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CONCRETE TECHNOLOGY – TOWARDS BETTER ENVIRONMENTAL SUSTAINABILITY

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Abstract
Concrete is a widely used construction material throughout the world and it is still in demand for future development of infrastructures. Extensive usage of concrete lead to huge consumption of non-renewable natural resources and energy; it is also responsible for emitting large amounts of carbon dioxide into the atmosphere which contributes to global warming. However, recent development in concrete technology has focused more towards environmentally friendly and sustainable practices. This paper reviews emerging concrete technology that will lessen the environmental effects of concrete usage such as the use of cement substitute materials (fly ash, rice husk ash, ground granulated blast furnace slag), and alternative aggregates from various industrial by-products. Other related technologies that could contribute to sustainable concrete industry are identified. Barriers in implementing the new emerging environmentally friendly concrete technologies are discussed such as the regulatory code of practices and various concrete standards and specifications. More research for better understanding of new concrete technology and tighter collaboration between researchers and regulatory bodies are needed to expedite the use of new concrete technologies which are more environmentalyl friendly by reducing natural resources consumption, energy and carbon dioxide emission.

Keywords: Concrete Technology, Cement Substitute Materials, Recycled Aggregate, Sustainable Development.

1. Introduction

Concrete is a widely used construction material throughout the world and has been the largest volume material used compared to other building materials. With the current rapid urbanization and industrialization process globally, the demand of concrete as building material has also increased rapidly. The global cement production has increased from 1.66 billion tonnes in 2000 to 3.06 billion tonnes in 2009 (U.S. Geological Survey 2010).

Extensive usage of concrete lead to huge consumption of non-renewable natural resources and energy, concrete industry today is the largest consumer of natural resources such as natural aggregates, limestone and fresh water. It is estimated that 8 billion tonnes of natural aggregates are used annually and approximately 1.5 tonnes of limestone is used to produce one tonne of Portland cement. The cement production is also responsible for emitting large amount of carbon dioxide to the atmosphere which contributes to global warming problem. For every tonne of Portland cement clinker produced, 1 tonne of carbon dioxide gas released to the atmosphere. The concrete industry alone responsible for 7% of the world carbon dioxide emission (Malhotra 1999).

It is not likely that this trend will change in the near future since concrete has wide application, broad availability, low cost components, relatively low technologies required in preparing and handling (easy to prepare) and producing the final product that is strong durable stone-like material. All these features that concrete posses has made it difficult to be replaced by other materials.

However, recent development in concrete technology has focused towards more environmental friendly and sustainable practices. This paper highlights some of the emerging concrete technology that will lessen the environmental impact of concrete usage such as the use of cement substitute materials namely; fly ash, rice husk ash, ground granulated blast furnace slag and other pozzolanic materials. The use of alternatives aggregates such as recycled concrete and various industrial by-products, producing more durable concrete to enhance its service life, developing a lightweight concrete for certain application to minimize raw material usage and the introduction of new formulated cementitious binders.

2. Cement substitute materials

Substituting cement in producing concrete will decrease the carbon dioxide emission to the atmosphere. In the cement manufacturing process, the raw materials (limestone and others) will be heated up to 1500^{o}C in a rotating kiln. In this process, calcium carbonate (limestone) broke down to calcium oxide and carbon dioxide (CO_2);

$$CaCO_3 \xrightarrow[\Delta]{} CaO + CO_2$$

Calcium oxide (CaO) further reacts to produce cement clinker that than will be ground to fine particle. As we can see here, carbon dioxide gas released is part of the chemical process which is unavoidable. Therefore to reduce CO_2 emission, it is recommended that the cement usage must be minimised by the means of substituting it with alternative pozzolanic materials, especially those that are readily available by-products from various industrial processes.

There are many researches that report on successful substitution of cement. The use of fly ash, ground granulated blast furnace, silica fume or rice husk ash in concrete proven to be beneficial not just because it reduce cement usage (thus reducing carbon dioxide emission) but it is also recovers these industrial by-products and avoid disposal. Usage of these cement substitute materials also improves the durability of concrete produced.

Fly ash is one the most intensively explored material in concrete researches. This coal combustion by-product collected from power plant normally was disposed at landfill or by ponding and stockpiling. However various researches have shown that fly ash can be utilized in producing high performance concrete (Poon, Lam, and Wong 2000). High volume fly ash (HVFA) concrete where up to 60% of Portland cement replaced by fly ash produce concrete with higher compressive strength, excellent long term durability properties and higher resistance to chloride ion penetration (Bouzoubaâ, Zhang, and Malhotra 2000). The availability of fly ash is high, in 1992 there are 500 million tonnes of fly ash produced globally (Manz 1997) and the figure jump to 900 million tonnes in 2006 (Malhotra 2006). Despite the high availability of fly ash, the utilization of this material is very low; approximately only 7% from this figure was utilized in concrete industries.

Another widely used cement substitute material is ground granulated blast furnace (GGBF) slag. Blast furnace slag is a by-product of iron manufacturing process. It is estimated that, world production of GGBF slag in 2010 is between 230–270 million tonnes (U.S. Geological Survey 2012). GGBF can replace ordinary Portland cement up to 55% of its volume in concrete production (Shariq, Prasad, and Masood 2010). The benefits of using GGBF are; concrete produced have higher durability against alkali-silica reaction, chloride ingress, sulphate attacks and reduce the risk of reinforcement corrosion.

Beside the two materials mention above, the other man made pozzolan is silica fume. This material, a by-product in the reduction process of high purity quartz to produce silicon and ferrosilicon alloys, comes in the form of extremely fine particles. Silica fume is one of the most effective pozzolan, its usage will result in a very high compressive strength, very durable and very low permeability concrete (Shannag 2000). This material is available in limited quantity and at higher price compared to ordinary Portland cement, however, since the result is extremely satisfying, the investment will pay-off since the concrete structures produced is very durable and have a much longer service life.

Rice husk ash (RHA) is a by-product material obtained from the disposal of rice husk. It comes in the form of very fine particles which give high specific space area and contain non-crystalline silicon dioxide. This pozzolanic material when used in concrete will demonstrate significant improvement in mechanical and durability properties of concrete produced. RHA can replace up to 20% weight of ordinary Portland cement in concrete mixture (Givi et al. 2010).

3. Alternative Aggregates

Similar to substituting cement with industrial by-product, the use of alternative aggregates in concrete production will reduce the consumption of non-renewable raw material. There are two types of aggregates which are fine aggregates and coarse aggregates. Fine aggregates are normally river sands and coarse aggregates are crushed granite stone from quarry. Excessive river sand mining activity is a potential hazard to the environment and on the other hand, granite stone could be soon depleted. However, there are many aggregates replacement alternatives such as crush concrete from building demolition, broken glass (Taha and Nounu 2008), sanitary ceramic waste (Medina, Sánchez de Rojas, and Frías 2012), coconut shell (Gunasekaran, Annadurai, and Kumar 2012), reservoir sediments (Chen et al. 2012), bottom ash from coal combustion(Kim and Lee 2011) and foundry sand (Siddique and Singh 2011).

The most potential natural aggregate replacement is from construction and demolition (C&D) waste. It is estimated that more than one billion tonnes of C&D waste generated annually (Tam and Tam 2008). The uses of C&D waste either from natural disaster or building demolition projects are beneficial in economic and environmental sense. The usage of C&D waste has increased tremendously, mainly as road base and sub-base materials. In concrete application C&D waste can replace from 35% to 50% of natural aggregates (depending on the type of structure). Researchers conclude that recycled aggregates concrete is comparable to normal concrete in term of strength and durability (Tam and Tam 2008). Despite the successful usage of C&D waste in road construction and concrete there are still substantial amount of this materials being disposed in landfills. However, improvement in demolition techniques, processing, sorting and handling the C&D waste will improve the quality and lowering down the cost of recycled aggregates thus, making it more favourable to be used in the future.

4. Lightweight concrete

Lightweight concrete generally has relatively low mass density compared to normal concrete. According to the Draft International Standard Model Code for Concrete Construction (1977), the density of lightweight concrete is between 1200 to 2000kg/m^3. However, lower density concrete can be produced by using foamed concrete which as low as 300kg/m^3. This is because the coarse aggregate is omitted from the concrete mixture and the concrete mass is expanded with air. American Concrete Institute (1988) stated that lightweight concrete can be divided into three categories according to their density namely low (lower than 800kg/m^3), medium (800-1440kg/m^3) and high (1440-1900kg/m^3) .The low-density group normally has compressive strength between 0.35 to 6.9N/mm^2 and used as insulation material. Medium-density group has compressive strength between 6.9 to 17.3N/mm^2 and commonly used in non-structural concrete application. The high-density group has compressive strength exceeding 17.3 N/mm^2 and could be reaching up to 62.1N/mm^2 which can be used as structural material (Jones and McCarthy 2005). Beside suitable for certain structural application, further research on foamed concrete shows that it perform well in the marine environment (Alwi 2008). The use of lightweight concrete will reduce the consumption of non-renewable raw materials for aggregates and could be beneficial to the environment.

5. Enhancement of service life of concrete structures

Natural resources will be well preserved if the service life of a product is prolonged. In the concrete industry, if the building service life is design to reach 250 years instead of the conventional 50 years, the resource efficiency of concrete will be increase by five times (Mehta 2002). It is concluded that earlier practice of lowering initial cost and fast track construction method using cement that formulated to achieve high strength at early age causing the concrete structure begin to deteriorate at earlier than their designed service life (Mehta and Burrows 2001). This type of cement is prone to high thermal contraction and high drying shrinkage that will lead to cracking and loses of water-tightness earlier than the designated designed service life.

However currently there are many researches that focus on durability and enhancing concrete performance. Besides the new formulation to produce better concrete, recent awareness on proper maintenance, periodic inspection and evaluation will also lead to extending the service life of concrete structures. Repair work on concrete structures instead of removal and rebuild consume less natural resources and energy thus minimizes impact on the environment. It is important that when planning for development, life cycle cost approach is taken into consideration rather than just lowering initial cost but then suffering in repairing and replacing cost of the building in the future.

6. Other related technologies

There are other emerging technologies that will enhance the sustainability of concrete industry such as the new formulated cement Aether®. This Belite-rich cements containing calcium sulfo an aluminate and ferrite phase is develop by Lafarge. Aether® delivered similar performance to Portland cement but the manufacturing process emit 20–30% less CO_2 (Lafarge Group 2012).

Other low carbon cements that are being developed include Celitement and magnesium silicate cement. Celitement is developed by Karlsruhe Institute of Technology and able to reduce CO_2 emission up to 50% compared to the manufacturing process of the normal Portland cement (Stammermann et al. 2010). Magnesium silicate cement is developed by Novacem, a commercialization branch of Imperial College London. This cementitious binder was develop to obtain similar performance and cost as Portland cement but reduced CO_2 emission. By using magnesium silicate instead of calcium carbonate eliminate the release of CO_2 during raw materials processing. The lower temperature needed during the manufacturing process also contribute to further reduction of CO_2 emission and saving on fuels. In addition, Novacem cement absorb more CO_2 from the atmosphere throughout its service life than the CO_2 release during its manufacturing process thus making this cement a carbon negative material(Velandia et al. 2011).

7. Barriers in implementing new concrete technologies

Despite the various advancement and improvement in the concrete industry discussed earlier, the implementations of these innovations are rather slow and limited. Mehta (2002) identified three institutional barriers in implementing green technology concrete which are, construction business practice that focus on minimizing initial cost with speedy construction, outdated building codes that discourage the use of recycled materials and thirdly lack of holistic approach in education and research. The fast construction techniques adopted to increase profitability that normally practiced is proven not to be entirely true. Fast construction could lead to poor quality concrete which require costly repairs thus increasing the life cycle cost of the building.

Outdated building codes are normally prescriptive type specifications. This type of specifications limit the type and quantities of concrete ingredients and therefore the use of cement substitute materials and alternative aggregates are forbidden. However effort has been made to replace all this old prescriptive building codes with performance base codes. Performance specifications focus on the performance and function of the end products, the concrete mixture is flexible on the ingredients used and design mix but the concrete produced in the end must meet the performance criterion specified.

Other than the factors discussed earlier, to expedite the adoption of new green technologies by the industry or the end users, it is crucial to review the knowledge transfer mechanism, the training and education program and incentive program to beat conservatism among the industry players.

8. Conclusions

The concrete technology advancement has moving toward the right direction in contributing to the sustainable construction. Implementation of these technologies will reduce the consumption of non-renewable raw materials, reduce the CO_2 emission and better management of certain industrial by-products. Production of durable and long lasting concrete structures either will stabilise or decrease the concrete demand in the future thus making concrete a more sustainable building material. However, more works are needed to push these technologies to be adopted and implemented by actuators in the construction field. There are immediate needs to address this knowledge transfer gap issues and other barriers. More tightly collaboration between researchers, governing bodies, field actuators and users hopefully will expedite the implementation of these environmental friendly concrete technologies.

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PADANAN TABURAN KEBARANGKALIAN HALAJU ANGIN PANTAI TIMUR SEMENANJUNG MALAYSIA

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Abstrak
Tenaga angin adalah antara tenaga alternatif yang berpotensi untuk dikomersialkan bagi menggantikan sejumlah besar tenaga yang melibatkan pembakaran bahan api fosil. Keadaan angin di Malaysia tidak begitu berpotensi. Namun, beberapa kawasan dipercayai mempunyai potensi angin yang besar, terutamanya kawasan yang dilengkapi dengan solar panel yang sememangnya kaya di negara ini. Lokasi kajian iaitu Mersing (Johor Timur) dipilih bagi mewakili negeri Pantai Timur Semenenjung Malaysia. Keadaan tenaga angin dan sifatnya telah dikaji berdasarkan data yang dikumpul untuk tempoh enam tahun (2005-2010). Objektif utama kajian ini adalah untuk menganalisa data halaju angin yang boleh menggambarkan potensi tenaga angin di kawasan kajian sekaligus mengenalpasti suatu taburan terbaik yang dapat mewakili dan menganggarkan data daripada sesuatu kawasan kajian. Lima jenis taburan kebarangkalian yang dipadankan terhadap data kawasan kajian. Kaedah perhitungan yang terlibat bagi menentukan padanan terbaik adalah ujian Kolmogorv-Smirnov (Ks) serta tiga jenis pengukuran ralat. Penganggaran parameter dilakukan dengan menggunakan kaedah kebolehjadian maksimum. Berdasarkan keputusan yang diperoleh, padanan taburan kebarangkalian Frechet dapat mewakili data daripada kawasan kajian Mersing.

Kata Kunci: Potensi tenaga angin, halaju angin, taburan kebarangkalian, kebolehjadian maksimum.

Abstract
Wind energy is given a lot of attention because of the focus on renewable energy. Recently, wind energy conversion is given a serious consideration in Malaysia. The potential for wind energy generation in Malaysia depends on the availability of the wind resource that varies with specific location. In the present study, the wind energy potential of the location is statistically analyzed based on wind speed data, measured over six years period (2005-2010). The probability distributions are derived from the wind speed data and their distributional parameters are identified. Five types of probability distribution have been used to estimate the wind energy potential in Mersing (Johor Timur), the east cost of Malaysia. The goodness-of-fit tests are conducted to show that the distribution adequately fits to the data. Frechet distribution whose parameters are estimated using maximum likelihood estimator provide the best fits for the current location.

Keywords : Renewable energy, wind energy potential, wind speed, wind speed distribution

1. Pengenalan

Angin boleh didefinisikan sebagai pergerakan udara yang dipengaruhi oleh daya tekanan di atmosfera. Angin di Malaysia pada amnya lemah dan arahnya tidak menentu. Terdapat beberapa perubahan dalam corak tiupan angin tahunan di Malaysia. Walau bagaimanapun, corak tiupan angin yang paling jelas adalah kejadian angin monsun yang selalunya mempengaruhi aktiviti ekonomi penduduk di kawasan tertentu. Terdapat perubahan bertempoh dalam corak tiupan angin. Empat musim boleh dibezakan iaitu monsun barat daya, monsun timur laut dan dua musim peralihan monsun yang lebih pendek. Semasa musim-musim peralihan monsun, semasa palung khatulistiwa merentangi Malaysia, angin berkelajuan lemah dan arahnya berubah-ubah. Monsun barat daya biasanya bermula pada akhir bulan Mei atau awal bulan Jun dan tamat pada akhir bulan September. Angin lazim bertiup dari arah barat daya dengan kelajuan tidak melebihi 15 knot. Monsun timur laut bermula awal November dan berakhir pada bulan Mac. Angin lazim adalah dari arah timur atau timur laut dengan kelajuan antara 10 dan 20 knot. Negeri-negeri Pantai Timur Semenanjung Malaysia lebih terjejas di mana kelajuan angin boleh melebihi 30 knot. Sebagai negara yang dikelilingi laut, Malaysia merasai kesan nyata dari tiupan bayu laut dan bayu darat, terutama pada hari-hari yang tidak berawan. Pada petang yang cerah, bayu laut dengan kelajuan 15 knot akan terjadi dan boleh mencapai beberapa puluh kilometer ke dalam kawasan pendalaman.

Lanjutan daripada pengenalan angin ini, pengumpulan energi angin mampu menghasilkan tenaga angin yang berguna. Tenaga angin yang giat diperkatakan kini, merupakan salah satu teknologi yang telah dikenalpasti mampu menampung kekurangan tenaga fosil yang kian meruncing. Sistem tenaga angin yang mendapat tiupan yang cukup ini berupaya menjana tenaga elektrik manakala lebihannya digunakan untuk mengecas bateri dan menjalankan proses penyulingan air laut, sekiranya perlu. Secara purata, sesebuah kawasan yang mempunyai tiupan angin antara lima hingga tujuh meter sesaat boleh dianggap berpotensi untuk penjanaan tenaga. Ini terbukti apabila Pulau Terumbu Layang-Layang di Sabah, terdapat kincir angin untuk menjana kuasa elektrik bagi kegunaan kem Tentera Laut Diraja Malaysia (TLDM) dan tempat peranginan di sana.

2. Kajian Persuratan

Muzathik et. al (2009) menjalankan kajian ke atas potensi tenaga angin di Kuala Terengganu. Menggunakan data yang dicerap oleh Pusat Kajian Tenaga Keterbaharuan, Universiti Malaysia Terengganu (UMT) yang merangkumi data selama empat tahun bermula dari tahun 2004 hingga 2007, kajian mendapati bahawa halaju angin di kawasan berkenaan berbeza mengikut jenis dan musim monsun. Kajian membuktikan bahawa kawasan yang menerima pengaruh angin monsun timur laut ini berpotensi menghasilkan kuasa angin dengan bacaan 84.60 W/m^2 pada musimnya, dan bukan pada musim monsun barat daya di mana bacaan purata halaju angin juga berkurangan. Ini membuktikan bahawa pada musim berkenaan tenaga angin bertiup kencang berbanding pada bulan yang lain.

Ali A. Salih et. al (2009) menerokai kajian bagi menganggarkan parameter taburan kebarangkalian Weibull. Kaedah yang dipertengahkan dalam kajian ini adalah kaedah momen, kebolehjadian maksimum dan kaedah kuasa dua terkecil. Ketiga-tiga kaedah yang dinyatakan ini diuji dengan saiz sampel yang berbeza. Bagi mendapatkan kaedah yang tepat, nilai min ralat kuasa dua dan jumlah sisihan bagi setiap kaedah diperolehi dan dibandingkan. Hasil kajian mendapati semakin besar saiz sampel yang digunakan semakin kecil nilai min ralat kuasa dua dan jumlah sisihan. Daripada hasil perbandingan, kebolehjadian maksimum menunjukkan kaedah yang tepat dalam menganggarkan parameter taburan kebarangkalian Weibull.

Kajian Arnab Sarkar et. al (2011) menyatakan terdapat dua kepentingan memadankan data kelajuan angin ke dalam beberapa model statistik. Pertama adalah untuk menganggarkan potensi tenaga angin di sesuatu lokasi dan kedua untuk mengenalpasti kegagalan lesu akibat penumpahan vorteks berkala. Taburan Weibull dan taburan nilai ekstrim jenis I (Gumbel) dipadankan dalam kajian ini. Hasil didapati model Weibull adalah paling popular untuk menggambarkan iklim angin. Walau bagaimanapun, terdapat kelajuan ambang yang boleh dimodelkan oleh Weibull dan taburan nilai ekstrim seperti jenis II (Frenchet) dan jenis III (Weibull songsang). Justeru penganggar terbaik boleh didapati dikalangan taburan ini.

Kamisan et. al (2008) mengaplikasikan taburan kebarangkalian Gumbel terhadap data stesen Alor Setar, Senai, Langkawi dan Melaka. Kajian dijalankan dengan tujuan melihat kesesuaian data tersebut terhadap padanan taburan kebarangkalian yang tergolong dalam keluarga taburan kebarangkalian halaju angin ekstrem teritlak ini. Tiga jenis pengukuran ralat digunakan bagi menguji kebagusan data terhadap proses penyuaian ini. Melalui pengiraan ralat-ralat yang terpilih, kesemua kawasan kajian yang terlibat menunjukkan bacaan yang rendah. Dengan itu, penulis merumuskan bahawa taburan kebarangkalian Gumbel adalah bersesuaian untuk dipadankan dengan kesemua tempat kajian yang terlibat.

3. Metodologi

Fungsi kebarangkalian ketumpatan digunakan dalam pemodelan matematik untuk meramalkan kuasa ketumpatan angin dan menghitung output tenaga angin dagi sesuatu mesin kincir angin. Dalam kajian ini, lima jenis taburan disuaikan terhadap data halaju angin. Taburan yang digunakan adalah taburan Burr, Frechet, Gamma, Lognormal, Rayleigh dan Weibull. Setiap parameter taburan akan dianggarkan dengan kaedah keblehjadian maksimum boleh diwakili oleh formula berikut, $L(\theta; x_1, ..., x_n) = \prod_{i=1}^{n} f(x_i; \theta)$.

Taburan kebarangkalian Burr boleh dilihat hadir bersama-sama 3 parameter dan fungsi ketumpatan kebarangkaliannya boleh diwakili oleh persamaan, di mana *k* dan α ialah parameter bentuk manakala β ialah parameter skala, $f(x)=\dfrac{\alpha k\left(\dfrac{x}{\beta}\right)^{\alpha-1}}{\beta\left(1+\left(\dfrac{x}{\beta}\right)^{\alpha}\right)^{k+1}}$; $k,\alpha,\beta > 0$

Taburan Frechet hadir dengan 2 parameter boleh ditakrifkan sebagai taburan dengan fungsi ketumpatan kebarangkaliannya iaitu, $f(x)=\dfrac{\alpha}{\beta}\left(\dfrac{\beta}{x}\right)^{\alpha+1} eksp\left\{-\left(\dfrac{\beta}{x}\right)^{\alpha}\right\}$; $x \geq 0$; Justeru, fungsi kebolehjadian maksimumnya adalah, $\hat{\beta}=\left(\dfrac{1}{n}\sum_{i=1}^{n}x_i^{-\hat{\alpha}}\right)^{-\frac{1}{\hat{\alpha}}}$ dan $\dfrac{1}{\hat{\alpha}}=\dfrac{\sum_{i=1}^{n}x_i^{-\hat{\alpha}}\ln(x_i)}{\sum_{i=1}^{n}x_i^{-\hat{\alpha}}}=\dfrac{1}{n}\sum_{i=1}^{n}\ln(x_i)$

Taburan Lognormal dengan 2 parameter di mana μ dan σ masing-masing merupakan parameter skala dan bentuk. Fungsi ketumpatan kebarangkalian, $f(x)=\dfrac{1}{x\sigma\sqrt{2\pi}}eksp\left(-\dfrac{[\ln(x)-\mu]^2}{2\sigma^2}\right)$ manakala fungsi kebolehjadian maksimumnya adalah seperti berikut, $\hat{\sigma}=\dfrac{\sum_{i=1}^{n}\left(\ln x_i-\dfrac{\sum_{i=1}^{n}\ln x_i}{n}\right)}{n}$ dan $\hat{\mu}=\dfrac{\sum_{i=1}^{n}\ln x_i}{n}$

Taburan Weibull digambarkan dengan fungsi ketumpatan kebarangkalian yang mempunyai 2 parameter iaitu parameter skala dan parameter bentuk, $f(x)=\dfrac{\beta}{\alpha}\left(\dfrac{x}{\alpha}\right)^{\beta-1} eksp\left[-\left(\dfrac{x}{\alpha}\right)^{\beta}\right]$ *dengan* $x,\alpha,\beta>0$. Penganggar kebolehjadian maksimum bagi parameter α dan β boleh diwakili oleh persamaan berikut, $\hat{\beta}=\left[\left(\sum_{i=1}^{n}x_i^{\hat{\beta}}\ln x_i\right)\left(\sum_{i=1}^{n}x_i^{\hat{\beta}}\right)^{-1}-n^{-1}\sum_{i=1}^{n}\ln x_i\right]^{-1}$. Apabila parameter bentuk diperolehi, parameter skala boleh dianggarkan dengan $\hat{\alpha}=\left[\left(\dfrac{1}{n}\right)\sum_{i=1}^{n}x_i^{\hat{\beta}}\right]^{\frac{1}{\hat{\beta}}}$

Taburan Rayleigh ini mempunyai fungsi ketumpatan, $f(x)=\dfrac{2x}{\alpha^2}eksp\left[-\left(\dfrac{x}{\alpha}\right)^2\right]$ *dengan* $x,\alpha>0$,di mana α adalah parameter skala dan parameter bentuknya, β yang telah ditetapkan pada nilai 2. Didapati penganggar parameter bagi taburan kebarangkalian ini ialah, $\hat{\theta}=\dfrac{n}{\sum_{i=1}^{n}\dfrac{1}{x_i}}$

Penunjuk prestasi digunakan untuk ujian kebagusan penyuaian taburan terhadap data halaju angin. Ujian Kolmogorov-Smirnov bagi lima taburan ini diuji. Nilai-*p* atau aras keertian dicerap adalah aras paling minimum bagi penolakan hipotesis nol untuk data sampel yang diberi juga boleh digunakan sebagai perbandingan. Dimana penyataan hipotesis yang terlibat adalah seperti berikut:

H_0 : Data mengikuti taburan kebarangkalian yang dijangkakan.

H_1 : Data tidak mengikuti taburan kebarangkalian yang dijangkakan.

Selain daripada ujian Kolmogorov-Smirnov, tiga jenis ralat dihitung iaitu punca min ralat kuasa dua, min ralat peratusan mutlak dan ralat normal termutlak. Perbezaan ralat yang memberikan nilai paling kecil menunjukkan taburan yang dicadangkan adalah bersesuaian terhadap data di dalam kajian ini.

Jadual 1: Persamaan pengukuran ralat

Jenis Ralat	**Persamaan**
Punca min ralat kuasa dua	$\sqrt{\frac{1}{n}\sum_{t=1}^{n}(y_t-\hat{y}_t)^2}$
Ralat normal termutlak	$\frac{1}{n}\sum_{t=1}^{n}\lvert y_t-\hat{y}_t\rvert$
Min ralat peratusan mutlak	$\frac{100}{n}\sum_{t=1}^{n}\left\lvert\frac{y_t-\hat{y}_t}{y_t}\right\rvert$

4. Keputusan dan Analisis

Kriteria awalan data halaju angin dikenapasti. Jadual 2 menunjukkan keadaan tenaga angin dan sifatnya telah dikaji berdasarkan data yang dikumpul untuk tempoh enam tahun (2005-2010).

Jadual 2: Statistik diskriptif

Statistik	**Anggaran (m/s)**
Min	4.785
Sisihan piawai	1.0945
Pekali kepencongan	1.739
Kurtosis	3.198
Nilai minimum	0.5
Nilai maksimum	12.8
Saiz sampel	1826

Data bagi purata halaju angin ini mempunyai nilai min yang agak tinggi memungkinkan kawasan ini menerima angin yang agak kencang sepanjang enam tahun data diambil. Nilai serakkannya juga mempunyai bacaan yang tinggi menunjukkan nilai sisihan antara data minimum dan maksimumnya adalah besar. Nilai kepencongan yang positif iaitu 1.739 membuktikan bahawa taburan kekerapan taburan halaju angin adalah terpencong ke kanan.

Jadual 3: Nilai anggaran parameter bagi setiap taburan kebarangkalian

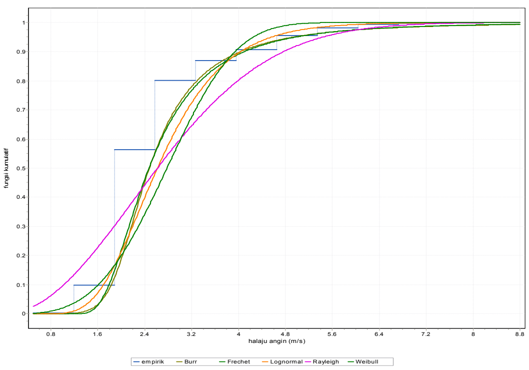
Taburan	**Anggaran parameter**		
Burr	$\hat{k}=0.3689$	$\hat{\alpha}=9.3002$	$\hat{\beta}=2.0627$
Fréchet		$\hat{\alpha}=3.7222$	$\hat{\beta}=2.2414$
Lognormal		$\hat{\mu}=0.9624$	$\hat{\sigma}=0.3379$
Weibull		$\hat{\alpha}=3.4435$	$\hat{\beta}=3.0922$
Rayleigh		$\hat{\alpha}=2.2225$	

Jadual 4: Ringkasan nilai ujian Kolmogorov-Smirnov dan ralat bagi setiap taburan kebarangkalian

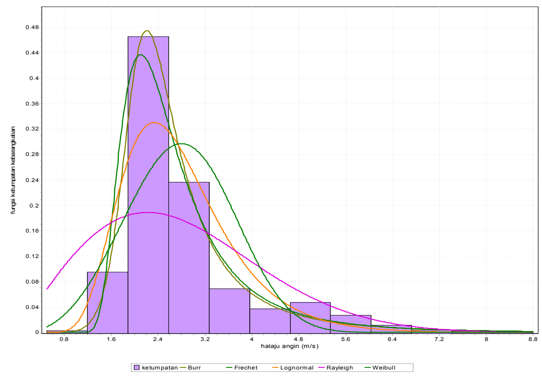
Taburan	**Nilai p Kolmogorov Smirnov**	**Punca Min Ralat Kuasa Dua**	**Ralat Normal Termutlak**	**Min Ralat Peratusan Mutlak**
Burr	*0.2484	0.1463	1.3183	0.9546
Fréchet	*0.0977	0.2222	1.0950	0.9048
Lognormal	0.0024	0.0783	1.1258	7.8500

Weibull	1.0997×10^{-4}	0.0263	1.4831	3.6292
Rayleigh	1.3321×10^{-5}	0.1088	1.1650	1.6192

Nilai-p diberikan tanda (*) memenuhi kriteria statistik yang ditetapkan, di mana hipotesis nol akan diterima pada aras keertian 0.05. Ringkasan daripada Jadual 4 menunjukkan dua jenis taburan kebarangkalian yang berpadanan dengan kawasan kajian, iaitu taburan Burr dan Frechet. Nilai ralat terendah dilakukan ke atas dua taburan kebarangkalian yang terpilih iaitu Burr dan Frechet. Taburan kebarangkalian Frechet didapati berpadanan dengan data kerana dua daripada tiga jenis ralat yang digunakan memberikan nilai yang rendah berbanding dengan nilai yang terdapat pada taburan lain yang terlibat.



Rajah 1: Graf perbandingan fungsi kumulatif antara taburan kebarangkalian



Rajah 2: Graf perbandingan fungsi ketumpatan antara taburan kebarangkalian

Didapati berdasarkan graf fungsi kumulatif, dua plot taburan, iaitu plot taburan kebarangkalian Burr dan Frechet seakan-akan mencecah garisan empirik yang dihasilkan. Keadaan yang agak rumit ini memerlukan graf fungsi ketumpatan kebarangkalian sebagai rujukan gambarajah kedua. Berdasarkan rajah 2, dua taburan kebarangkalian tersebut juga didapati membentuk plot mengikut alur histogram ketumpatan yang dihasilkan dengan baik. Namun begitu, taburan kebarangkalian Frechet didapati lebih mengikut bentuk histogram itu. Oleh itu, kajian menetapkan bahawa taburan kebarangkalian yang juga tergolong dalam keluarga data ekstrim ini dapat memberikan padanan yang paling baik berbanding taburan kebarangkalian yang lain.

5. Kesimpulan

Daripada hasil kajian, didapati kawasan yang terletak di pesisiran pantai seperti Mersing (Pantai Timur Semenanjung Malaysia) mempunyai tiupan angin di sekitar 2.6 hingga 12.8 m/s yang agak tinggi dan sekata. Ini kerana kawasan ini menerima banyak pengaruh angin laut seperti angin bayu laut serta menerima pengaruh besar daripada monsun pada waktu tertentu lebih-lebih lagi pada bulan November hingga Mac. Justeru angin di kawasan ini dipercayai berpotensi dalam penjanaan tenaga elektrik. Setelah menjalankan beberapa ujian kebagusan penyuaian, kawasan kajian terbukti mempunyai tiupan angin yang kuat berpadanan dengan taburan Frechet. Sesuai dengan sifatnya yang selalunya dapat memadankan data halaju angin yang bersifat ekstrim. Nilai anggaran bagi parameter skala, α dan bentuk, β masing-masing adalah 3.7222 dan 2.2414. Fungsi ketumpatan kebarangkalian bagi kawasan ini boleh dinyatakan seperti berikut,

$$f(x) = \frac{3.7222}{2.2414}\left(\frac{2.2414}{x}\right)^{4.72} eksp\left(-\left(\frac{2.2414}{x}\right)^{3.72}\right)$$

Penghargaan

Setinggi penghargaan kepada Jabatan Meteorologi Malaysia diatas kerjasama yang diberi. Projek penyelidikkan ini bawah Geran Dana Kecemerlangan (600-KPK(PJI.5/2/2/4)(49).

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