COMPARISON OF SOIL-WATER CHARACTERISTIC CURVE (SWCC) ON UNBURNED AND BURNED SOIL AT VARYING TEMPERATURE

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O you who have believed,

Seek help through patience and prayer.

Indeed Allah is with the patience.

(Al-Qur’an 2:153)

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ABSTRACT

Fires can reduce soil infiltration capacity, induce soil water repellency and increase runoff and erosion. This study examines the effect of temperature under natural and laboratory condition of soil samples collected from hillside at Jalan Gambang. The unburned and burned soil sample were obtained from site. In addition, the soil samples under laboratory condition were burned at three temperatures, i.e. 105, 440 and 800°C. Various soil properties were studied, including specific gravity, Atterberg limits, swell index and organic matter content. The soil-water characteristic curve (SWCC) of all soil samples were also determined. The SWCC were established using chilled-mirror dew point technique. Experimental results demonstrated that temperature at 105°C resulted in an increment in liquid limit, plastic limit and SWCC. At 440°C, the liquid limit, organic matter content and SWCC were reduced and the swell index was eliminated. Heating the soil at 800°C completely eliminated the liquid limit, plastic limit, swell potential and organic content of soil tested. The soil suction decrease with increasing temperature. From overall experimental results, the natural burned soil was predicted had experienced a fire at temperature between 105°C to 440°C.

ABSTRAK

Kebakaran boleh mengurangkan kapasiti penyusupan air, menyebabkan tanah tidak menyerap air dan meningkatkan aliran dan hakisan. Kajian ini mengkaji kesan suhu di bawah keadaan semula jadi dan makmal sampel tanah yang diambil dari lereng bukit di Jalan Gambang. Sampel tanah yang tidak terbakar dan dibakar diperolehi daripada lapangan. Di samping itu, sampel tanah di bawah keadaan makmal telah dibakar pada tiga suhu, iaitu 105, 440 dan 800 ° C. Pelbagai ciri tanah telah dikaji, termasuk graviti tentu, had Atterberg, indeks pengembangan dan kandungan bahan organik. Lengkung ciri tanah-air semua sampel tanah juga ditentukan. Lengkung ciri tanah-air telah ditubuhkan menggunakan teknik titik embun sejuk cermin. Keputusan eksperimen menunjukkan bahawa suhu pada 105 °C menyebabkan kenaikan dalam had cecair, had plastik dan lengkung ciri tanah-air. Pada 440 °C, had cecair, kandungan bahan organik dan lengkung ciri tanah-air telah dikurangkan dan indeks pengembangan telah dihapuskan. Pemanasan tanah pada 800°C menghapuskan had cecair, had plastik, pengembangan kandungan yang berpotensi dan organik tanah yang diuji. Kadar serapan air berkurang dengan peningkatan suhu. Daripada keputusan eksperimen keseluruhan, tanah di lapangan diramalkan telah mengalami kebakaran pada suhu antara 105 ° C hingga 440 ° C.

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LIST OF SYMBOL

Ca	Calcium
Fs	Free Swell
Gs	Specific Gravity
K	Potassium
M_A	Mass of crucible and soil sample after ignition
Mc	Mass of crucible
Mg	Magnesium
Ms	Mass of crucible and oven dried soil sample
Na	Sodium
V_0	Volume of dry soil
V_1	Soil volume after swelling

LIST OF ABBREVIATIONS

ASTM	American Society for Testing Material
BS	British Standard
FS	Free Swell
SWCC	Soil-Water Characteristic Curve

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Global temperature has increased 0.6°C in the past three decades, but it increased to 0.8°C in the past century (Hansen et al., 2006). Global temperature will warm up by 1.5°C to 4.5°C if the carbon dioxide concentration reaches the predicted level of 600 parts per million by the year 2050 (Masih, 2010; Solomon et al., 2009). As anthropogenic warming continues, the characteristics of droughts and heat waves will also be altered (Tangang et al., 2012). Malaysia shows warming trend in the annual mean temperature with increasing 0.04°C every year (Quadir et al., 2002). Climate change is expected to increase the frequency, duration and intensity of extreme weather events and associated droughts, wildfires and rainfall events (Karl et al., 2008). As the global temperature increase with no increasing in rainfall amount will lead to a much drier forest and make fire ignition occur easier (Wotton and Flannigan, 1993). The relationship between meteorological conditions and fire occurrence is well established. Forest fires tend to be more severe when temperature is high and air humidity and fuel moisture are low (Pinol et al., 1998).

Many physical, chemical, mineralogical and biological soil properties can be affected by forest fire (Certini, 2005; DeBano, 1999; Solera et al., 2011). The energy generated during the ignition and combustion of fuels provides the driving force that is responsible for the changes that occur in the physical, chemical, and biological properties of soils during a fire. The magnitude of change occurring during a fire depends largely upon the level of fire severity, combustion and heat transfer, magnitude and depth of soil heating, proximity of the soil property to the soil surface, and the threshold temperatures at which the different soil properties change (Beyers et al., 2008). Wildfire can profoundly impact soil properties by consumption of organic matter (Perez et al., 2004) and alteration of soil structure (Ulery and Graham, 1993; Duriscoe and Wells II, 1982; Fonseca et al., 2011; Solera et al., 2011; Hubbert et al., 2006), which in turn impacts the soil-water characteristic curve (SWCC). SWCC is a major governing factor for soil water movement which measure of the amount of water that can be stored in a soil, and together with infiltration, determines the rate of precipitation. It is therefore an important parameter in process-based hydrologic and erosion models. In this study, the suction-water content soil-water characteristic curve was established.

1.2 PROBLEM STATEMENT

Global temperature shows warming trend for the past few decades and expected to increase continuously which will increase the frequency, duration and intensity of extreme weather events and associated droughts, wildfires and rainfall events. Forest become drier and make fire ignition occur easier as the global temperature increases. Many physical, chemical, mineralogical and biological soil properties can be affected by fire depends on the level of fire severity, combustion and heat transfer, magnitude and depth of soil heating, proximity of the soil property to the soil surface and the threshold temperature at which the different soil properties change. Changes in soil properties impacts the SWCC which is an important parameter in process-based hydrologic and erosion models. In this study, the changes in soil properties between unburned and burned soil at different temperature were investigated. Other than that, the differences in SWCC of unburned and burned soil were also established.

1.3 RESEARCH OBJECTIVE

The objective of this research were as follows: (i) To determine the properties of unburned and burned soil at varying temperature (ii) To establish the drying suction- water content soil-water characteristic curve and (iii) To predict temperature of forest fire occurred on site.

1.4 SCOPE OF STUDY

In this study, the soil sample obtained from hillside at Jalan Gambang, Kuantan was considered. Several laboratory tests were conducted in Soil and Geotechnical Laboratory in University Malaysia Pahang to investigate the water retention behavior of unburned and burned soil at varying temperature. In this study, only drying soil- water characteristic curve was established and only one technique were used which is chilled-mirror dew-point technique.

1.5 THESIS OVERVIEW

The thesis is divided into five consecutive chapters.

Chapter 2 explains in detail on climate change in Malaysia and the range of temperature that affect soil properties. It also presented the previous researches on the effects of fire on physical properties and its effect on soil-water characteristic curve of different type of soil and fire severity.

Chapter 3 presents the research methodology which conducted tests on physical properties, determination of organic content and establishment of soil- water characteristic curve. In this chapter, it has a detailed explanation of methodology of every test.

Chapter 4 presents the result for every test conducted on physical properties and determination of organic matter. Lastly, the graph of drying suction water content soil-water characteristic curve was presented.

Chapter 5 explains the conclusion based on changes on physical properties and soil organic matter for unburned and burned soil at varying temperature. The graph of drying suction water content soil-water characteristic curve for each soil sample was compared.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, the previous studies of burned soil were discussed. The soil suction, soil suction measurement technique and soil suction controlling technique were presented. The review on SWCC also discussed.

2.2 CLIMATE CHANGE

Climate is defined as long-term weather patterns that depict a region while global climate change refers to a change in either the average state of the climate or in its variability, persisting for several decades or longer. This includes changes in average weather conditions on land, which are changes in average global temperature and changes in how frequently regions experience heat waves, droughts, rising tides, storms etc.(Masih, 2010). Climate change could occur naturally and man-made. Climate change that happens due to natural phenomenon is a consequence of a change in the sun's energy or Earth's orbital cycle (Crowley et al., 2000; Masih, 2010). Climate change also occurs by increasing amount of carbon dioxide released into the atmosphere due to human activities such as burning of fossil fuels, conversion of natural prairie to farmland and deforestation. Carbon dioxide emission from fossil-fuel burning and industrial processes accelerating around the globe from 1.1% per year for 1990-1999 to 3.3% for 2000-2004 (Raupach et al., 2007). In the past three decades, globe temperature has increased 0.6°C but in the past century, it has increased to 0.8°C (Hansen et al., 2006). Most computer climate models predict that the globe will warm up by 1.5°C to 4.5°C if the carbon dioxide concentration reaches the predicted level of 600 parts per million by the year 2050 (Masih, 2010; Solomon et al., 2009). As anthropogenic warming continues, the characteristics of droughts and heat waves will also be altered (Tangang et al., 2012).

Malaysia shows warming trend in the annual mean temperature with increasing 0.04°C every year (Quadir et al., 2002). Peninsular Malaysia and Northern Borneo showed warming trends of between 2.7°C-4.0°C/100 years. South-western Borneo showed either lower or insignificant warming rates. Kuching and Bintulu showed comparatively lower rates of between 1.0°C-1.5°C/100 years while Miri was showing no significant warming or cooling trend (Tangang et al., 2007). Climate change is expected to increase the frequency, duration and intensity of extreme weather events and associated droughts, wildfires and rainfall events (Karl et al., 2008)

2.3 FOREST FIRE

As the global temperature increase with no increasing in rainfall amount will lead to a much drier forest and make fire ignition occur easier (Wotton and Flannigan, 1993). The relationship between meteorological conditions and fire occurrence is well established. Forest fires tend to be more severe when temperature is high and air humidity and fuel moisture are low (Pinol et al., 1998). Fires have an impact on millions of hectares of rainforest, increase deforestation rates by as up to 50% in some regions and cause billions of dollars in damages in the tropics.

Within Southeast Asia and Latin America, out-of-control fires burned more than 20 million hectares in 1997–1998. This is equivalent to half of California and is far from a complete accounting of unintentional burning in the tropics, because burning in many regions has not been well measured. The fire season of 2000 was one of the toughest on record in the United States, with about 3.4 million hectares burned. While in 1997–1998, Indonesia was faced with 8 million hectares of burning. The story is similar across the tropics: 3 million hectares burned in Bolivia, 2.5 million hectares burned throughout Central America, and in Brazil, 5 million hectares burned in a single Amazonian state (Cochrane et al., 2003). The worst wildfire season in Mexico's history affecting 849,632 hectares occurred in 1998 due to severe drought (Bromirski et al., 2008). Forest fires and their resulting smoke haze are a relatively new phenomenon in Malaysia. Nevertheless, the problem of forest fires seems to be increasing and recurring periodically. In terms of the numbers of hectares affected by fire, the figure for 1997 was the worst since 1992 (Setiawan et al, 2004)

Fire is classified into three criteria according to its severity. The fire is classified as low severity burn if less than two percent of the area is severely burned. The area is classified as moderate severity burned if less than ten percent of the area is severely burned while it is classified as high severity burned if the severely burned area is more than ten percent. Many physical, chemical, mineralogical and biological soil properties can be affected by forest fire (Certini, 2005; DeBano, 1999; Solera et al., 2011). The energy generated during the ignition and combustion of fuels provides the driving force that is responsible for the changes that occur in the physical, chemical, and biological properties of soils during a fire. The magnitude of change occurring during a fire depends largely upon the level of fire severity, combustion and heat transfer, magnitude and depth of soil heating, proximity of the soil property to the soil surface, and the threshold temperatures at which the different soil properties change (Beyers et al., 2008).

2.4 EFFECT OF FOREST FIRE ON SOIL

Effect of fire on soil colour are evident. When the soil is affected by low to moderate fires, the ground is covered by a layer of black or grey ash until plant recolonisation modifies the albedo (Certini, 2005). Severely burned forest will have 1-8 cm thick reddened layer result from Fe oxide transformation and nearly complete removal of organic matter. The underlying layer was a blackened layer with thickness of 1-15 cm formed as result of charring (Ulery et al., 1993).

Soil water content can be affected by fire through changes in infiltration, water repellency, evapotranspiration and rainfall interception (Vermeire et al., 2005). Researchers reported a reduction in moisture content of 80% at the soil depth of 0-1 cm from 20.1 cm3 cm-3 pre-fire to 4.1 cm3 cm-3 post-fire beneath chaparral vegetation (DeBano et al., 1979). Hubbert et al. (2006) found that the moisture content of burned soil within the 0–5 cm depth was reduced from a mean of 0.13–0.03 cm^3 cm^{-3}. The fire probably evaporated most of the water in soil near the surface, but evapotranspiration likely accounted for some of the moisture reduction at 2–5 cm between the time of pre-fire sampling and sampling after the fire occurred. However, a few researchers found that there are no significant changes in moisture content between unburned and burned soil (Vermeire et al., 2005).

Fire and associated soil heating can destroy soil structure, affecting the pore size distribution in the surface horizons of a soil (Beyers et al., 2008). A research conducted by Hubbert et al. (2006) suggest 39% reduction of clay fraction from 5.4% to 3.1% after fire without significant changes in the sand of silt fraction. Another research also suggest the decrease of clay content but increase proportion of sand. The reduction in the clay fraction suggest that fire cause coarsening of soil particles (Ulery et al., 1993). The increase in sand fraction cause increase of hydrophobicity potential of the soil (Vermeire et al., 2005). In the research led to investigate the changes in soil structure of Mediterranean shrublands in the Montesinho

Natural Park, Northeast Portugal, the soil textural classes were not touched by fire. However, there were slight changes in silt and clay contents, which in general, varied in opposite directions, with gains of silt and losses of clay in soil (Fonseca et al., 2011). In the research conducted to investigate changes in soil physical properties of Pine Canyon soil after fire, the researchers found that there are reduction in clay fraction after heating with increase of sand-size particles while the silts remain unaffected. These result suggest that the reduction of clay fraction will cause the soils on steep slopes become less stable due to loss of cohesive influence of clay (Duriscoe et al., 1982). However, there are researcher found the reduction of silt and sand fraction with increase of clay fraction (Stoof et al., 2010). In contrast, there are a research that stated that fires does not affect directly on particle size distribution (Certini, 2005).

Soil pH is inexorably increased by the fire as a result of organic acids denaturation. However, significant increases occur only at high temperature (450°C-500°C). The capacity of ash to neutralize soil acidity is well correlated with the sum of the concentration of K, Ca and Mg in the ash itself. The topsoil pH could increase immediately after burning due to the production of K and Na oxides, hydroxides and carbonates. According to Li Xue et al. (2014), research conducted to investigate the effects of a wildfire on soil properties in a Pinus massoniana forest in South China, soil pH increased significantly from 4.6 before fire occur to 5.6 after one-year post-fire and then decreased progressively to 4.7 after four years and 4.5 after seven years post-fire, whereas it decreased from 4.6 to 4.4 in the unburned soils. In contrast, the neo-formed calcite was still present 3 years after burning and maintained moderately alkaline soil pH (Certini, 2005). According to research conducted by Fonseca et al. (2011), soil pH decreased more visible on topsoil. Soil pH increased significantly from 4.6 before fire occur to 5.6 in the soil one-year post-fire and then decreased progressively to 4.7 and 4.5 in the soils four and seven years post-fire, respectively, whereas it decreased from 4.6 to 4.4 in the unburned soils.

According to research conducted by Li Xue et al. (2014), the bulk density increased in the burned soil by 30% after one year the fire occurred and 20% after four years, and the bulk density returned to original level in the unburned soil after seven years post-fire. A research conducted by Hubbert et al. (2006), also shows increment in median soil bulk density at the 0–5 cm depth by 26% from 0.94 g cm-3 pre-fire to 1.18 g cm-3. Researchers prove that the destruction of soil aggregation and the loss of organic matter contribute to the increase in bulk density.

2.5 EFFECT OF SOIL PROPERTIES AT ELEVATED TEMPERATURE

The resilience against fire is affected by climate, vegetation and topography of the burnt area. Low to moderate severity fires eliminate undesired species which cause renovation of the dominant vegetation, impermanent increase of pH and available nutrients. Fire has also enhanced the hydrophobicity of the soil, which reduce the ability of soil to soak up water and increase the probability for soil erosion. Severe fires, for example wildfires, cause removal of organic matter, deterioration of both structure and porosity, loss of nutrients, ash entrapment in smoke columns, leaching and erosion, and alteration of both quantity and specific composition of the microbial and soil-dwelling invertebrate communities (Certini, 2005). Fire intensity is an integral part of fire severity in that it refers to the rate at which a fire is producing thermal energy in the fuel-climate environment where it occurs. It can be measured in terms of temperature, and heat release. During forests fires, maximum ground temperatures are typically in the range of 200°C to 300°C. In heavy fuels like slash, soil surface maximum temperatures are usually around 500°C to 700°C, but instantaneous temperatures in excess of 1500°C can occur (Neary et al., 1999). According to Beyers et al. (2008), temperature in the forest floor can easily reach 600 °C or higher during burning.

Sensitive soil properties are those that are changed at temperatures less than 100°C. Examples of sensitive materials are living microorganisms, plant roots, and seeds. Moderately sensitive soil properties which are sulfur, organic matter and soil properties dependent upon organic matter changed at temperatures between 100 and 400°C. Losses of organic matter can occur at temperatures below 100°C. Volatile constituents in organic matter are lost at temperatures up to 200°C. Destructive distillation destroys about 85% of the soil organic matter at temperatures between 200 and 300°C. Above 300°C, the greater part of the residual organic matter consists of carbonaceous material finally lost upon ignition. Heating the soil to 450°C for 2 hours, or to 500°C for half an hour destroys about 99% of the organic matter. Relatively insensitive soil properties includes clays, calcium, magnesium, potassium and other minerals do not change until temperatures have reached over about 450 °C. The most sensitive textural fraction is clay, which begins changing at soil temperatures of about 400 °C when clay hydration and clay lattice structure begin to collapse. At temperatures of 700 to 800 °C, the complete destruction of internal clay structure can occur. However, sand and silt are primarily quartz particles that have a melting point of 1,414 °C (Beyers et al., 2008).

A study conducted by Abu-Zreig et al. (2001) revealed that temperature had a significant effect on soil physical properties. However, the relative change in these properties was higher when temperature ranged from 100 to 300 °C. Soils were generally not affected by temperatures below 100 °C. At 400 °C, the average liquid limit were decreased by 80%. However, at 400 °C, plastic limits were completely eliminated for all soils tested. The liquid limit decreases very rapidly with the temperature in the interval of 100 and 300 °C, while it decreases very slowly between 300 and 1000 °C. The plastic limit decreases rapidly with the temperature in the interval of 100 and 300 °C. Starting from 400 °C to higher temperatures, the clays show non-plastically behavior. The specific gravity decreases rapidly with the temperature in the interval of 100 and 600 °C, while this decrease is very slow in the interval of 600 and 1000 °C (Tan et al., 2004).

2.6 SOIL SUCTION

Engineers are aware of the importance of soil suction in geotechnical applications. In addition, the engineering properties of unsaturated soils are significantly influenced by soil suction. The coefficient of permeability decreases with an increase in soil suction. The shear strength increases with increases in soil suction. An understanding of the flow behavior through unsaturated soils is required for numerous applications in geotechnical and geo-environmental areas. The shear strength of a soil is also required for the prediction of the stability of slopes, the bearing capacity of foundations and pressure against earth retaining structures (Fredlund, 1995).

Soil suction can also be referred as the free energy state of the soil water (Mantri and Bulut, 2014) that can be found in all ground that lies above the water table (Hu Pan et al., 2010). In engineering practice, soil suction has two components namely matric suction and osmotic suction. The sum of matric and osmotic suction is defined as total suction of the soil (Krahn and Fredlund, 1971). Matric suction is defined as the capillary component of the free energy whereas osmotic suction is defined as the solute component of the free energy (Mantri and Bulut, 2014).

2.6.1 Soil Suction Measurements

There are different method to measure soil suction. There are indirect method which use another medium to determine soil suction and direct method. This paper reports on direct and indirect soil suction measurement methods. Direct suction measurement techniques mainly include axis-transition technique, tensiometer and suction probe. Indirect suction measurement techniques are divided into three categories, namely, measurement techniques of matric suction, osmotic suction and total suction. Indirect matric suction measurement techniques include time domain reflectometry (TDR), electrical conductivity sensors, thermal conductivity sensor (TCS) and in-contact filter paper technique. Indirect osmotic suction measurement techniques chiefly include squeezing technique and saturation extract method. Indirect total suction measurement techniques include psychrometer technique, relative humidity sensor, chilled-mirror hygrometer technique and non-contact filter paper method (Hu Pan et al., 2010).

2.7 SOIL-WATER CHARACTERISTIC CURVE

Soil-water characteristic curve defined as relationship between water content and soil suction (Zapata et al., 2000; Fredlund, 1994; Olsen et al., 2008). Water content can be presented in gravimetric water content, volumetric water content or degree of saturation. The form of water content most often used when soil water suction is initially measured is gravimetric water content. However, when published, the most commonly used form of water content is volumetric water content. The degree of saturation, S, is also used sometimes as a measure of water content for the SWCC (Zapata et al., 2000).

SWCC depend on soil texture, structure, organic matter content and bulk density (Vereecken et al., 1989; Gupta and Larson, 1979). A study conducted by (Pachepsky et al., 2002) suggest that increasing in plasticity, stronger grade for non-plastic soils, and harder dry consistency lead to the increase in SWCC at both -33 kPa and -1500 kPa matric potentials. Wildfire can profoundly impact soil properties by consumption of organic matter (Perez et al., 2004) and alteration of soil structure (Ulery and Graham, 1993; Duriscoe et al., 1982; Fonseca et al., 2011; Solera et al., 2011; Hubbert et al., 2006), which in turn impacts the SWCC. Changes in soil properties depend on fire severity and frequency of fire (Certini, 2005). According to Rawls et al. (2003), the effect of changes in organic carbon content on SWCC depends on the proportion of textural components and the amount of organic carbon present in the soil. At low carbon contents, an increase in carbon content leads to an increase in SWCC in coarse soils and to decrease in water retention in fine-textured soils. At high carbon contents, an increase in carbon contents results in an increase in water retention of all textures. A study conducted by Ebel (2012) on the impact of wildfire on SWCC in the Colorado Front Range, United States suggest that the primary driver for measured differences in SWCC in burned and unburned soils was organic matter content and not soil-particle size distribution. The study also suggest that high-severity wildfire can homogenize SWCC across the landscape by erasing SWCC differences resulting from organic matter content, which for this site may be affected by slope aspect.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The characteristic of unburned and burned soil were investigated though laboratory test. The physical properties of unburned and burned soil were determined by specific gravity, Atterberg limit test, and free swell test. The organic matter content was determined by loss on ignition test. Soil- water characteristic curve of unburned and burned soil were established by using chilled-mirror dew-point technique. In this chapter, all the tests conducted were discussed.

3.2 SELECTION OF MATERIAL

The soil sample for both unburned and burned soil were obtained at the hillside at Jalan Gambang, Kuantan. The samples were brought back to the laboratory in sealed bags.

3.3 SAMPLE PREPARATION

Samples were crushed and kept in plastic seal bags. To prepare burned soil, the unburned soil was burned in furnace at different temperature (105°C, 440°C, 800°C). Some of each samples were added with deionized water to 1.2 times the liquid limit value to prepare slurry specimens. All the slurry specimens were kept in seal bags before being tested.

3.4 PROPERTIES OF UNBURNED AND BURNED SOIL

The laboratory test included specific gravity test, Atterberg limit test, free swell test, and loss on ignition test. All the tests followed different standards as shown in Table 3.1.

Table 3.1: Standard used for the physical properties test

Physical Properties	Method
Specific gravity, Gs	Density bottle (Small pycnometer) (BS 1377: Part 2: 1990: 8.3)
Liquid limit, LL	Cone penetrometer method (BS 1377: Part 2: 1990: 4.3)
Plastic limit, PL	(BS 1377: Part 2: 1990: 5.3)
Shrinkage limit, SL	Standard Test Method for Shrinkage Factors of Soils by the Wax Method (ASTM D 4943 - 08)
Swell index, Cs	Free swell test (ASTM D4829)
Determination of organic matter	**Method**
Loss on Ignition	(BS 1377: Part 3: 1990: 4.3)

3.4.1 Specific gravity test

This test follow BS 1377: Part 2: 1990: 8.3. About 10 g oven dried soil sample that passed 2mm sieve was transferred to the density bottle. The distilled water was added about half to three-fourth of the density bottle and was placed in the vacuum desiccator. The soil sample was left in the desiccator for at least one hour until no further loss of air was apparent. The distilled water was added until the density bottle full and was left for an hour in room temperature. Then the soil and water was removed from the bottle. The density bottle was refilled with water until full and was left for an hour. The test was repeated twice for the same soil sample. The apparatus set-up were as shown in Fig. 3.1. The specific gravity can be calculated using Eq. 3.1.

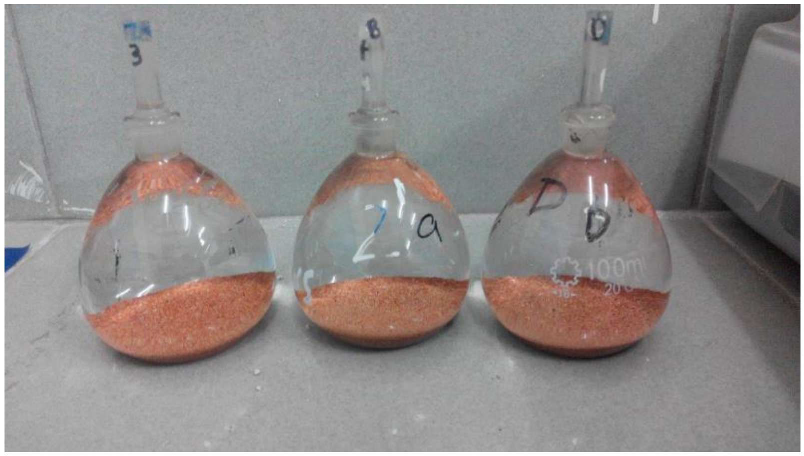

Fig. 3.1: Apparatus set-up for specific gravity test

$$G_s = (W_2 - W_1)/\left((W_4 - W_1) - (W_3 - W_2)\right) \quad (3.1)$$

Where W_1 = Weight of bottle + Stopper

W_2 = Weight of bottle + Stopper + Dry soil

W_3 = Weight of bottle + Stopper + Soil + Water

W_4 = Weight of bottle + Stopper + Water

3.4.2 Liquid limit test

This test was follow the BS 1377: Part 2: 1990: 4.3. About 250 g oven dried soil passing 0.425mm were left air dried for at least 30 minutes. Distilled water were added to the soil sample to form paste and then transferred to the cylindrical cup of cone penetrometer apparatus, ensuring that no air is trapped in the soil sample. The penetrometer was adjusted that the cone point touches the surface of the soil paste. The vertical clamp was released to penetrate into soil paste under its own weight for 5 seconds. The test was repeated for three times of values of penetration in the range of 13.5 to 27.5mm. The graph of water content versus cone penetration was plotted. The moisture content corresponding to cone penetration of 20mm was taken as liquid limit of the soil.

3.4.3 Plastic limit test

This test was follow the BS 1377: Part 2: 1990: 5.3. The soil paste was rolled out a thread on a flat surface. The plastic limit is defined as the moisture content where the soil paste begin to break apart at diameter 3.2mm.

3.4.4 Shrinkage limit test

Shrinkage limit test follow ASTM D4943–08. The soil sample was added with distilled water until it reaches 1.2 times liquid limit of the soil sample. Weight of empty container is recorded. Then, grease is applied on internal of the container and weight again. The soil sample transferred to the cylindrical cup of cone penetrometer apparatus, ensuring that no air is trapped in the soil sample and the weight is recorded. The soil sample was left air dried until no changes in the soil weight. The weight of metal cup with soil sample after oven dried were recorded. The dry soil sample is tied with thread and coated with wax. The weight of dry soil with thread and weight of dry soil with thread and wax were recorded. The dry soil with thread and wax is weight in air and in water. The graph of void ratio versus water content was plotted. The moisture content corresponding to void ratio of the soil was taken as shrinkage limit of the soil. The apparatus set-up for the test is shown in Fig. 3.2.

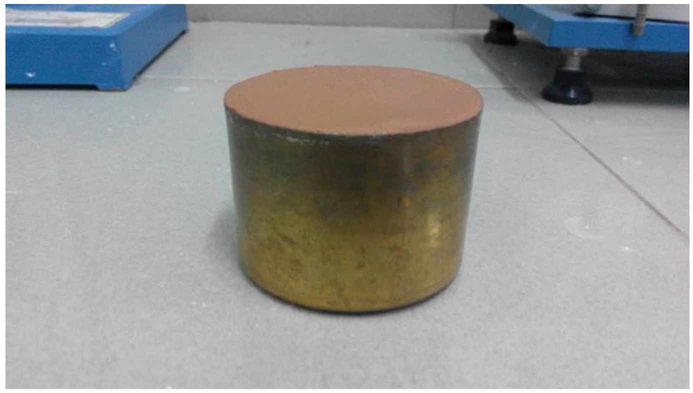

Fig. 3.2: Apparatus set-up for shrinkage limit test

3.4.5 Free Swell Test

This test was follow ASTM D4829. The 10ml soil sample was poured into a cylinder and distilled water was added until it reaches 50ml. The soil sample was left air dried until there is no changes in its volume. The apparatus set-up for the test is shown in Fig. 3.3. The free swell test can be determined by using the Eq. (3.2)

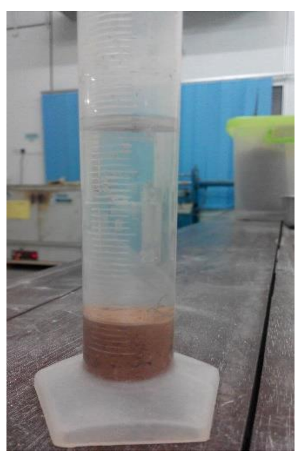

Fig. 3.3: The apparatus set-up for free swell test

$$FS = (V_1 - V_0)/V \times 100 \tag{3.2}$$

Where FS = Free swell, %

V_1 = Soil volume after swelling, cm^3

V_o = Volume of dry soil, 10 cm^3

3.4.6 Loss on Ignition

This test follow BS 1377: Part 3: 1990: 4.3. The soil sample dried for at least one hour, cooled in a desiccator for 30 minutes was added into the crucible until half full and weigh. The soil sample was oven- dried for 24 hours before it was cooled and reweigh. Then, the soil sample was heated in a furnace with 440℃ for three hours, cooled in a desiccator and weigh again. The heating repeated until no further changes in the soil weight. The loss in ignition can be calculated by using Eq. 3.3.

$$\text{Loss in ignition} = (M_S - M_A)/(M_S - M_C) \times 100\% \tag{3.3}$$

Where M_S = Mass of crucible and oven dried soil sample

M_A = Mass of crucible and soil sample after ignition

M_C = Mass of crucible

3.5 SOIL-WATER CHARACTERISTIC CURVE

Soil-water characteristic curve defined as relationship between water content and soil suction. Water content can be presented in gravimetric water content, volumetric water content or degree of saturation. In this study gravimetric water content was used. The soil sample were added with deionized water with increment of 2%. Then the soil sample was kept in sealed bag for at least seven days. Soil suction has two components namely matric suction and osmotic suction. The sum of matric and osmotic suction is defined as total suction of the soil. In this study, total suction is obtained by chilled-mirror dew-point technique using Decagon WP4 PotentiaMeter device.

3.5.1 Chilled-mirror dew-point technique

The capability of a chilled mirror device for measuring soil water retention curve was investigated on fine grained soils having plasticity indices ranging from about 15 to 80. In Decagon’s chilled mirror devices, a test specimen is inserted into a sealed chamber that contains a mirror together with means to chill and detect condensation on the mirror. The temperature at which condensation begins determines the water potential in the head space of the sealed chamber. When a test specimen is inserted into the chamber, moisture is transferred between the specimen and the head space until equilibrium is reached. At equilibrium, the water potential in the head chamber equals the water potential in the specimen. In soils, the water potential is usually called suction. The graph of gravimetric water content versus log total suction is plotted.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 PHYSICAL AND CHEMICAL PROPERTIES

In this chapter, the result for all the tests were discussed. The soil properties of unburned and burned soil which are specific gravity, Atterberg limits, swell potential and organic matter content were also discussed.

Table 4.1: Effect of temperature on properties of unburned and burned soil at varying temperature

Properties	Unburned	Burned			
		Natural	105°C	440°C	800°C
Specific gravity, *Gs*	2.65	2.58	2.64	2.69	2.63
Liquid limit (%)	56.4	55	62.8	46.4	-
Plastic limit (%)	29.69	37.14	30.28	32.10	NP
Shrinkage limit (%)	32	40	30.00	21.40	-
Free swell (%)	5	5	5	0	0
Organic matter content (%)	0.36	0.51	0.31	0.20	0.00

4.1.1 Effect of temperature on specific gravity

Table 4.1 shows effect of temperature on specific gravity of unburned and burned soil. Specific gravity of natural burned soil reduced from 2.65 to 2.58. In a study conducted by Young-Suk Song (2007), they suggest that specific gravity for natural burned soil is lower compared to unburned soil. There is no significant changes in specific gravity at 105°C. However at 440°C, it shows increment but reduced at 800°C. It is contrast with study conducted by Tan et al, (2004) that stated specific gravity reduced rapidly from 100°C to 600°C and does not show significant decrease for interval of 600°C to 1000°C.

4.1.2 Effect of temperature on liquid limit

Table 4.1 shows liquid limit for natural burned soil is slightly lower compared to unburned soil. Burned soil at 105°C shows increment by 11% from unburned soil but at 440° and 800°C, it reduced with increasing temperature until it reached zero at 800°C. The result showed similar pattern with study conducted by Abu-Zreig (2001) which suggest that liquid limit decreased with increasing temperature. However, it in contrast with research conducted by Tan et al. (2004) which stated that liquid limit decreased rapidly at temperature between 100°C to 300°C and does not show significant changes between 400°C to 1000°C.

4.1.3 Effect of temperature on plastic limit

The effect of temperature on plastic limit is shown in Table 4.1. There is increase in plastic limit of natural burned soil by 25% from unburned soil. At a temperature of 105°C and 440°C, the plastic limit slightly increased by 2% and 8%, respectively. At temperature 800°C, the plastic limit reached non-plastic (NP) state. The result contrast with study conducted by

Tan et al. (2004) and Abu-Zreig (2001) which suggest that plastic limit reduced as temperature increase until it reached zero at 400°C.

4.1.4 Effect of temperature on shrinkage limit

From Table 4.1 shows the effect of temperature on shrinkage limit. The shrinkage limit of natural burned soil increased by 25% but it reduced at 105°C and 440°C by 33% and 50%, respectively. The shrinkage limit reached zero at temperature 800°C.

4.1.5 Effect of temperature on free swell

The effect of temperature on free swell is shown in Table 4.1. The swell index in both unburned and burned soil samples do not show any significant changes. The swell index for burned soil at 105°C does not show any significant changes compared to unburned soil. However, it reduced to zero after burned at 440°C and 800°C.

4.1.6 Effect of temperature on organic content

From the result in Table 4.1, the organic matter increase to 0.51% in natural burned soil from 0.36% in unburned soil which may cause by the ash in natural burned soil sample (Ebel, 2012). At temperature of 105°C to 400°C, organic matter content reduced as the temperature increased until it reached zero at 800°C. According to a review on effects of fire on properties of forest soils conducted by Certini (2005), loss of organic matter is the most intuitive change soils experience during burning.

4.2 DRYING SUCTION- WATER CONTENT SWCC

The suction of the unburned and burned soils at various water content are presented in Fig. 4.1. Referring to Fig. 4.1, the suction-water content SWCC of natural burned soil is slightly below that of unburned soil. A study conducted by Alauzis et al. (2004) measured major declines in organic matter content and soil-water retention resulting from wildfire. At temperature of 105°C, the suction-water content SWCC is higher than unburned soil sample due to higher plasticity of the soil. A study conducted by Pachepsky et al. (2002) suggests that water retention increase with increasing plasticity. The suction-water content SWCC of burned soil at 440°C is lower compared to burned soil at 105°C, natural burned soil and unburned soil while burned soil at 800°C has lowest suction-water content SWCC due to non-plastic behavior and zero organic matter content. According to Ebel (2012), the primary driver for differences in SWCC in unburned and burned soil is organic matter content.

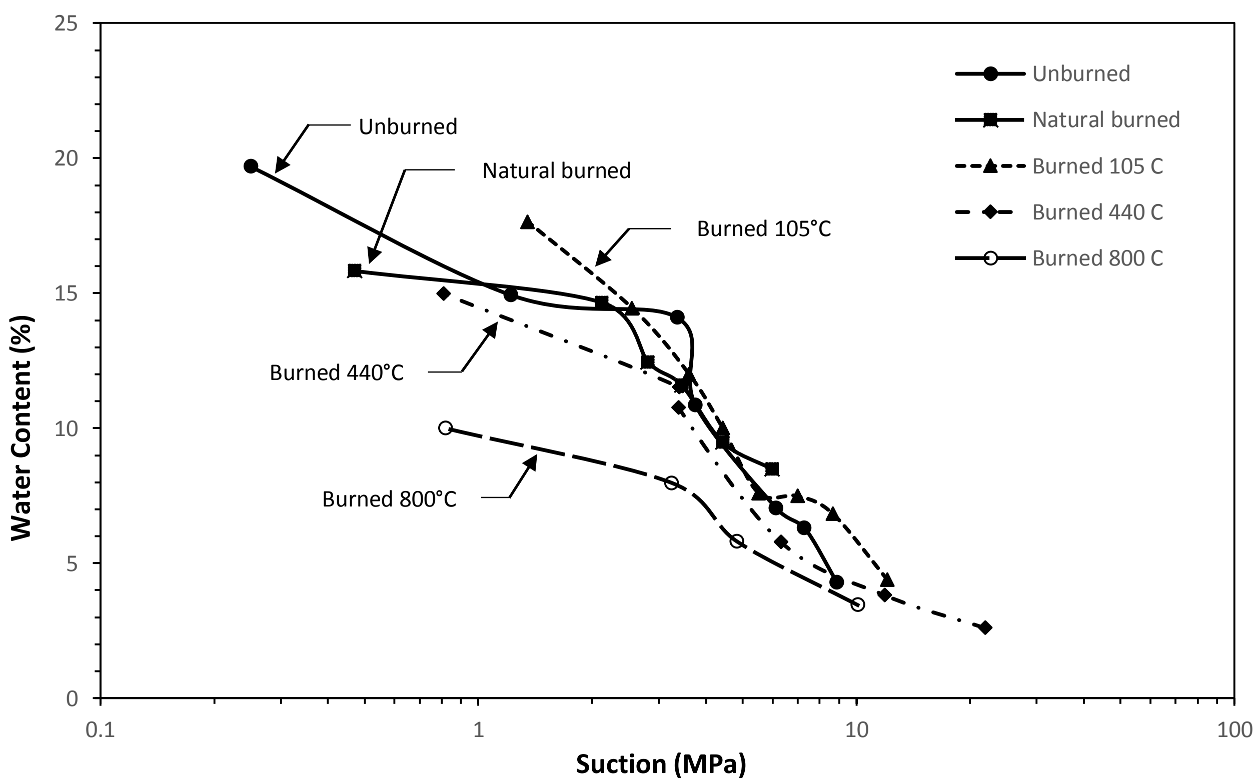

Fig. 4.1: Suction-water content SWCCs of the unburned and burned soils studied

CHAPTER 5

CONCLUSIONS

The objective of the thesis was to establish experimentally the drying soil water characteristic curves (SWCCs) of unburned and burned soil at varying temperature using chilled-mirror dew-point technique. The physical and chemical properties of unburned and burned soils were determined following the standard laboratory procedure.

Based on the findings reported in this thesis, the following conclusions were drawn.

1. This study proved that temperature had significant effect on soil properties which consist of specific gravity, Atterberg limits, swell potential, organic matter content and SWCC. However, the changes in these properties were higher when the temperature ranged from 440°C to 800°C.
2. Experimental results demonstrated that temperature at 105°C resulted in an increment in liquid limit, plastic limit and SWCC.
3. At 440°C, the liquid limit, organic matter content and SWCC were reduced and the swell index was eliminated.
4. At 800°C, liquid limit, plastic limit, swell potential and organic content were completely eliminated.
5. From overall study, the natural burned soil was estimated experienced fire at temperature between 105°C to 440°C.

References

Ulery A. L., Graham R. C. (1993). Forest Fire Effects on Soil Color and Texture.

ASTM 2008. D4943-08. Standard test method for shrinkage factors of soils by the wax method.

Wotton B. M., Flannigan M. D. (1993). Length of the fire season in a changing climate.

BS 1377-2. 1990. Methods of tests for soils for civil engineering purposes. Part 2: Classification tests. British Standard Institution.

BS 1377-3. 1990. Methods of tests for soils for civil engineering purposes. Part 3: Chemical and electro-chemical tests. British Standard Institution.

Stoof C. R., Wesseling J. G., Ritsema C. J. (2010). Effects of fire and ash on soil water retention.

Certini G. (2005). Effects of fire on properties of forest soils: a review.

Zapata C, E., Houston W. N., Houston S. L., Walsh K. D. (2000). Soil-Water Characteristic Curve Variability.

Cochrane M. A. (2003). Fire science for rainforests.

Crowley T. J. (2000). Causes of Climate Change Over the Past 1000 Years.

Fredlund D.G., Xing A. (1994). Equations for soil-water characteristic curve.

Duriscoe D. M., Wells II W. G. (1982). Effects of Fire on Certain Physical Properties of Selected Chaparral Soils. Proceedings of the Symposium on Dynamics and Management of Mediterranean-Type Ecosystems.

Neary D. G., Klopatek C. C., DeBano L. F., Ffolliott P. F. (1999). Fire effects on belowground sustainability: a review and synthesis.

DeBano L. F. (1999). The role of fire and soil heating on water repellency in wildland environments: a review.

Quadir D. A., Shrestha M. L., Ali Khan T. M., Ferdousi N., Rahman M., Mannan A. (2002). Variations of Surface Air Temperature over the Land Areas in and around the Bay of Bengal.

Ebel B. A. (2012). Wildfire impacts on soil-water retention in the Colorado Front Range, United States.

Tangang F, T., Juneng L., Ahmad S. (2007). Trend and interannual variability of temperature in Malaysia: 1961–2002.

Fonseca F., Leite M., de Figueiredo T. (2011). Soil properties in burned and unburned Mediterranean shrublands of Montesinho Natural Park, Northeast Portugal. 3rd International Meeting of Fire Effects on Soil Properties.

Fredlund D. G. (1995). Prediction of Unsaturated Soil Functions using the Soil-Water Characteristic Curve.

Tangang F. T., Juneng L., Salimun E., Sei K. M., Le L. J., Muhamad H. (2012). Climate Change and Variability over Malaysia: Gaps in Science and Research Information.

Vereecken H., Maes J., Feyen J., Darius P. (1989). Estimating the soil moisture retention characteristic from texture, bulk density and carbon content.

Olsen H. W., Repola K., and Wienecke C. J. (2008). Chilled Mirror Measurements of Soil Water Retention Curves.

Holtz W. G. and Gibbs H.J. 1956. Engineering Properties of Expansive Clays. Transactions of the American Society of Civil Engineers. 121: 641-677

Pan H., Qing Y., Pei-yong L. (2010). Direct and Indirect Measurement of Soil Suction in the Laboratory.

Setiawan I., Mahmud A. R., Mansor S., Mohamed Shariff A. R. , Nuruddin A. A. (2004). GIS-grid-based and multi-criteria analysis for identifying and mapping peat swamp forest fire hazard in Pahang, Malaysia.

Krahn J. and Fredlund D. G. (1971). On total, matric and osmotic suction.

Solera J. M., Cerda A., Arcenegui V., Jordan A., Zavala L. M. (2011). Fire effects on soil aggregation: A review.

McMichael A. J., Lendrum D. C., Kovats S., Edwards S., Wilkinson P., Wilson T., Nicholls R., Hales S., Tanser F., Sueur D. L., Schlesinger M., Andronova N. (2006). Global temperature change.

Beyers J. L., Brown J. K., Busse M. D., DeBano L. F., Elliot W. J., Ffolliott P. F., Jacoby G. R., Knoepp J. D., Landsberg J. D., Neary D. G., Reardon J. R., Rinne J. N., Robichaud P. R., Ryan K. C., Tiedemann A. R., Zwolinski M. J. (2008). Wildland Fire in Ecosystems: Effects of Fire on Soils and Water.

Gonzalez-Perez J. A., Gonzalez-Vila F. J., Almendros G., Knicker H. (2004). The effect of fire on soil organic matter-a review.

Pinol J., Terradas J., Lloret F. (1998). Climate Warming, Wildfire Hazard, And Wildfire Occurence In Coastal Eastern Spain.

Hubbert K. R., Preisler H. K., Wohlgemuth P. M., Graham R. C., Narog M. G. (2006). Prescribed burning effects on soil physical properties and soil water repellency in a steep chaparral watershed, southern California, USA.

Vermeire L. T., Wester D. B., Mitchell R. B., Fuhlendorf S. D. (2005). Fire and Grazing Effects on Wind Erosion, Soil Water Content, and Soil Temperature.

DeBano L. F., Rice R. M., Conrad C. E. (1979). Soil Heating in Chaparral Fires: effects on soil properties, plant nutrients, erosion, and runoff.

Xue L., Li Q. and Chen H. (2014). Effects of a Wildfire on Selected Physical, Chemical and Biochemical Soil Properties in a Pinus massoniana Forest in South China.

Abu-Zreig M. M., Al-Akhras N. M., Attom M. F. (2001). Influence of heat treatment on the behavior of clayey soils.

Alauzis M. V., Mazzarino M. J., Raffaele E., Roselli L. (2004). Wildfires in NW Patagonia long-term effects on a Nothofagus forest soil.

Masih J. (2010). Causes and Consequences of Global Climate Change.

Raupach M. R., Marland G., Ciais P., Quere C. L., Canadell J. G., Klepper G., Field C. B. (2007). Global and regional drivers of accelerating CO2 emissions.

Tan O., Yılmaz L., Zaimoglu A. S. (2004). Variation of some engineering properties of clays with heat treatment.

Rawls W. J. and Pachepsky Y. A. (2002). Soil Consistence and Structure as Predictors of Water Retention.

Bromirski P. D., Brooks H. E., Cavazos T. (2008). Weather and Climate Extremes in a Changing Climate.

Gupta S. C. and Larson W. E. (1979). Estimating Soil Water Retention Characteristics From Particle Size Distribution, Organic Matter Percent, and Bulk Density.

Mantri S. and Bulut R. (2014). Evaluating Performance of a Chilled Mirror Device for Soil Total Suction Measurements.

Solomon S., Plattner G. K., Knutti R., Friedlingstein P. (2009). Irreversible climate change due to carbon dioxide emissions.

Bromirski P. D., Brooks H. E., Cavazos T. (2008). Weather and Climate Extremes in a Changing Climate.

Rawls W. J., Pachepsky Y. A. , Ritchie J. C., Sobecki T. M., Bloodworth H. (2003). Effect of soil organic carbon on soil water retention.

Song Y. S., Chae B. G. (2007). Change for Engineering Properties of Top Soils in Wildfire Area.