidelines [13]. Other than these, a seaport should also render some marine services like pilotage, mooring, ship handling, harbor towing, salvage and rescue, escorts towing, anchor handling and survey and research, etc. These can be found under different components of Port User's Information Network as shown in Figure 2.

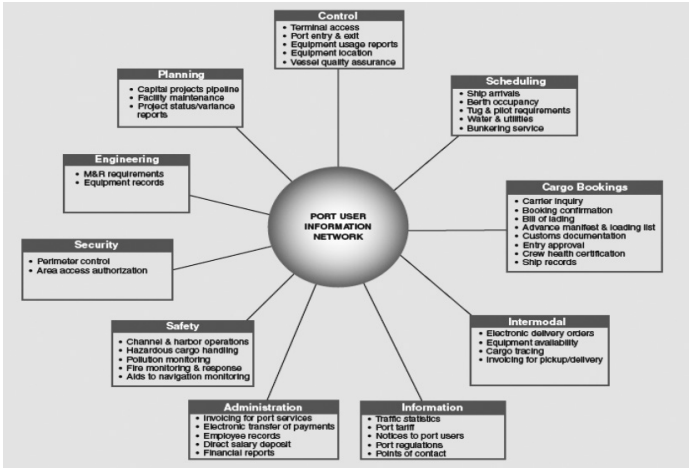

Figure 2: Marine Services under Different Group in Port User Information Network, Source: Port Reform Toolkit 2007

Marine services are port-bound activities accomplished to confirm the safe and prompt flow of vessel traffic in port approaches and harbors and a safe and secured stay at berth when moored or at anchor. Safe means port conditions ensure that ships using the port, the port environment and the marine environment are sheltered from danger. Prompt means ships are not unduly delayed and that the ships' port transit times, as a part of the total turn-around time in the port, are kept to a minimum.

Although ports may define marine services differently and may have different methods of providing them, the term is used to refer generally to services having a navigational attitude, be it maritime safety, vessel traffic efficiency, or marine environment protections, which are the prime requirement of IMO [14].

Other services (for example, immigration and customs services, security and port state control), as mentioned below, may also affect port proficiency and safety. A variety of other aspects may be regulated by a port authority [15] under a port's law, such as:

- Inquiries with respect to any case where damage has been caused by or to a ship in port.
- Keeping and placing buoys, beacons and other navigational aids as well as provision and maintenance of lighthouses.
- The landing of personnel belonging to an armed service.
- Cleaning of basins, works and premises.
- The use and manning of harbor craft (sometimes requires fire-fighting capabilities).
- Provision and maintenance of pontoons.
- Manning and use of tugs and other vessels.
- Special police powers for patrol boat personnel (may also be included in the harbormasters function).
- Disaster control and emergency communication procedures.
- Fire-fighting procedures and operations.
- Prohibiting the embarkation and disembarkation of persons except at such places as may be authorized by the port authority.

While important to the overall operation of a port, the above other services are not dealt with in this section, since these are merely related with the procurement of marine service vessels.

The specific marine services rendered by a modern sea port depend largely on the scopes of the port's marine responsibilities and jurisdiction. The scope of the port's marine jurisdictions does not follow a general rule and there exists no international legislation or standard practice that defines the responsibilities of port authorities. However, there are some obligatory requirements as guided by IMO in order to protect the safety of the port and the environment. Usually, marine services provided by a port authority are geographically delimited by the area directly under control of the authority, which may encompass only the waterfront of riparian berths (the port's domain). However, there are countries where the port authority is also responsible for managing lighthouse services outside its immediate area of control. This extended area may cover harbor waters and approaches as far as the open sea.

4.1 Harbormaster's Function

The harbormaster (or port captain) manages port activities relating to maritime safety and the protection of the marine environment. The legal basis of the harbormaster's function is embedded in the port by law or, in the case of this state-owned port, in a specific law or ministerial decree. The harbormaster has specific legal powers to act in emergency situations. In some countries, the harbormaster may work for an independent public entity such as the coast guard. However, the MPA harbormaster is part of the port authority organization and heads the marine department.

The harbormaster is responsible for ensuring the efficient flow of traffic through port and coastal waters (including allocation of vessels to public berths) and on behalf of the government or port authority for coordinating all marine services. The harbormaster operates out of a port coordination center (or Captain's Room), which is often part of an elaborate vessel traffic management system.

4.2 Chief Engineer (Marine)

i) Responsible for focusing attention of the major decision / task of each / level in the decision making structure and ensuring constant applications of overall policies of the board in the field of marine related activity like procurement, repair and maintenance of marine service vessels.
ii) Assesses port development requirements in the field of marine engineering and services. Prepare development schemes; determine technical and economic feasibility of projects and monitoring of ongoing maritime projects.
iii) Responsible for preparing design, specification and contract documents for new building, repair and maintenance of different type of marine service vessels and marine structures for the port.
iv) Ensure optimum use of marine service vessels and different machinery and equipment installed/operated at marine workshop.

4.3 Pilotage Services

Pilots usually constitute a closed group of professionals (often master mariners), who are keenly aware of their unique position in the port environment. Successful vessel management relies heavily on the efficient functioning of the pilot organization, a fact that pilots may use to maximum advantage during port reform. In MPA, the pilotage services are a part of the port authority and the harbormaster also serves as head of the pilotage services.

4.4 Tugboat Operations

Tugboat services are considered as those destined to help maneuver ships on the instructions of its captain, using one or more tugs that use their engine power or accompany the ship within the waters of the service zone of the port. Tugboat operations are typically carried out by private firms in different modern ports of the world. However, most of the port, worldwide like MPA, is still providing the tugboat services, since private sector did not come up for the same. Generally, if the volume of ship traffic is not sufficient to support a tugboat service on a commercial basis, a port authority may be obliged to provide such services itself. Sometimes neighboring ports can share tugboat services to reach volumes sufficient to sustain a commercial operator which is not possible practically here in Bangladesh, since other ports are not so close to any of the sea port.

4.5 Mooring Services

A mooring refers to any permanent structure to which a vessel may be secured. Examples include quays, wharfs, jetties, piers, anchor buoys and mooring buoys. A ship is secured to a mooring to forestall free movement of the ship on the water. An anchor mooring fixes a vessel's position relative to a point on the bottom of a waterway without connecting the ship to shore. Mooring, therefore, refers to the act of attaching a ship to a mooring structure. In MPA, the mooring services are a part of the port authority and under the control of harbormaster also serves as head of the pilotage services.

4.6 Vessel Traffic Services

A vessel traffic system (VTS) is a marine traffic monitoring system established by harbor or port authorities, similar to air traffic control for aircraft. Typical VTS systems use radar, closed-circuit television (CCTV), VHF radio-telephony and automatic identification system to keep track of vessel movements and provide navigational safety in a limited geographical area.

4.7 Aids to Navigation

An aid to navigation (AtoN) is a device or system external to a vessel that is designed to enhance the safe and efficient navigation of the vessel such as lighthouses, buoys, beacons, lights, leading marks and radio position fixing systems.

Like other national maritime authority, the responsibility for aids to navigation is in the hand of Mongla Port Authority within port approaches and in port areas. The provision and maintenance of buoys and beacons are contracted out with close supervision by MPA officers. Because aids to navigation are generally part of an integrated maritime infrastructure, the costs of providing these services are included in the general port dues. Mongla port has only one very old buoy laying vessel to provide aids to navigation services necessary of safe passages of different incoming and outgoing ships.

4.8 Other Marine Services

Generally, emergency response services are carried out by a variety of public organizations such as the port authority (harbormaster), fire brigade, health services and police. Some ports have sophisticated tools available to aid in crisis management, such as prediction models for gas clouds. Such tools are often integrated in a traffic center of the local vessel traffic management system (VTMS). Other than above emergency services, vessels resting in outer anchorage or in the harbor area needs emergency medical services and needs supply of drinking water for the crew or might be under fire. For the purpose, all sea ports must have ambulance ship and also water carrying barge to provide the respective services to the incoming and outgoing ships as well as tugboat or patrol boats with firefighting options. However, MPA has fire-fighting tug and water barge but no ambulance ship till now. MPA does not have any waste collection vessels or any reception facilities too.

4.9 Dredging of the Harbor and Waterway

Dredging operations to keep the port channel navigable by a port authority is of utmost importance. Often, the port authority or the competent maritime administration does not have enough expertise to exercise sufficient control over both maintenance and capital dredging. Port authorities with large water areas under their control should employ sufficient competent personnel to prepare dredging contracts and oversee dredging operations. Sounding is an activity that should preferably be carried out (or contracted out) by the port authority itself. Dredging is usually carried out by private dredging companies. It might be cost effective for some ports to use their own dredges, especially when continuous and important maintenance dredging is required. For the large quantity of dredging, MPA employs competent contractors though they have their own cutter suction dredgers to carry out maintenance dredging in the Passur channel.

5.0 MARINE SERVICE VESSELS NEEDED BY A SEAPORT

Port operations are a necessary tool to enable maritime trade between business partners. To ensure smooth port operations and to avoid congestion in the harbor it is inevitable to permanently improve the port's physical infrastructure, invest in human capital, fostering connectivity of the port and upgrade the port operations to prevailing standards. Hence, port operations are regulated by a number of policies, reforms and regulations that influence the infrastructure and operations of port facilities including different marine services.

There is a variety of marine services which are being provided by a maritime port as well as there are some compulsory marine related responsibilities of a sea port according to IMO and UNCLOS guidelines as mentioned before. A sea port needs a number of different types of marine service vessels with different capacities as per the handling capacities of the port. The list of various types of marine service vessels providing different marine services as well as other services to ensure safe, secured and environment friendly services to port users, ships and other stake holders by a sea port according to IMO and UNCLOS requirement have been presented in Table 1.

Table 1: List of Marine Service Vessels needed by a Sea Port according to IMO and UNCLOS requirement

Sl No.	Type of Vessels	Sl No.	Type of Vessels
1	Escort, towing and ship handling tug	12	Mooring boat
2	Fire-fighting tug	13	Pilot boat
3	Buoy Laying Vessel	14	Dispatch Vessel
4	Search and Rescue vessel	15	Self-propelled Water supply barge
5	Security Patrol boat	16	Ambulance Vessel
6	Navigation and Hydrographic Survey & Research Vessel	17	Inspection vessel
7	Oil Spill Management vessel	18	Cutter Suction Dredger
8	MARPOL Waste/ Garbage Collection Fleet & Reception Facility	19	Work Boat
9	Wreck Removal/ Floating Crane ship	20	Crane boat
10	Trailing Suction Hopper Dredger	21	House Boat
11	Salvage Ship	22	Training Vessel

6.0 REVIEW OF THE STATUS OF EXISTING MARINE SERVICE VESSELS OF MPA

It has been already mentioned that a maritime port has to provide a number of marine services as per requirements of IMO guidelines which on the other hands requires a number of different types of marine service vessels. The performance as well the efficiency of providing these marine services to incoming and outgoing ships to the port depends mostly on the availability and performance of the marine services vessels. It has been learnt that from the beginning of its activities, 32 (thirty two) numbers of different types of marine service vessels were acquired by MPA at different time from which 6 (six) vessels are obsolete now. The types of vessels are; tugboat, mooring boat, pilot boat, dispatch launch, survey vessel, self-propelled water barge, dredger, workboat, crane boat, house boat, inspection launch, buoy laying vessel, oil spill management vessel and fire-fighting tug. Table 2 shows the list, age and present status of different marine service vessels of Mongla Port Authority.

We can see that Mongla port, itself, is providing the tugboat services to different incoming and outgoing ships, since there is

no involvement of private sector in any of the maritime port of the country for the same. Generally, if the size of vessel traffic is not sufficient to support a tugboat service on a commercial basis, private sector does not come up and as a result, a port authority may be obligated to provide such services itself. Sometimes neighboring ports can share tugboat services to reach volumes sufficient to sustain a commercial operator which is not possible practically here in Bangladesh, since other ports are not so close to Mongla port. There are 6(six) tugboats of MPA including one firefighting tug. However, M.T Mehgdoot is 73 years old and is not providing any services now.

It is also seen that Mongla port has its own pilotage and mooring services and has few pilot boats and mooring boats to provide pilotage and mooring services to different incoming and outgoing ships. However, these are not being considered adequate in view of the necessity of fast movement and the increased port area. Like other national maritime authority, the responsibility for aids to navigation is in the hand of Mongla Port Authority within port approaches and in port areas. The provision and maintenance of buoys and beacons are not contracted out and are carried out by MPA Marine Department. Because aids to navigation are generally part of an integrated maritime infrastructure, the costs of providing these services are included in the general port dues. However, it is seen from Table 2 that there is only one buoy laying vessel of MPA which is 33 years old.

It is also seen from the Table 2 that there are two dispatch launches and one inspection launch which are very old and lifetime has already expired. The dispatch launch are used to carry pilot form the port to the pilot station in the Akram Point and also carry out delivery of different necessary items in case of emergency. The inspection launch is used for inspection of any marine establishment as well as channel condition by the officials of the port. There is one survey boat and two self-propelled water barges (one is non-working) in the fleet too. The only old survey boat serves the necessities of surveying in the

Table 2: Information on Existing Marine Service Vessels of MPA

Sl No.	Name of the Vessel	Type of the Vessel	Country of Manufacture	Year of Build	Life Span (Year)	Present Condition
1	M T Meghdut	Tug Boat	USA	1942	73	Active
2	M V Sarathi-2	Tug Boat	KSY, BD	1973	44	Active
3	M V Sarathi-1	Tug Boat	JAPAN	1973	44	Non-working
4	M T Shibsha	Tug Boat	GERMANY	1983	34	Inactive
5	M T Chandana	Tug Boat	INDIA	2015	2	Active
6	F FT Agniprohori	Fire Fighter Tug	BELGIUM	1979	38	Active
7	M L Usha	Pilot Boat	USA	1967	50	Active
8	M L Urmee	Pilot Boat	USA	1967	50	Active
9	M L Gangchil	Pilot Boat	NWML,BD	2013	5	Active
10	M L Mayurpankhi	Pilot Boat	NWML	2013	5	Active
11	Chalna Pilot-1	Pilot Boat	HOLLAND	1980	37	Non-working
12	M L HIra	Mooring Boat	USA	1967	50	Active
13	M L Moti	Mooring Boat	USA	1967	50	Active
14	M L Mukta	Mooring Boat	USA	1967	50	Active
15	M L Panna	Mooring Boat	KSY, BD	2003	14	Active
16	M L Kanti	Work Boat	-	1979	38	Scrapped
17	M L Mohua	Work Boat	-	1977	40	Scrapped
18	S P Ruhi	Self-Propelled Water Craft	DEW,BD	1980	37	Inactive
19	M V Trishna	Self-Propelled Water Barge	KSY, BD	2004	13	Active
20	M L Rajhongsha	Dispatch Launch	USA	1968	49	Active
21	M L Balaka	Dispatch Launch	USA	1968	49	Active
22	M L Jhnuk	Inspection Launch	KSY, BD	1983	34	Active
23	B L V Malancha	Buoy Laying Vessel	GERMANY	1984	33	Active
24	M L Anushandhani	Survey Vessel	DEW, BD	1997	20	Active
25	C D ImmamBukhari	Dredger	NWML	2013	4	Active
26	C D ImmanShafi	Dredger	INDIA	2015	2	Active
27	C D Ballian	Crane Boat	NWML	2013	4	Active
28	House Boat	House Boat	NWML	2013	4	Active
29	M L Annesha	Work Boat	DEW,BD	1979	38	Active
30	Dolphin-1	Work Boat	INDIA	2015	2	Active
31	Dolphin-2	Work Boat	INDIA	2015	2	Active
32	Oil Spill Management Vessel	Oil Spill Management Vessel	Finland	2018	0	Active

Note: There are in total 32 nos. of marine service vessels in MPA at present, out of which 6 nos. are obsolete, the rest 26 nos. as shown above are operating at the moment.

port channel as and when required and the only workable water barge fulfills the requirement of drinking and fresh water of the incoming ships to the port.

M V Sarathi-1

Chalna Pilot-1

Figure 3: Photograph of two Non-working Vessels of Mongla Port

We know that vessels of 9.0 m, 8.0 m and 7.0 m loaded draught can take berth in the anchorage, mooring buoys and jetties respectively. In the Passur channel the draught varies between 4.9 m to 6.1 m. There is continuous requirement of dredging of the channel and the berths. In view of the same, MPA has procured two numbers of cutter suction dredgers to carry out maintenance dredging of the channel and jetty areas including necessary crane boats, house boats and other accessories. However, MPA did not have any Trailing Suction Hopper Dredger which is the most suitable means for channel and outer anchorage dredging of Mongla Port. MPA has also few work boats which are used for different support services, though two of the same are non-working now.

The control of dangerous goods for maritime cargoes is usually performed by a specialized branch of any maritime port authority. The same goes for the handling of dangerous goods in port terminals. Oversight and regulation of land transport of dangerous goods is normally a responsibility of the government. The highly sensitive and technical nature of this work makes it close monitoring by customs department and coastguard as well as port authority. But MPA does not have any specialized security patrol boat at present, though port patrol services are part of the harbormaster's resources and therefore, are managed by MPA. As mentioned before, MPA has two dispatch launches, one inspection launch and one survey vessel in its fleet.

Waste management services in modern ports are under strict control of the port authority. Proper waste management can be expensive for shipping lines. With high costs, ship captains might be tempted to dump waste into the sea or into port waters. Control of such dumping practices is extremely difficult, especially for chemical cargoes. However, there are no vessels for waste management services and port reception facilities at Mongla port at the moment though according to IMO requirement, waste management and oil spill management vessels are very much necessary for a port. Indeed, an oil spill management vessel has been procured recently, which is not adequate for the purpose.

Table 3 gives a summary of different types of marine service vessels of Mongla Port Authority categorized based on their ages. It is seen from the same Table 3 that the age of the oldest vessel is 74 (seventy four) years and there are 8 (eight) number of vessels from 49 to 50 years old and few others are more than 30 years old.

It is also seen from Table 3 that out of 32 (thirty two) vessels, 19 (nineteen) vessels are more than 30 years old, 12 (twelve) vessels are less than 15 years of age and one vessel is between 15 to 30 years. Therefore, it is very much necessary to replace 20 (twenty) numbers of old vessels since it seems that using these vessels might cause danger any time.

Table 3: Summary of Different Types of Marine Service Vessels of Mongla Port Authority

Sl No.	Type of Marine Service Vessels of MPA	Existing Marine Service Vessels	Existing Non-operating Vessels	Vessels with more than 30 years old	Existing Vessels to be replaced	Existing Vessels to be used
		(Nos.)	(Nos.)	(Nos.)	(Nos.)	(Nos.)
1	Escort, Towing and Ship Handling Tug	5	2	4	4	1
2	Fire-fighting Tug	1	-	1	1	-
3	Buoy Laying Vessel	1	-	1	1	-
4	Survey & Research Vessel	1	-	-	1 (20 years old)	-
5	Oil Spill Management Vessel	1				1
6	Mooring Boat	4	-	3	3	1
7	Pilot Boat	5	1	3	3	2
8	Self-propelled Water Supply Vessel	2	1	1	1	1
9	Inspection Vessel/Launch	1	-	1	1	-
10	Dispatch Launch	2	-	2	2	-
11	Cutter Suction Dredger	2	-	-	-	2

7.0 ASSESSMENT OF THE MARINE SERVICE VESSELS REQUIREMENT FOR MPA

Ports not only play as a link in transportation for interchange, but they function as self-sustaining industry that is linked with domestic and international trade. At some places, they also act as foreign exchange earner not only in the form of transshipment or hub port but as part of supply chain management by providing logistics services to the industry. That is why a port needs to be treated as an industry when it is being planned. The planning of a port should not only be concerned by simply demand and supply of throughput but more than that of institutional framework, application of technology, marketing strategy, handling capacity and ultimately economic impact analysis for the development and implementation of a huge project. It may be through expansion of an existing port or may be a green field project. It is very difficult to develop a single typology for all types of port; rather it can be tried to cover generic features of ports that apply to all classes of ports. According to the Port Reform Tool Kit of World Bank [10], the total port assets have been classified into four parts such as Basic Port infrastructure, Operational Port Infrastructure, Port Superstructure and Port Equipment. Among them, *port equipment* as listed, are to support the operation and maintenance of the port operations. Due consideration should be given to plan for those equipment, since those equipment assist

in the successful and efficient operation of a port. For instance, the cargo handling equipment at a fully automatic terminal of Rotterdam port greatly improves the productivity of the port. But again there needs to be a tradeoff between the capital cost of that equipment and manpower cost and the revenue collection by the port. Anyway, through technological improvements and advances like ship/shore and cargo handling equipment, the efficiency of a port throughput improves. The relevant port equipment as listed in Port Reform Tool Kit-16 is as follows:

- Tugs
- Line handling vessels
- Dredging equipment
- Ship/ shore handling equipment
- Cargo handling equipment (apron and terminal)

On the other hand among others a Port Plan includes:

- Search and Rescue operation
- Oil Spill Contingency
- Media
- Civil Unrest
- Grounding of vessel
- Sinking of vessel
- Fire protection and prevention
- Pollution mitigation and control
- Air pollution (Toxic cloud)
- Chemical spillage mitigation
- Bomb threat / terrorism
- Medical emergency
- Hazardous substances washed ashore
- ISPS

From the above discussion, it is seen that in order to implement a proper port planning procedure, different types of marine service vessels are necessary, which are the parts of port operational infrastructures as well as port equipment [16]. In view of the same, Table 4 has furnished a list of different marine service vessels needed by a modern maritime port to provide safe and efficient marine services as per IMO requirement as well as the existing vessels of MPA.

Table 4: Required Different Types of Marine Service Vessels for a Seaport and the Existing Different Service Vessels of MPA, which can be used further

Sl No.	Type of Marine Service Vessels	Useable Service Vessels (Nos.)	Sl No.	Type of Marine Service Vessels	Usable Service Vessels (Nos.)
1	Escort, Towing and Ship Handling Tug	1	13	Pilot Boat	2
2	Fire-fighting Tug	-	14	Pilot Mother/ Dispatch Vessel	-
3	Buoy Laying Vessel	-	15	Self-propelled Water Supply Vessel	1
4	Search and Rescue Vessel	-	16	Ambulance Vessel	-
5	Security Patrol Boat	-	17	Inspection Vessel/ Launch	-
6	Survey & Research Vessel	-	18	Dispatch Launch	-
7	Oil Spill Management Vessel	1	19	Training Vessel	-
8	Waste Collection Fleet & Reception facilities		20	Cutter Suction Dredger	2
9	Wreck Removal/ Floating Crane ship	-	21	Work Boat	2
10	Trailing Suction Hopper Dredger	-	22	Crane boat	1
11	Sand Carrier		23	House Boat	1
12	Mooring Boat	1	24	**Total**	**12**

Note: Marine Service Vessels of more than 15 (fifteen) years of age have not been considered, since these needs immediate and gradual replacement.

From Table 4, it is seen that MPA is far behind the required different types of marine service vessels to become a modern port and to provide necessary marine services to incoming and outgoing ships in the port. MPA needs adequate numbers of tugboat including fire-fighting tug, buoy laying vessel, search and rescue vessel, security patrol vessel, survey and research vessel, waste collection vessel, wreck removal or salvage ship, trailing suction hopper dredger, pilot mother vessel/dispatch vessel and ambulance ship.

8.0 ASSESSMENT OF THE REQUIRED NUMBER OF MARINE SERVICE VESSELS

It is found that cargo throughput, container throughput and the ships call at Mongla port is increasing gradually [17]. Therefore, in order to provide necessary marine services the number of marine service vessels should also be increased simultaneously with the number of ships call as well as cargo and container throughput. Figures 4 to 7 shows the number of marine service vessels of MPA with the ship call, cargo throughput and container throughput in recent years.

It is seen from Figure 4 that number of cargo ships call is increasing gradually from 2007 as well as cargo throughput increases sharply though the number of marine service vessels did not increase at all.

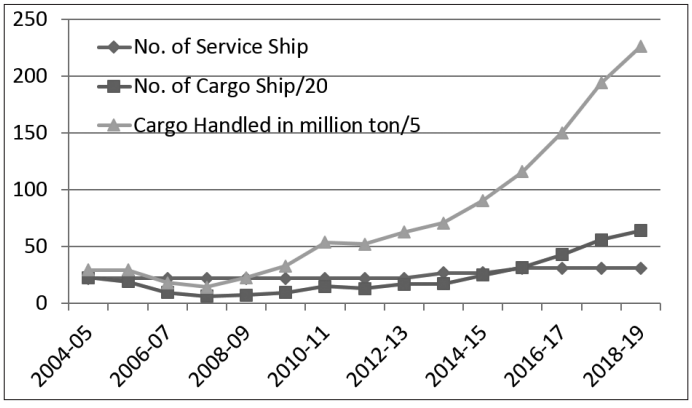

Figure 4: Variation of Marine Service Vessel, Cargo Ship and Cargo throughput

It is seen from Figure 5 that number of container ships call is increasing gradually from 2011-12 as well as container throughput also increases enormously though the number of marine service vessels are increasing in a very slower rate. However, from 2013-14 container ships-call drops sharply as well as container throughput drops gradually.

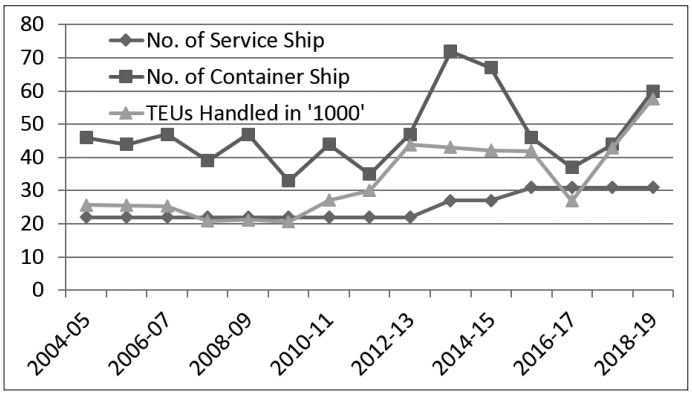

Figure 5: Variation of Marine Service Vessel, Container Ship and Container throughput

It is seen from Figure 6 that number of total ships call is increasing gradually from 2007-08 as well as total cargo throughput also increases sharply and the number of marine service vessels also increases slightly.

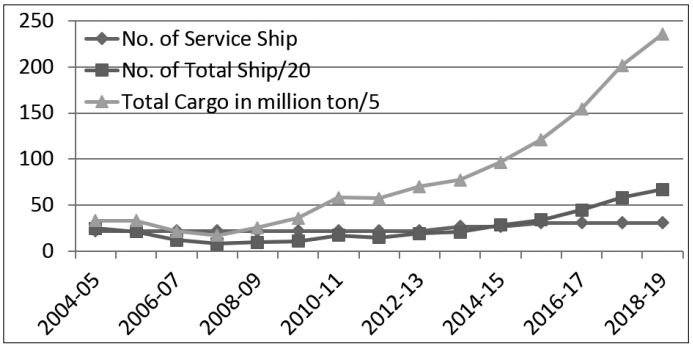

Figure 6: Variation of Marine Service Vessel, Total Ship and Total throughput

Figure 7 shows the future prediction of cargo ship call at MPA and also the prediction of marine service vessel requirement at same rate of increase of cargo ship call. It is assumed that the number of service vessels at 2015 is 25, which are providing services at present though 12 vessels are more than 30 years old and need replacement. It is seen that the number of marine service vessel requirements in 2020 are 26 with assumption of same rate of increase of marine service vessels with the increase of cargo ship and 26 with the rate of increase of service vessel as 50% rate of increase of cargo ship. Therefore, if we assume the rate of increase of service vessel as the 50% rate of increase

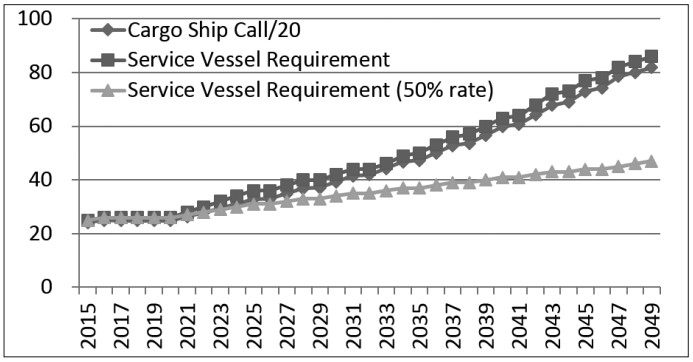

Figure 7: Requirement of Marine Service Vessels with Cargo Ship forecast

of container ship, MPA needs 1 more new service vessel and 12 vessels need to be replaced within 2020. The numbers of service vessel requirements in 2030 are 42 and 34 respectively with assumption of same rate of increase of marine service vessels as the increase of cargo ship and the rate of increase of marine service vessels as 50% rate of increase of cargo ship. Therefore, if we assume the rate of increase of marine service vessels as the 50% rate of increase of cargo ship, MPA needs 1 more marine service vessel within 2020 and MPA needs 9 more marine service vessels within 2030. However, 13 numbers old vessels need to be replaced gradually.

Figure 8 shows the future prediction of cargo throughput at MPA and also the prediction of marine service vessel requirement at the same rate of increase of cargo throughput. As mentioned before, it is assumed that the number of marine service vessels at 2015 is 25. It is seen that the number of marine service vessel requirements in 2020 are 36 and 31 respectively with assumption of same rate of increase of marine service vessel as the increase of cargo throughput and the rate of increase of marine service vessel as 50% rate of increase of cargo throughput. The numbers of service vessel requirements in 2030 are 61 and 41 respectively with assumption of same rate of increase of marine service vessels as the increase of cargo throughput and the rate of increase of marine service vessel as 50% rate of increase of cargo throughput. Therefore, if we assume the rate of increase of marine service vessels as the 50% rate of increase of container throughput, MPA needs 6 more marine service vessels within 2020 and MPA needs 15 more marine service vessels within 2030. However, thirteen (13) numbers of old vessels have to be replaced as mentioned before gradually.

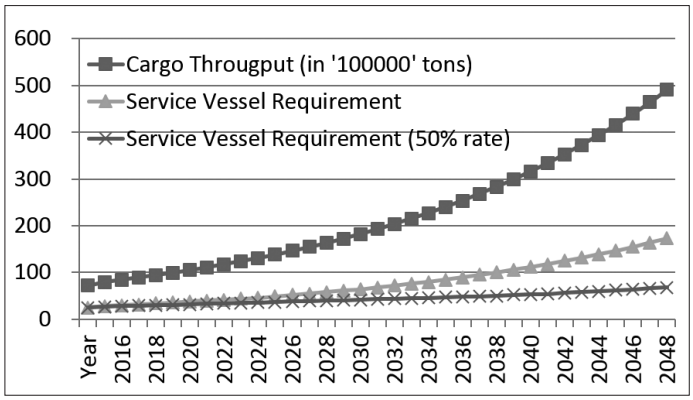

Figure 8: Requirement of Marine Service Vessels with Cargo Throughput forecast

Figure 9 shows the future prediction of container ship call at MPA and also the prediction of marine service vessel requirements at the same rate of increase of container ship call. It is assumed that the number of marine service vessel at 2015 is 25, which are providing services at present though 12 vessels are more than 30 years old and need replacement. It is seen that the number of marine service vessel requirements in 2020 are 133 and 65 respectively with assumption of same rate of increase of marine service vessels with the increase of container ship and the rate of increase of marine service vessel as 50% rate of increase of container ship. Therefore, if we assume the rate of increase of marine service vessel as 50% rate of increase of container ship, MPA needs 40 more marine service vessels within 2020. The

numbers of marine service vessel requirements in 2030 are 314 and 100 respectively with assumption of same rate of increase of marine service vessels as the increase of container ship call and the rate of increase of marine service vessel as 50% rate of increase of container ship call. Therefore, if we assume the rate of increase of marine service vessels as the 50% rate of increase of container ship call, MPA needs 40 more marine service vessels within 2020 and 75 more marine service vessels within 2030.

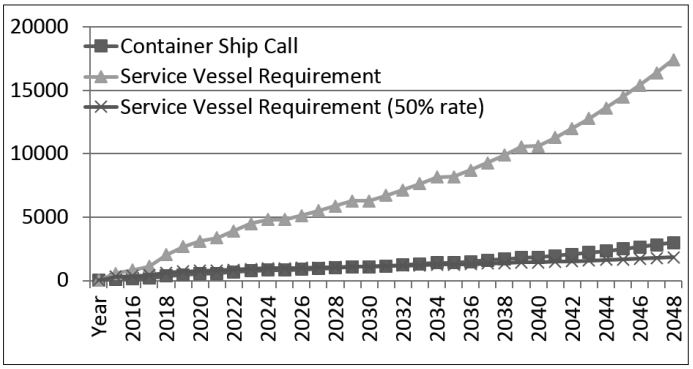

Figure 9: Requirement of Marine Service Vessels with Container Ship forecast

Figure 10 shows the future prediction of container throughput at MPA and also the prediction of marine service vessel requirement at same rate of increase of container throughput. As mentioned before, it is assumed that the number of marine service vessel at 2015 is 25 as mentioned before. It is seen that the number of marine service vessel requirements in 2020 are 134 and 65 respectively with assumption of same rate of increase of marine service vessel as the increase of container throughput and the rate of increase of marine service vessel as 50% rate of increase of container throughput. The numbers of marine service vessel requirements in 2030 are 393 and 113 respectively with assumption of same rate of increase of marine service vessel as the increase of container throughput and the rate of increase of marine service vessel as 50% rate of increase of container throughput. Therefore, if we assume the rate of increase of marine service vessel as the 50% rate of increase of container throughput, MPA needs 10 more marine service vessels within 2020 and 88 more marine service vessels within 2030.

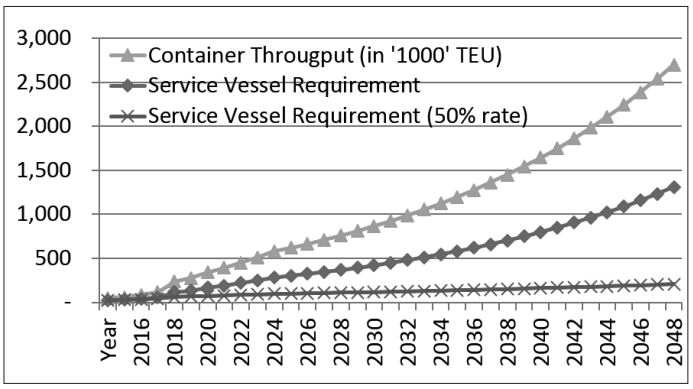

Figure 10: Requirement of Marine Service Vessels with Container Throughput forecast

Figure 11 shows the future prediction of total ship call at MPA and also the prediction of marine service vessel requirement at same rate of increase of total ship call. It is assumed that the number of marine service vessel at 2015 is 25, which are providing services at present though 12 vessels are more than 30 years old and need replacement. It is seen that the number of marine service vessel requirements in 2020 are 42 and 33 respectively with assumption of same rate of increase of marine service vessels the increase of total ship call and the rate of increase of marine service vessel as 50% rate of increase of total ship call. Therefore, if we assume the rate of increase of marine service vessel as the 50% rate of increase of total ship call, MPA needs 8 more new vessels and 13 replacements within 2020. The numbers of marine service vessel requirements in 2030 are 81 and 45 respectively with the assumption of same rate of increase of marine service vessel as the increase of total ship call and the rate of increase of marine service vessel as 50% rate of increase of total ship call. Hence, if we assume the rate of increase of marine service vessels as the 50% rate of increase of total ship call, MPA needs 10 more marine service vessels within 2020 and MPA needs 12 more marine service vessels within 2030. Moreover, 13 numbers of old vessels have to be replaced as before gradually. **Therefore, total number of new marine service vessels requirement is 23 by 2020 and 12 more by 2030.**

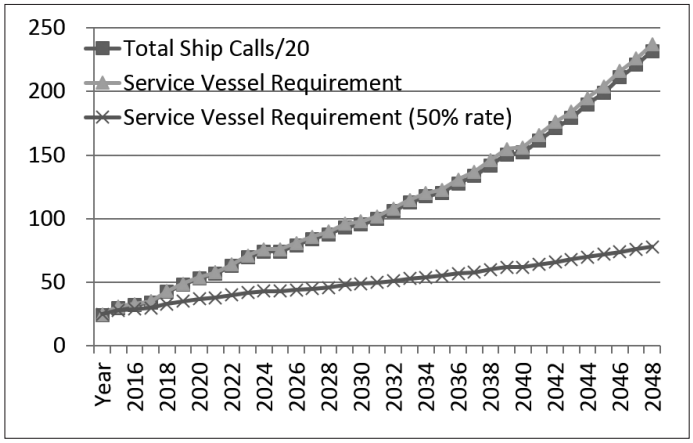

Figure 11: Requirement of Marine Service Vessel with Total Ship forecast

It is to be mentioned that since the marine service vessels will provide services to the incoming and outgoing ships not the containers, therefore, it is wise to assess the future requirement based on the total ship call, not the total cargo or container throughput. In view of the same, the necessary marine service vessels to be procured by MPA within 2020 and 2030 have been presented in Table 5.

Table 5: List of the Existing Usable Marine Service Vessels of MPA and Required Number of different Type of Similar Vessels according to IMO Guidelines

Sl No.	Type of Marine Service Vessels	Usable Service Vessels (Nos.)	New Vessel Requirement By (Nos.)	
			2020	2030
1	Escort, Towing and Ship Handling Tug	1	2	1
2	Ship Handling Small tug	-	1	1
3	Buoy Laying Vessel	-	1	1
4	Search and Rescue Vessel	-	1	-
5	Security Patrol Boat	-	2	-

6	Survey & Research Vessel	-	1	1
7	Oil Spill Management Vessel	1	2	-
8	Waste Collection Fleet & Reception facilities including ancillary vessels and accessories	-	1	1
9	Wreck Removal/ Floating Crane ship	-	1	-
10	Trailing Suction Hopper Dredger	-	1	1
11	Sand Carrier		2	1
12	Mooring Boat	1	1	1
13	Pilot Boat	2	1	2
14	Pilot Mother/ Dispatch Vessel	-	1	1
15	Self-propelled Water Supply Vessel	1	2	-
16	Ambulance Vessel	-	1	-
17	Training Vessel	-	1	-
18	Dispatch Launch	-	-	-
19	Inspection Vessel	-	1	-
20	Cutter Suction Dredger	2	-	-
21	Work Boat	2	-	1
22	Crane boat	1		-
23	House Boat	1		-
	Total	**12**	**23**	**12**

Note: Vessels of more than 15 (fifteen) years old has not been considered, since these needs replacement.

9.0 PROCUREMENT PLAN

Procurement Planning is one of the most important steps in the public procurement cycle. The procurement plan is expected to list all the requirements that are under the responsibility of a particular procurement entity and that are expected to be procured over a period of time. There are instances where some items that are below a certain monetary threshold are not listed on the procurement plan. However, effort should be made to have everything that a particular procurement entity is responsible for procuring listed on the procurement plan of that procurement entity. The procurement plan should also be updated regularly (if required), but constant updating should be avoided. The fact that the procurement plan needs updating is an indication that it is not expected to be a static document. This, however, should not lessen the importance of procurement planning as the primary tool used for triggering procurement actions. This means that all procurement actions taken by a particular procurement entity should be guided by an approved procurement plan.

The procurement plan isn't only useful for determining what needs to be procured and by when, but it's also for determining the need for additional manpower to support the preparation of specifications and bid documents, requesting, receiving and evaluating offers, contract negotiation, award and administration and the number of procurement requirements within a certain period of time. Once the procurement plan is prepared and approved after allocation of funds and consolidation (bundling) of similar requirements to attract a broader pool of supplies and for economies of scale, it should only be allowed to change through approved amendments and all requirements procured by the responsible procurement entity should be found on the approved procurement plan. Only for exceptional reasons should a particular procurement shall be allowed to commence without being listed on the approved procurement plan or on an approved amendment of the procurement plan.

In order to fulfill its statutory aims and tasks in providing navigation safety in Mongla seaport and the approaches and to provide services to incoming ships as well as to ship owners in seaport waters, MPA should plan to procure the following marine service vessels by 2020 as shown in Table 6 for necessary purposes.

Table 6: Procurement Plan for Marine Service Vessels for MPA

First Phase under DPP-1: (3) • Waste Collection Fleet & PRF-1 • Oil Spill Management Vessel-2	First Phase under DPP-4: (4) • Ambulance Vessel • Training Vessel • Security Patrol Boat • Self-propelled Water Supply Vessel
First Phase under DPP-2: (7) • Escort, Towing and Ship handling/ Fire-fighting Tug • Pilot Mother/ Dispatch Vessel • Search and Rescue Vessel • Survey & Research Vessel • Buoy Laying Vessel	First Phase under DPP-5: (5) • Inspection Vessel • Security Patrol Boat • Mooring Boat • Self-propelled Water Supply Vessel • Pilot Boat
First Phase under DPP-3 (1) • Wreck Removal/ Floating Crane ship	First Phase under DPP-6: (3) • Trailing Suction Hopper Dredger • Sand Carrier (2)

For the procurement of rest 12 (twelve) Marine Service Vessels by 2030, DPP can be prepared considering the immediate requirement and suitable combination at that time.

10.0 CONCLUSIONS AND RECOMMENDATIONS

Mongla Port is one of the principal maritime ports of Bangladesh. Even if, in theory, there should be a ratio of 60% – 40% handling of maritime trade between Chittagong and Mongla, the reality is far from that with Chittagong currently totalizing 90% of the country's international trade. Mongla Port has the capacity to handle 6.5 million M. tons of cargo and 50,000 TEUS of container per year. In the year 2009-10, 1.65 million M. tons of cargo and 20,500 TEUS of container were handled. That means, the present capacity of this port is not fully utilized.

In Bangladesh, the industries are located in and around Dhaka-Chittagong. The business community of Dhaka and its surrounding areas is less interested to import and export their cargo through Mongla Port because of lack of fair road and bridge connections. The present government has given emphasis for the development of Mongla Port and pushes the construction of the Padma Bridge at Mawa point. When Padma Bridge will be operational, the distance from Dhaka to Mongla will be 170 km. So, the business community of Dhaka and its surrounding areas will be more interested to use Mongla Port for importing & exporting cargos as the transportation distance from Dhaka to Mongla will be shorter than Dhaka to Chittagong.

At present, jute and jute goods, frozen cargo and other general cargo are exported from Mongla port. Moreover, import of heavy machinery and equipment, fertilizer, food grain, sugar,

motor vehicles, raw materials of industry, etc. through Mongla Port will increase. As a matter of consequence, the act of establishing different types of new industries in the south-western part of the country, scope of huge employment, expansion of trade and business and overall activities of Mongla Port will increase and develop rapidly. Nevertheless, in connection with the sub-regional discussions ongoing with the Indian, Nepalese and Bhutanese governments aiming at developing regional operational corridors, it seems that the current government has decided to start again the development of the Mongla port. A 2-phased development plan has been drafted and is about to be funded by the national authorities and senior management was appointed in this regard.

In view of the fulfillment of mandated responsibilities of Mongla port with specific emphasis to faster and adequate marine services to the incoming and outgoing ships and also to enhance surveillance, security patrol, emergency transportation and search and rescue operation, the study has been carried out. The marine services provided by MPA have been studied with special emphasis to the services to be provided according to IMO and UNCLOS requirement and a procurement plan has been proposed which will facilitate the requirement of procurement of necessary marine service vessels to render mandated marine services of MPA to different incoming and outgoing ships to the port.

It is recommended that in order to improve the quality of marine services to be provided as per requirement of IMO and UNCLOs, MPA should procure different types of 35 (thirty five) numbers of marine service vessels as proposed in the procurement plan in the previous section. For the procurement of rest 12 (twelve) marine service vessels by 2030, procurement plan can be prepared considering the immediate requirement and suitable combination at that time.

It is pertinent to mention that the research has potential limitation. The number of marine service vessels is identified based on the trade and traffic prospects, which is mainly considered from some previous studies and the recent performance statistics of the port. Even though infrastructure is one of the main reasons for using the Chittagong Port instead of Mongla but the users of the port that is the trading communities have their reason. An investigation of users' choice through primary data collection will provide a better understanding of the port sector development of the country. ■

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PROFILES

DR M REAZ H KHODOKER, PEng, is a Professor in the Naval Architecture and Marine Engineering Dept, Military Institute of Science and Technology, Mirpur, Dhaka, Bangladesh. He is also serving as Visiting Professor (Part-time) in Master in Port & Shipping Management and Master in Maritime Science, Bangbandhu Sheikh Mujibur Rahman Maritime University, Pallabi, Mirpur-12, Dhaka, Bangladesh.

He was a Professor in the Dept. of Naval Architecture and Marine Engineering, BUET and served as the Head of department for 2(two) years from 2001 to 2003. He was also the Chairman of Bangladesh Inland water Transport Authority (BIWTA) during 2004 to 2006.

He was also involved in a number of professional, advisory and consulting activities like Editor of Journal, Keynote speaker in a number of National and International Seminars, Key Consultant in a number organizations (BIWTA, BIWTC, CPA, MPA, etc.) and projects under Government and World Bank. He was also advisor and consultant in a number of private organizations.

Email address: mr9hasan@gmail.com

KHANDAKER RASEL HASAN, is a PhD researcher at Australian Maritime College, University of Tasmania, Australia and an Assistant Professor, Department of Port and Shipping Management at Bangabandhu Sheikh Mujibur Rahman Maritime University (BSMRMU), Bangladesh. His research interest is port management, port logistics, supply chain management and shipping. Before joining the BSMRMU worked as Deputy Director (Planning) at Bangladesh Inland Water Transport Authority (BIWTA). He is a Member of Institute of Chartered Shipbroker, UK since 2009. He has numbers of research article published in international and national journals. He also worked at several projects funded by different of development partners including World Bank, JICA, DFID and ADB. He worked as a Short Term Consultant for World Bank, Dhaka Office from November 2018 to July 2020.

Email address: kraselhasan@gmail.com

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