PROPERTIES AND ENVIRONMENTAL IMPACT OF RECYCLING CIGARETTE BUTTS (CBs) IN FIRED CLAY BRICK

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ABSTRACT

Brick is one of the man-made building materials that have been used since the early human civilization. Due to the attractive appearance, strength and durability, it often used for construction, civil engineering works and landscape design. This study is focused on the effects of incorporating cigarette butts (CBs) into fired clay brick. The investigation includes characterization, optimum percentage of CBs incorporated, physical and mechanical properties, leachability and indoor air quality. Therefore, clay soil samples obtained from Hoe Guan Brick Sdn Bhd were used as control in this research while 2.5% and 5.0% by weight of CBs were incorporated into the clay bricks for subsequent experiments. Different heating rates were used during the firing processes which are 1^{o}C/min**,** 3^{o}C/min and 5^{o}C/min respectively. All samples were fired at 1050^{o}C. The results suggested that the heating rates of 1^{o}C/min with 2.5% CBs are adequate to achieve optimum properties. The results also indicated that the maximum compressive strength of fired clay brick was obtained with 2.5% CBs of fired clay brick at 1^{o}C/min heating rate compared to others. The density becomes lightweight by 16% to 21% compared to conventional bricks as the percentage of CBs increased. The thermal conductivity of the bricks also improved from 24.6% to 46.1% with the increasing of CBs. In addition, leachability results indicated that the leaching of heavy metals were below the United States Environmental Protection Agency (USEPA) and Environmental Protection Agency Victoria (EPAV) regulations. Finally, laboratory testing for Indoor Air Quality (IAQ) revealed that CB Brick complied with the Industry Code of Practice on Indoor Air Quality (ICOP-IAQ).

ABSTRAK

Bata adalah salah satu daripada bahan binaan buatan manusia yang telah digunakan sejak awal tamadun manusia. Oleh kerana penampilan yang menarik, kuat dan berketahanan, ia sering digunakan untuk pembinaan, kerja-kerja kejuruteraan awam dan reka bentuk landskap. Kajian ini memberi tumpuan kepada kesan menggabungkan puntung rokok (CBs) ke dalam batu bata tanah liat. Penyiasatan termasuklah pencirian, peratusan optimum kemasukan puntung rokok, ciri-ciri fizikal dan mekanikal, larut resapan dan kualiti udara dalaman. Oleh itu, sampel tanah liat diperolehi daripada Hoe Guan Bata Sdn Bhd telah digunakan sebagai kawalan dalam kajian ini manakala 2.5% dan 5.0% puntung rokok mengikut berat telah dimasukkan ke dalam bata tanah liat untuk eksperimen berikutnya. Kadar pemanasan yang berbeza telah digunakan semasa proses pembakaran iaitu 1°C/min, 3°C/min dan 5°C/min. Semua sampel telah dibakar pada 1050°C. Keputusan mencadangkan kadar pemanasan 1°C/min dengan 2.5% CBs adalah mencukupi untuk mencapai ciri-ciri yang optimum. Hasil menunjukkan bahawa kekuatan mampatan maksimum bata tanah liat dibakar telah diperolehi dengan 2.5% puntung rokok pada 1°C/min kadar pemanasan berbanding dengan yang lain. Ketumpatan menjadi ringan sebanyak 16% kepada 21% berbanding dengan bata konvensional apabila peratusan puntung rokok meningkat. Kekonduksian terma bata juga bertambah baik daripada 24.6% hingga 46.1% dengan peningkatan peratusan puntung rokok. Di samping itu, keputusan menunjukkan bahawa hasil larut lesap logam berat adalah mematuhi peraturan-peraturan United States Environmental Protection Agency (USEPA) dan Environmental Protection Agency Victoria (EPAV). Akhir sekali, ujian makmal untuk Kualiti Udara Dalaman (IAQ) mendedahkan bahawa bata puntung rokok mematuhi Industry Code of Practice on Indoor Air Quality (ICOP-IAQ).

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LIST OF SYMBOLS AND ABBREVIATIONS

%	-	Percent
$\leq$	-	Less-than or Equal to
$\geq$	-	Greater-than or Equal to
°C	-	Degree Celsius
°C/min	-	Degree Celsius per minute
µ	-	micro
µm	-	Micro meter
A	-	Area
AAS	-	Atomic Absorption Spectroscopy
Al	-	Aluminium
Al_2O_3	-	Aluminum oxide
As	-	Arsenic
Ba	-	Barium
BS	-	British Standard
C	-	Ceiling limit
CaO	-	Calcium oxide
CB Brick	-	Cigarette Butt Brick
CBA	-	Clay Brick Organization
CBs	-	Cigarette Butts
Cd	-	Cadmium
Ce	-	Cerium
CETP	-	Code on Envelope Thermal Performance
Cfu/m^3	-	Colony Forming Unit per Cubic Meter
cm^3	-	Cubic centimeter
CO	-	Carbon Monoxide
Co	-	Cobalt
CO_2	-	Carbon Dioxide
Cr	-	Chromium
Cs	-	Cesium
Cu	-	Copper
CuO	-	Copper(II) oxide
EN	-	European Standard
EPA	-	Environmental Protection Agency
EPAV	-	Environmental Protection Agency Victoria
ER	-	Empty Room
et al	-	And others
ETS	-	environment tobacco smoke
FDA	-	Food and Drug Administration
Fe	-	Ferum
Fe_2O_3	-	Ferric oxide

FEMA	-	Flavor and Extract Manufacturers Association
g	-	Gram
g/cm^3	-	Gram per cubic meter
Ga	-	Gallium
GAST	-	Global Adult Tobacco Survey
HCHO	-	Formaldehyde
IAQ	-	Indoor Air Quality
ICOP-IAQ	-	Industry Code of Practice on Indoor Air Quality
ISO	-	International Organization for Standardization
k	-	thermal conductivity
K_2O	-	Potassium oxide
K_a	-	Aspect Ratio Factor
kg/m^3	-	Kilogram per cubic meter
kN	-	Kilonewton
L	-	thickness
L/min	-	Liter per minute
La	-	Lanthanum
LL	-	Liquid Limit
LOI	-	Loss of Ignition
L_s	-	Actual Length – Dry Length
M_1	-	Dry Mass
m_1	-	Mass of wet brick
M_2	-	Wet Mass
m_2	-	Submerged mass of brick
mg/L	-	Milligram per litre
mg/m^3	-	Milligram per cubic meter
MgO	-	Magnesium oxide
mm	-	milimeter
Mn	-	Mangan
MnO	-	Manganese(II) oxide
m_o	-	Ambient mass
Mo	-	Molybderium
MOH	-	Ministry of Health Malaysia
Mpa	-	Megapascal
N/mm^2	-	Newton per millimeter square
NA	-	Not Available
Na_2O	-	Sodium oxide
Nb	-	Niobium
ND	-	Not Detectable
Ni	-	Nickel
O_3	-	Ozone
OMC	-	Optimum Moisture Content
P_2O_5	-	Phosphorus pentoxid
PAHs	-	polycyclic aromatic hydrocarbon
Pb	-	Lead
PI	-	Plasticity Index
PL	-	Plastic Limit
PM_{10}	-	Particulate Matter
ppm	-	part per million
PVA	-	polyvinyl acetate

Q	-	Heat flow
Rb	-	Rubidium
RECESS	-	Research Centre for Soft Soil
RH	-	Relative humidity
RMK10	-	Rancangan Malaysia ke10
S	-	Shrinkage
Sb	-	Antimony
Sc	-	Scandium
SEM	-	Scanning Electron Microscope
SiO_2	-	Silicon dioxide
Sn	-	Tin
SO_3	-	Sulphur trioxide
Sr	-	Strontium
SrO	-	Strontium oxide
TCLP	-	Toxicity Characteristic Leaching Procedure
TEL	-	Thermal Environmental Laboratory
Th	-	Thorium
Ti	-	Thallium
TiO_2	-	Titanium dioxide
TVOC	-	Total volatile organic compounds
twa	-	time-weighted average
U	-	Uranium
USEPA	-	Unites States Environmental Protection Agency
UTHM	-	Universiti Tun Hussein Onn Malaysia
UTM	-	Universal Testing Machine
V	-	Vanadium
VOCs	-	Volatile organic compound
W/mK	-	Watt per meter Kelvin
WHO	-	World Health Organization
WiSC	-	Walk in Stability Chamber
wt.	-	Weight
XRF	-	X-Ray Fluorescence
Y	-	Yttrium
Zn	-	Zinc
ZnO	-	Zinc oxide
Zr	-	Zirconium
ZrO_2	-	Zirconium dioxide
ΔT	-	temperature gradient
ρ	-	Density

CHAPTER I

INTRODUCTION

1.0 Introduction

Along with rapid economic development and growing in population, Malaysia is dealing with challenges of waste management. Various approaches developed, nevertheless the implementation of waste management still gets less attention by most management teams. Example of solid waste management problems is lack of disposal areas, ineffective disposal method and illegal disposal area by irresponsible parties. Malaysia has no alternative, except to handle waste disposal properly in order or have to deal with environmental risks. In fact, cigarette butts (CBs) are one of the most littered items in the world (Slaughter *et al.*, 2011; Micevska *et al.*, 2006; Warne, 2002).

In Malaysia, CBs is difficult to manage because it often combined with domestic waste and it is very challenging to separate CBs waste due to their small size but large in volume. This problem is getting complicated when the number of discarded CBs is growing. According to National Health and Morbidity Survey, approximately about 3 million out of 28 million people in Malaysia (21.5%) are hardcore smokers (Osman and Azlan, 2007). Meanwhile, a statistic by Ministry of Health Malaysia (2000) in “Modul Berhenti Merokok 2001” reported that teenagers dominate smoking habits every day. With this high statistic, there is a huge number of CBs need to be disposed (MOH, 2001). Moreover, the attitude of those smokers that disregard CBs as waste and have been discarded CBs directly to the environment will cause worst environmental pollution.

The impact of CBs littering is not only towards the environment, but it is also harmful to the marine life and aquatic life. The butts were found in the stomach of fish, birds, whales and other marine life that swallow this poisonous filter (Roe & David, 2007). Furthermore, the Environmental Protection Agency (EPA) states that the cigarette butts can take up to 15 years to degrade (Ha, 2007). There are about 4,200 chemical compounds classified as tobacco constituents, but 10,000 not have yet to be discovered (Rodgman & Perfetti, 2009).

Meanwhile, a rapid growth of the construction sector led to an increasing of the demand of construction materials in Malaysia. According to the National Housing Policy in Malaysia Tenth Plan (RMK10, 2014), has determined that the housing sector will be further enhanced to provide adequate housing and quality public services as well as full equipped. According to a report in the RMK10, the government has targeted the construction of 78,000 units of affordable housing to meet the needs of low-income nation in Malaysia. Therefore, following with a high demand housing sector and the rapid growth of construction projects, the demand for low cost raw materials for construction also rose up.

1.1 Problem Statement

Malaysia is currently facing with litter pollution; especially CBs that is toxic to the environment (Register, 2000). CBs may be littered directly to the environment or indirectly via runoff water or carried away from streets and sidewalks to storm drains (Novotny *et al*., 2009; Sawdey *et al*., 2011). This problem will increase as the attitudes of some people are not concerned about this matter. The government has allocated a variety of methods to reduce CBs waste, but it is still less effective even though the program of “Hari Tanpa Tembakau Sedunia Peringkat Kebangsaan 2013” has been launched (MOH, 2013). According to a survey of Global Adult Tobacco Survey (GAST) released by World Health Organization, there are more than 40% of Malaysia men smoke, or a total of 4.7 million adults smokers, meanwhile, almost no women (less than 1%) smoke in Malaysia (WHO, 2012).

CBs are also known as cigarette filters are designed to absorb vapors and to accumulate smoke components. CBs contain hazardous chemicals such as lead, cadmium and arsenic that are partially filtered out through the smoking process. CBs are forms of non-biodegradable litter and can take approximately 12 months to break down in fresh water and up to 5 years to break down in seawater. According to Kadir & Mohajerani (2010), it is difficult to recycle CBs because there is no easy mechanism or efficient and economical procedures to ensure the separation of chemical trap inside the CBs. Furthermore, the chemicals that leach out from CBs could give a serious impact to human and marine life.

From previous researchers, attempts have been made to incorporate many types of waste in the production of bricks, zinc smelting slag (Hu *et al*., 2014); sludge (Victoria, 2013; Arsenovic, 2012; Hegazy *et al*., 2012); waste tea (Demir, 2006); limestone dust, wood sawdust (Turgut & Algin, 2007); kraft pulp waste (Demir *et al*., 2005); hydraulic limes and hydrated calcium lime (Costigan *et al*., 2010). Incorporating such wastes into brick bodies always involves at least two environmental benefits; incorporating of wastes that are difficult to dispose and savings in clay raw materials (Abi, 2014; Victoria, 2013). Moreover, fibrous waste mostly improved the thermal properties as the waste could act as pore formers additives and producing lightweight brick.

Meanwhile, environmental concern on building materials become increased especially when it related with the demand for low cost raw materials for construction. Recently, researchers have been promoting alternative low cost raw materials for example to incorporate different types of waste into building material specifically on fired clay brick as it is one of the most demanding building materials, but little was known regarding their emissions and the effect on indoor air quality (IAQ). Not so many researchers are focusing on this issue except few researchers have investigated on IAQ by incorporating several wastes into fired clay brick (Hu *et al*., 2014; Victoria, 2013; Arsenovic *et al*., 2012; Chiang *et al*., 2009; Weng *et al*., 2003). Therefore, in this study, CBs waste was collected and incorporated in fired clay brick as an alternative disposal method to CBs and cater its pollution problems. Investigation on its advantages of the brick properties as well as its impact towards the environment either through leaching or emission also have been carried out. The choice to use CBs in fired clay brick is due to the several following factors; (a) bricks are made of clay, therefore they are homogenous and can blend with other substances (Ribeiro *et al*., 2004), (b) high temperature during firing process of fired clay brick will allows volatilization of dangerous components, thus changes the chemical characteristic of the materials and eliminates the toxic components through fixation process (Vieira *et al*., 2006; Weng *et al*. 2003).

1.2 Objective of the Study

The aim of this study was to investigate the impact by incorporating CBs in fired clay bricks. The objectives of the study were:

(i) to determine the characteristic of Cigarette Butts (CBs).
(ii) to identify the optimum percentage of incorporating CBs into fired clay brick.
(iii) to analyze the physical and mechanical properties by incorporating CBs into fired clay brick.
(iv) to evaluate the impact of CBs incorporation into fired clay brick towards leachability and indoor air quality (IAQ).

1.3 Scope of the Study

The scope of work of this research is to examine the possibility of CBs to be incorporated in fired clay bricks. Preliminary laboratory work such as soil classification test including liquid limit (LL), plastic limit (PL) and plasticity index (PI) were carried out according to the BS 1377:1990. The CBs was collected weekly around Parit Raja and Taman Universiti restaurant. Before proceed with brick manufacturing, clay soil sample and CBs were analyze with X-Ray Fluorescence Analysis (XRF), conducted at Analytical Laboratory, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia (UTHM).

The sample preparation to manufacture fired clay brick was conducted at the Research Centre for Soft Soil (RECESS). Meanwhile, the physical and mechanical properties such as compressive strength, water absorption, firing shrinkage and dry density were carried at Structural Laboratory. To obtain the microscopic porosity image of manufactured brick, Scanning Electron Microscope (SEM) was conducted at Mechanical Laboratory, Faculty of Mechanical and Manufacturing Engineering, UTHM. Another test for leachability was conducted at Water and Wastewater Laboratory and Analytical Laboratory, Faculty of Civil and Environmental Engineering, UTHM. On the other hand, the IAQ was conducted at the Thermal Environmental Laboratory (TEL), Faculty of Mechanical and Manufacturing Engineering, UTHM.

In this study, different percentages of CBs (0%, 2.5% and 5.0%) were incorporated into fired clay brick. Different heating rates of brick firing were also conducted during firing stage with 1°C/min, 3°C/min and 5°C/min. The firing temperature was used up to 1050°C. The physical and mechanical properties were tested according to BS 3921:1985. Meanwhile, for the thermal properties, Hot Guarded Plate Method was used according to BS EN ISO 8990. The leachability test was conducted according to the Environmental Protection Agency (EPA) Method 1311, Toxicity Characteristic Leaching Procedure (TCLP). For the determination of IAQ; the laboratory building scale was operated in a small scale chamber and exposed to temperature and humidity follow Industry Code of Practice on Indoor Air Quality (ICOP-IAQ).

1.4 Significance of Study

The idea of recycling CBs started when most of the developed countries especially Australia, New Zealand and some in the United Kingdom do their yearly cleanup day and count every single littered item on the streets. For 7 years in a row, CBs has become the most littered item compared with others, although receptacles provided almost everywhere (Clean Up Day, 2012; Cigwaste, 2009).

By realizing that Malaysia has high smokers and very little receptacles provided to throw the CBs, the CBs must be recycled in an appropriate method. By incorporating CBs into fired clay brick could become an alternative disposal method for CBs as well as reduces CBs waste in landfill, waterways, streams and seawater (Sawdey *et al*., 2011; Slaughter, 2010). Furthermore, CBs is a toxic material that contains more than 4000 chemicals. This will be harmful to the environment when the littering of CBs dissolved in any sources of water.

Besides to overcome pollution problems, recycling CBs in fired clay brick could help to reduce raw material consumption during manufacturing of brick. This is because raw material needs to preserve for the future generation. Therefore, sustainability is one of the concepts that have been taking attention by several researchers to recycle those wastes into building material.

In this study, CB Brick could be a potential insulation material as CBs could act as pore-forming additives that will reduce the thermal conductivity of the manufactured CB Bricks due to its cellulose acetate fiber content. An adequate brick in terms of physical and mechanical properties could be also manufactured. The issue of leachability and IAQ will become a concern when waste is recycled into building material that is not being focus by most of the researchers.

Incorporating different waste material will provide a different effect on the IAQ. It is essential to provide not only good properties of building material, but good IAQ as it may affect health, activities and performance of occupants. Therefore, investigation will be carried out to produce better IAQ and safer building material for human and the environment. Leachability study needs to be done in order to predict how high metal will be leached from CBs. In this study, IAQ was also conducted in laboratory building scale. This result will significantly become an indicator on the environment impact of waste incorporation in building material as it is one of the main concerns apart from producing a good quality of bricks in terms of properties.

1.5 Summary of Findings

Chapter one provides an overview of CBs littering problems and environmental impact associated with CBs. During this study, objectives were briefly explained which covered physical and mechanical properties, characteristic of waste and the impact of CBs littering toward the environment. With the increasing concern from the insufficient building materials for construction activities and environmental awareness, several attempts have been made to incorporate many types of waste in the production of fired clay bricks. Therefore, the next chapter will provide a comprehensive literature review that help to understand the areas of concern.

CHAPTER II

LITERATURE REVIEW

2.0 Introduction

Tobacco and smoking have a long history. The tobacco plant widely spread in America since the first century. In early 1880's, many peoples had begun using tobacco, but in small amounts. According to Jacobs (1997), James Bonsack invented the cigarette-making machine in 1881 and afterward cigarette smoking became widespread. According to Food and Agriculture Organization (1990), there are approximately 80% of all grown tobacco used in cigarette manufacturing and China recorded as the largest world's producer on tobacco.

2.1 Cigarette

Commercial cigarettes manufactured are apparently simple objects consisting mainly of a tobacco blend, paper, polyvinyl acetate (PVA) glue to stick to the outer layer of paper together, and a cellulose acetate based filter. In 1994, Reynold (2010) reported that there are 599 flavoring ingredients, sugar and processing aids used by major U.S tobacco companies in tobacco made, but the exact quantities of these chemicals in tobacco are still unknown. These chemical's ingredients commonly used in foods and beverages, or permitted for use in foods by the United States (U. S) Food and Drug Administration (FDA), or given the status "Generally Recognized as Safe in Foods" (GRAS) by the FDA, the Flavor and Extract Manufacturers Association (FEMA) or other expert committees (Reynold, 2010). The levels of ingredients are based on a dry-weight percentage of the tobacco. According to Geiss and Kotzias (2007), a cigarette seldom contains one type tobacco. It includes a mixture, of several types of tobacco from a variety of sources. To keep the tobacco moist, chemicals including pesticides, herbicides, insecticides, fungicides and rodenticides are included in cigarettes (Glantz *et al*., 1996).

Figure 2.1a shows the image of a cigarette and figure 2.1b shows the cross section of cigarette. Label 1 is a cellulose acetate which is used to make a filter. This filter is commonly made of 95% of cellulose acetate. Cellulose acetate is the standard term used to express a variety of acetylated cellulose polymers. They are specifically designed to absorb vapors and accumulate particulate smoke components. Label 2 is responding to tipping paper to cover the filter. They are formulated not to adhere to the lips of smokers. Label 3 refers to roll paper to cover the tobacco. Label 4 is a mixture on tobacco blend.

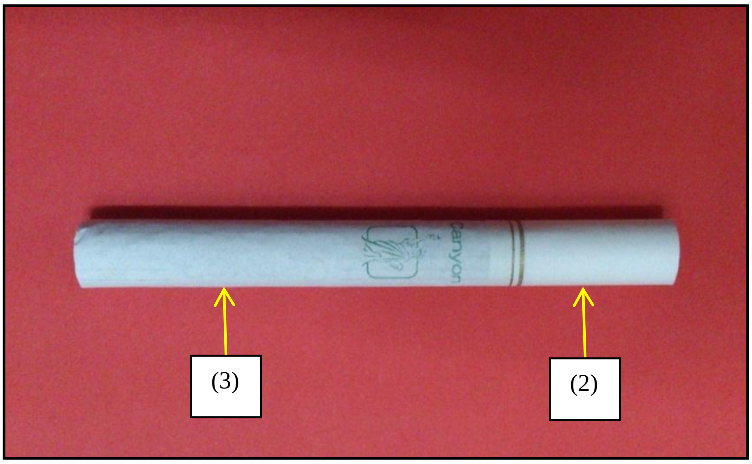


Figure 2.1a: Cigarette Butts

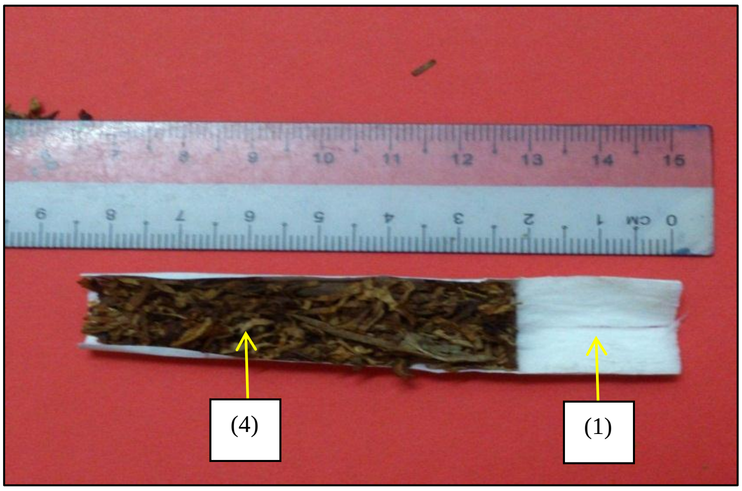
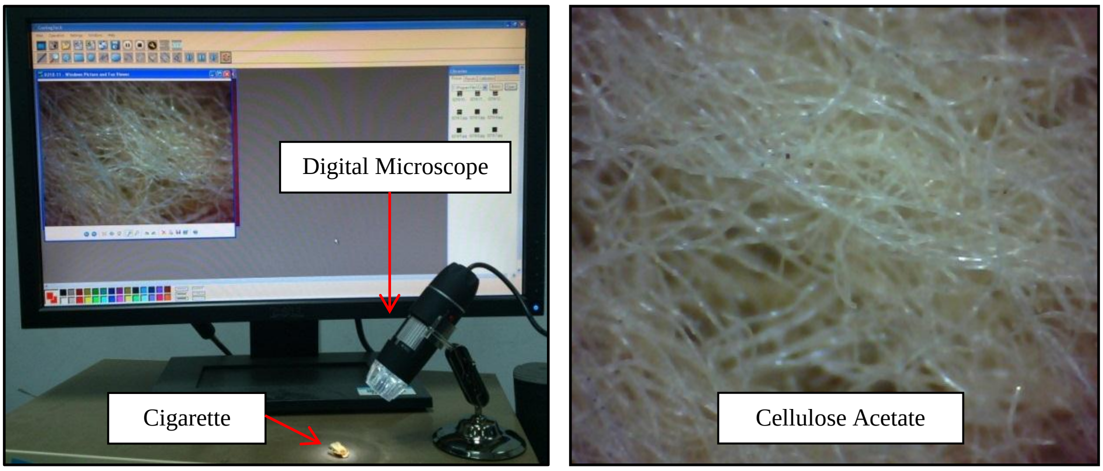


Figure 2.1b: Cross Section of Cigarette

2.2 Cigarette Butts (CBs)

The common name for the remnants of a cigarette after smoking is a cigarette butt (CBs). It comprises about 30% of the cigarette's original length. The butts are composed of cellulose acetate (fibres) and are coated with paper. The fibers which are approximately 20µ in diameter, treated with titanium dioxide and packed tightly together with over 15000 by using triacetin (binding agent) to produce the butt (Pauly *et al*., 2002). Technically, cellulose acetate is biodegradable, where it can only biodegrade under conditions described as severe biological circumstances (Puls *et al*., 2011; Ishigaki *et al*., 2004; Ash, 1993). Ash (1993) also found that cellulose acetate is a plastic that is extremely slow to degrade in the environment and estimated to degrade up to 18 months under ideal conditions. Figure 2.2 shows the microscopic image of cellulose acetate with magnifications of up to 50 to 500 times its original size by using digital microscope scanner. Figure 2.2b shows the closed up of cellulose acetate.



(a) (b)

Figure 2.2: (a) The digital microscope equipment set up, (b) Cellulose acetate

By considering an environmental perspective, CBs contain thousands of hazardous chemicals such as cadmium, arsenic and lead that are partially filtered out during smoking (Slaughter, 2010). Moriwaki, Kitajima and Katahira (2009) also found that arsenic; nicotine, polycyclic aromatic hydrocarbon (PAHs) and several heavy metals are released into the environment by littering CBs at roadside. When these chemicals leached out from the filters, hazardous toxin would leach out after entering aquatic environments, waterways and land.

2.3 Brick

Brick is the man-made building materials that have been used since the early human civilization. Bricks are broadly used for construction, civil engineering work and landscape design since it has an attractive appearance, strength and durability, fire and weather resistance, thermal and sound insulation. The quality of brick usually depends on the composition of raw materials, production method, firing method and firing temperature (Karaman and Esmeray, 2006).

2.3.1 Manufacturing of Clay Brick

The manufacturing process of clay brick can divide into four general phases; winning and storage, forming the brick, drying process, firing and cooling (Marotta *et al*., 2005). The clay is prepared, grinding, mixing, wetting and cleaning process is done to remove impurities. The clay afterward continue the screening process to control the particle size and go to the pugmills where large mixing chamber is used to blend clays with water. Usually 18-25% water content is enough to produce a plastic, relatively homogenous mass that is ready for molding phase (CBA, 2002). Next, drying process at temperature 150°C will be continued during production of clay bricks. According to CBA (2002), before the brick fired, they must be dried properly (moisture content has to be reduced to 8% of the volume for the clamp kiln). The last phase for making clay bricks is firing and cooling. Bricks are continuously fired in tunnel kiln (Figure 2.3) or periodic kiln, within two days (900ºC to 1200ºC).

A research by Johari *et al*. (2010) discovered that the best firing temperature was to be 1200ºC with good mechanical properties performance. Finally, the manufactured clay bricks continue with cooling down period that is required two or three days in a periodic kiln and not more than two days in continuous kiln.

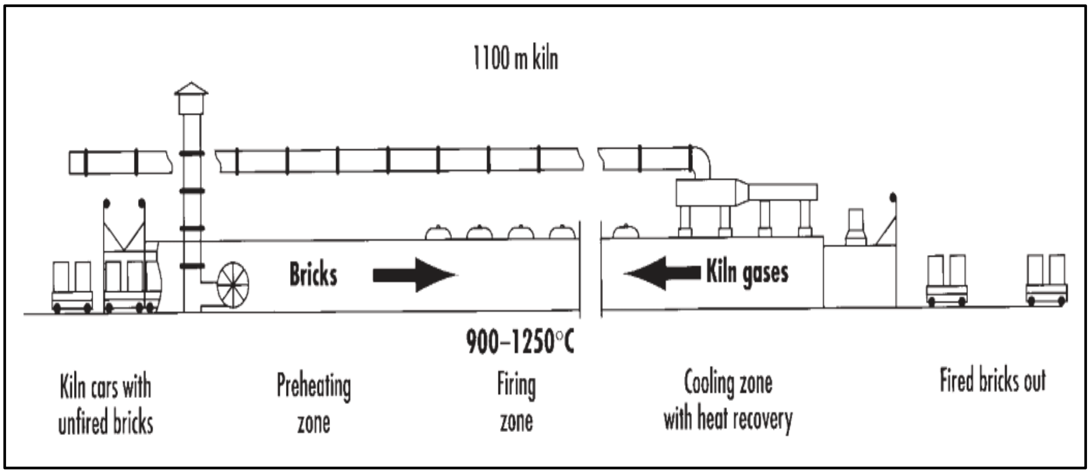


Figure 2.3: Tunnel kiln (Lyons, 2007)

2.3.2 Types of Brick

According to BS 3921: 1985, the difference between solid, perforated, fogged and cellular is according to their physical form. Solid bricks do not have holes, cavities or depressions. Perforated bricks have holes not exceeding 25% of the gross volume of the brick. Fogged bricks have depression in one or more of the bed faces, but their total volume does not exceed 20% of the gross volume of the brick. Cellular bricks may have holes or cavities are not exceeding 20% of the gross volume of the brick, a cavity being a hole closed at one end. Types of brick can be clearly seen in Figure 2.4 given by Lyons (2007).

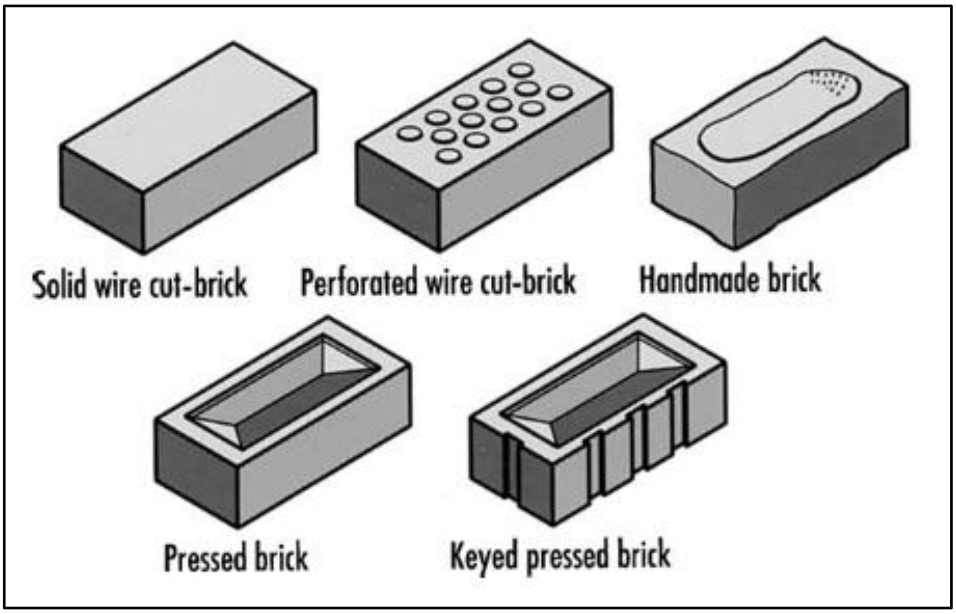


Figure 2.4: Types of brick (Lyons, 2007)

2.3.3 Brick Size

The form of brick may define as a rectangular prism of a size that can be handled conveniently with one hand. Brick is designated in terms of their coordinating sizes and work sizes (BS 3921: 1985). Coordinating size also known as "format" indicating the space allocated to a brick, including an allowance for a nominal 10 mm mortar joint. Meanwhile, work size is the measurements for a brick specified for the manufacture, to which its actual size should conform within specified allowable deviations. The formats of bricks shall be consistent in size that conforms to the standard BS 3921:1985 as shown in Table 2.1. Meanwhile, Figure 2.5 shows the brick size of the brick (Janicki, 2012).

Table 2.1: Standard size of clay brick

Coordinating Size			Work Size		
Length (mm)	Width (mm)	Height (mm)	Length (mm)	Width (mm)	Height (mm)
225	112.5	75	215	102.5	65

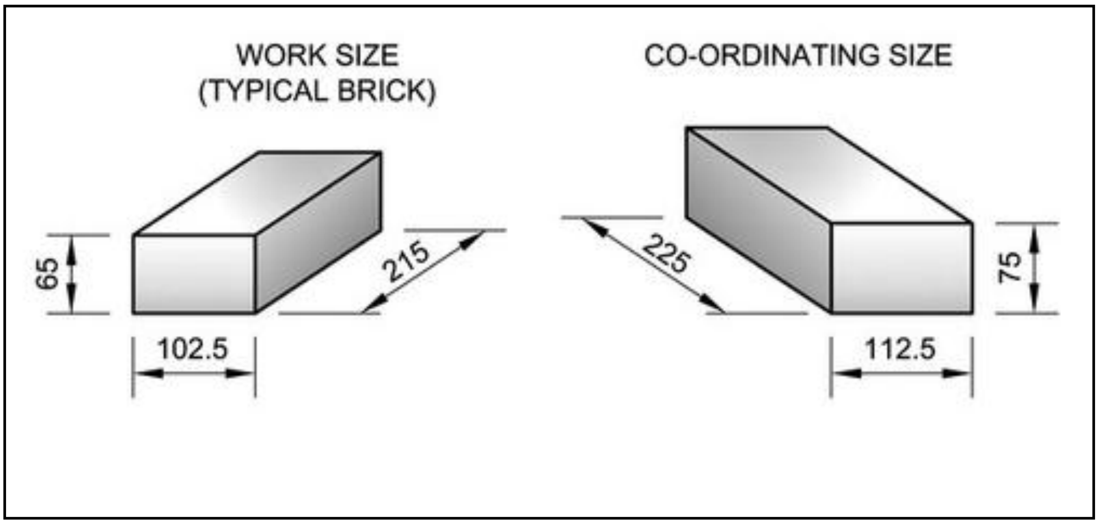


Figure 2.5: Brick Size (Janicki, 2012)

2.4 Fired Clay Bricks

Clay has been used to make bricks. Because of the versatility of clay, when it mixed with water, clay mineral give a plastic mass that can be formed by pressure and fired in a furnace (Seynou *et al*., 2011). This firing process transforms the clay into a building component in high performance of properties.

Fired clay brick can describe as common, facing or engineering brick. Common brick has no visual finish, and ordinarily used for general building work especially where brickwork is to be rendered, plastered or unseen in the finished work. It is also widely used as interior wall surface or exterior walls that are below the ground level.

Facing brick are manufactured to give an attractive finish. It was intended to be used in both structural and nonstructural masonry, where appearance required. The colour which may be uniform or multicoloured resulted from the mixes of clay used and the firing condition. Facing brick is available in a wide range of colours, textures, smooth, light or sandy. It often applies on the top or the surface of the wall for ecstatic factor.

Engineering bricks usually are dense, strong, used to support heavy loads, and also where the effects of impact damage, water absorption or chemical attack that needs to be minimized. They are usually classified as either Class A or Class B (Table 2.2). Moreover, they are further subdivided into facing and commons according to their properties.

2.5 Specification of Fired Clay Brick

Fired clay bricks vary considerably in physical and mechanical properties. They may be said to perform well in various aesthetic appearance such as durability, resistance to rain penetration, compressive strength, fire resistance, sound insulation, low thermal and moisture movement, economy, versatility in application and low maintenance requirements (Lyons, 2007). The physical and mechanical properties of clay brick can divide into five parameters which are compressive strength, water absorption, firing shrinkage, dry density and thermal conductivity.

2.5.1 Compressive Strength

The compressive strength of a brick is usually assessed by testing the sample of bricks. According to Victoria (2013), compressive strength of brick is affected by the porosity, pore size, and type of crystallization. Meanwhile, Fernandes *et al*. (2010)

suggested that the compressive strength depend on the origin of raw materials, manufacturing process and the degree of combustion. While incorporating waste into clay brick, several researcher has found that compressive strength also greatly dependent on the amount of waste in the brick and the firing temperature (Phonphuak, 2013; Sutas *et al*., 2012; Kadir and Mohajerani, 2012; Karaman *et al*., 2006).

According to BS 3921: 1985, the compressive strength must not be less than the stated strength for the appropriate class of brick. Clay bricks vary in strength from about 7N/mm^2 to well over 100N/mm^2. These should be a maximum of 70N/mm^2 for Class A engineering brick and 50N/mm^2 for Class B. Meanwhile, if others from both classes, the compressive strength is said over 5N/mm^2 for non loading application. Table 2.2 shows the classification of bricks by compressive strength and water absorption.

Table 2.2: The classification of bricks by compressive strength and water absorption (BS 3921, 1985)

Class	Compressive strength N/mm^2	Water Absorption % by mass
Engineering Brick A	≥ 70	≤ 4.5
Engineering Brick B	≥ 50	≤ 7.0
Damp – proof course 1	≥ 5	≤ 4.5
Damp – proof course 2	≥ 5	≤ 7.0
All others	≥ 5	No limits

2.5.2 Water Absorption

Water absorption is a measure of available pore spaces and is expressed as a percentage of dry brick weight. It is a key factor that affects the durability of bricks (Victoria, 2013; Phonphuak, 2013; Hegazy *et al*., 2012). Fernandes *et al*., (2010) determined that the water absorption as the capacity of the fluid to be stored and to exchange within the brick, favoring deterioration and reduction of mechanical strength. This porosity of bricks is shown to have some relation with water absorption (Demir, 2006). It was thought that an increase in water absorption value is due to an increase in the porous structure because of the existence both organic and inorganic content (Saiah, 2010; Folaranmi, 2009; Kadir and Mohajerani, 2008a).

Water absorption of bricks may vary considerably according to its type and the process of manufacture. By referring to BS 3921: 1985, it only specifies maximum average levels of water absorption, expressed as a percentage of the dry weight of the brick. These should be a maximum of 4.5% for Class A engineering bricks, or bricks used for damp-proof courses and an upper limit of 7.0% for Class B engineering bricks. Meanwhile, for other than both class, there are no limit for water absorption.

2.5.3 Firing Shrinkage

Clay brick may shrink during drying and firing process, thus, allowances are made in the manufacturing process to achieve the desired size of the brick. According to Karaman *et al*. (2006), shrinkage occurs when water between clay particles leaves particles come closer. A study by Weng *et al*. (2003) suggested that a good quality of bricks exhibit the shrinkage below 8%. Meanwhile, BIA (2004) has set the desirable limit for firing shrinkage (2.5% to 4%) and drying shrinkage (2% to 4%). To control excessive shrinkage and defects in the structure of the brick, evaporation of the free water surrounding the particles in plastic clay needs to controlled (CBA, 2002).

During the manufacturing of clay brick, temperature and amount of waste are the factors affecting firing shrinkage. High temperature and higher amount of waste will lead to high increasing of shrinkage (Weng *et al.*, 2003; Fatih and Umit, 2001). Therefore, these factors need to control during the firing stage to minimize the shrinkage of brick.

2.5.4 Dry Density

Density is the ratio between dry brick weight and the volume of clay brick, which measuring the proportion of clay found in the volume (Fernandes *et al.*, 2010). Dry density can be defined as the ratio of an object's mass over volume where mass is the amount of matter enclosed in an object. It varies from 2250kg/m^3 to about 2800kg/m^3, however, in general, the solid density of bricks are closed to 2600kg/m^3 (Kadir and Ariffin, 2013). Ali (2005) clarified that raw materials and manufacturing process can affect brick density, in a range between 1300kg/m^3 to 2200kg/m^3. Another study by Karaman *et al*. (2006) also found that the density of a brick also depends on specific gravity of clay, method of manufacture and degree of burning.

According to Phonphuak (2013), Kadir and Mohajerani (2010), Chiang *et al*. (2009) and Demir (2006) incorporation such waste in raw clay soil will decrease the density of a brick. This is due to the formation of pores inside the brick during firing stage. There are great advantages of lightweight bricks including lowering structural dead load, easier handling, lower transport cost and lower thermal conductivity (Celik *et al*., 2014; Kadir and Mohajerani, 2013; Phonphuak, 2013; Chiang *et al*., 2009).

2.6 Thermal Conductivity

Rathakrishnan (2012) define heat transfer as a science of energy transfer due to a temperature difference and there are three methods of heat transfer; conduction, convection and radiation. Table 2.3 shows the definition of these three modes (Rathakrishnan, 2012).

Table 2.3: Three methods of heat transfer (Rathakrishnan, 2012)

Modes	Definition
Conduction	• Is an energy transfer process from more energetic particles of a substance to the adjacent, less energetic ones as a result of the interaction between the particles
Convection	• Is the mode of heat transfer between a solid surface and the adjacent liquid or gas that is in motion
Radiation	• The heat transfer mode in which the energy is emitted by matter in the form of electromagnetic waves as a result of the changes in the electronic configuration of the atoms or molecules, dictated by their temperature.

Heat transfer by conduction comprises transfer of energy within a material without any motion of the materials as a whole. The Law of Heat Conduction also known as Fourier's Law states that the time rate of heat transfer through a material is proportional to the negative gradient in the temperature and to the area at right angles, to that gradient, through which the heat is flowing. The law said that the heat conducted through a cross section is proportional to the temperature difference

(Serth, 2007). This proportionally constant is called the thermal conductivity of the materials. From Fourier's Law;

$$Q = \frac{kA\Delta T}{L} \quad (2.1)$$

Therefore,

$$k = \frac{QL}{A\Delta T} \quad (2.2)$$

Where the thermal conductivity, k can define as the heat flow, Q per surface area A which is generated by the temperature gradient (ΔT) through the sample with thickness (L). Both factors are connected by the thermal conductivity (k). The unit for thermal conductivity is (W/mK).

Çengel (2007) defined thermal conductivity as the quantity of heat transmitted through a unit thickness of materials in the direction as a result of temperature difference under steady boundary condition. It can be expressed as the ability of the materials to conduct heat.

Code on Envelope Thermal Performance for Building (CETP, 2008) had listed the thermal conductivity value for different materials. Table 2.4 shows the k-value for primary building materials that is commonly used (CETP, 2008).

Table 2.4: k-value for building material (CETP, 2008)

Material	Density (kg/m^3)	k-value (W/mK)
1. Asphalt, roofing	2240	1.226
2. Glass, sheet	2512	1.053
3. Brick		
a. Dry (covered by plaster or tiles inside)	1760	0.807
b. Common brick wall (directly exposed to weather outside)	-	1.154
4. Concrete	2400	1.442

Table 2.4: (Continued)

Material	Density (kg/m^3)	k-value (W/mK)
	64	0.144
5. Concrete, lightweight	960	0.303
	1120	0.346
	1280	0.476
	144	0.042

2.6.1 Factors Affecting the Thermal Conductivity of Materials

Thermal design value for each building is different according to the intended use. It is important to determine thermal conductivity because it will influence the usage of the material in engineering application. The current demands for reducing energy consumption and usage of energy efficiency in building has required the researcher to proposed high performance of insulation materials especially clay brick (Shimizu *et al*., 2013; Katsube *et al*., 2006). The purpose of determination design thermal values are to analyze energy consumption, design of heating and cooling equipment, determine surface temperature, compliance with national building codes and consideration of non-steady state thermal conditions in buildings.

The thermal conductivity of materials is known to be a function of their porosity or density (Casa and Castro, 2014; Görhan and Şimşek, 2013; Gualtieri *et al*., 2010). Several researchers claimed that the thermal conductivity of brick is directly related to density (Saiah *et al*., 2010; Sutcu and Akkurt, 2009). Thermal conductivity will decrease as the density decreased because more air entrapped within the material. This would be happen during burning process, waste is easily burned out and removed the additives thus decreasing thermal conductivity of brick (Demir, 2006; Ugheoke *et al*., 2006).

In the meantime, the porosity also important in considering the thermal conductivity of materials. Many building materials, for example, clay bricks contain a certain volume of space or commonly known as porosity. The thermal conductivity decreases with increasing porosity. Saiah *et al*. (2010) found that during the combustion process, the organic matter created pores that increase the porosity from 11% to 18% thus decreased the thermal conductivity value by up to 32%.

2.7 Leachability

Environmental concern of the impact using building materials to human is becoming important (Cusidó and Cremades, 2012; Liu *et al*., 2009; Fujimori *et al*., 2004). Most bricks will be used outdoor and they will be exposed to rains (Liu *et al*., 2009). According to Hu *et al*. (2014); Victoria (2013); Cusidó and Cremades (2012); Sarode *et al*. (2010) and Liu *et al*. (2009), several studies have been made to investigate the potential of heavy metals that leached out to the environment from manufactured brick. Therefore, Toxicity Characteristic Leaching Procedure (TCLP) was conducted to determine the mobility of both organic and inorganic analysis present in liquid, solid and multiphase waste (EPA, 1992).

With the increasing level of trace and heavy metals in construction materials, it adversely affects the occupants. In this study, CBs was used in building materials. CBs contain thousands of chemicals that are toxic to humans and animals. Moreover, a study found that the toxicity of CBs leachates is in part due to heavy and traced metals (Micevska *et al*., 2006). To predict how much metals leached from the materials, investigation of their leaching behavior is needed. A study by Moerman & Potts (2011) suggested that heavy metals of Al, Ba, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sr, Ti and Zn most commonly leached from CBs.

2.8 Indoor Air Quality

Human is spending around 80% to 90% of their times indoors (Sarigiannis *et al*., 2011; Bruinen de Bruin *et al*., 2008). This indoor environment is often contaminated with various air pollutants (Posudin, 2008). A research by WHO (2002) in Program of Indoor Air Pollution reported that every year, indoor air pollution is responsible for more than 1.6 million annual death and 2.7% of the global burden of disease.

Indoor air quality (IAQ) has been receiving increased attention as it is required for a healthy indoor environment. Industry Code of practice on Indoor Air Quality (ICOP-IAQ: 2012) by Department of Occupational Safety and Health, Ministry of Human Resources Malaysia propose a standard to set minimum standards that give protection of health to employees and other occupants of an indoor or enclosed environment served by general mechanical ventilation and/or air conditioning system.

Meanwhile, the beginnings of poor IAQ are well known. Poor IAQ can cause a variety of short-term and long-term health problems. In ICOP-IAQ, problems can be due to air pollutants, contaminants or to inadequate pollution control despite otherwise normal or baseline rates of ventilation. Sources of indoor pollution are from different origins like the occupants themselves, inadequate materials or materials with technical defects, the work performed within, excessive or improper use of standard product, combustion gasses and cross contamination coming from other poorly ventilated zones. In ICOP-IAQ, there are four parameters to indicate IAQ to specify whether an indoor environment is comfortable and healthy or otherwise. There are chemical contaminants such as environmental tobacco smoke (ETS), carbon dioxide, formaldehyde and carbon monoxide; physical condition such as air temperature, humidity and air velocity; biological agents such as virus, spores and mites; and radiation such as radon. Table 2.5 shows the list of indoor air contaminant and the acceptable limits for ICOP-IAQ.

Table 2.5: List of indoor air contaminant (ICOP-IAQ, 2012)

Indoor Air Contaminants	Acceptable Limits		
	ppm	mg/m^3	Cfu/m^3
Chemical Contaminants			
a) Carbon monoxide	10	-	-
b) Formaldehyde	0.1	-	-
c) Ozone	0.05	-	-
d) Respirable particulates	-	0.15	-
e) Total volatile organic compounds (TVOC)	3	-	-

Table 2.5: (Continued)

Biological Contaminants			
a) Total bacterial counts	-	-	500*
b) Total fungal counts	-	-	1000*
Ventilation performance indicator			
a) Carbon dioxide	C1000	-	-

Notes:

- For chemical contaminants, the limit are eight-hour-time-weighted-average airborne concentrations
- mg/m^3 is milligrams per cubic meter of air at 25 °Celsius and one atmosphere pressure
- ppm is parts of vapor or gas per million parts of contaminated air by volume
- C is the ceiling limit
- Cfu/m^3 is colony forming units per cubic meter
- C is the ceiling limit that shall no be exceeded at any time. Readings above 1000ppm are indication of inadequate ventilation
- *excess of bacterial counts does not necessary imply health risk but serve as an indicator for further investigation.

The effects due to poor IAQ can be categorized into several major types. There are health effects due to environment tobacco smoke (ETS), sick building syndrome and *legionella* disease. ETS is defined as substances in indoor air arising from tobacco smoke where it is the combination of two forms of smoke from burning tobacco products; (1) side stream smoke, (2) mainstream smoke (ICOP-IAQ:2012). Mainstream smoke is generated by the smoker drawing air through the cigarette; meanwhile side stream smoke goes directly into the surrounding air from the combustion of the cigarette (Behan *et al*. 2005).

According to ICOP-IAQ: 2012, “sick building syndrome” is commonly used for illness that occurs among occupants as a result of poor IAQ in building. Most of the occupant will complains of symptoms related with acute discomfort such as headache, throat irritation, dizziness and sensitivity to odours. Moreover, sometimes they have difficulty to trace to any particular cause. As a result, the health problems will be increased.

Legionaire disease is another example of building illness and caused by bacteria. The bacteria *legionella pneumophila* will grow in condition where nutrient, water and temperature are met. This major source of the organism can be identified in water-cooling towers and warm water system. Without proper treatment, legionella can proliferate and disturbed through the building.

This assessment of ICOP-IAQ is done to identify the sources of the air contaminants, assess the exposure of the occupants to the air contaminants, and evaluate the adequacy of existing control measures and to recommend appropriate control measures to prevent or reduce risks. In this assessment, there are many factors that need to be considered. For example the sources of indoor air contaminants, employees are either directly or passively expose to environments tobacco smoke, employees either expose to air contaminants from indoor or outdoor sources, prescribe activities, the adequacy of mechanical ventilation, action to be taken to improve IAQ at the workplace.

2.8.1 List of indoor air contaminant

Morani *et al.* (1995) and Godish (1995) had listed the main pollutants of indoor air include inorganic pollutants, organic pollutants, physical pollutants, environmental tobacco smoke, combustion generated, microbial and biological contaminants and radioactive pollutants.

2.8.1.1 Total Volatile Organic Compounds (TVOCs)

Total volatile organic compounds (TVOCs) have received a great attention due to high abundances and associated impact on health especially in indoor environment. Guo and Murray (2001) defined TVOC is the one single parameter that is simpler and faster for the calculation of the concentrations (or emission rates) rather than evaluating several dozens of individual VOCs. Sources of VOCs including from carpet, building material, wood panel, paint, occupants, pets and other sources (Posudin, 2008).

2.8.1.2 Carbon Dioxide (CO_2)

Carbon Dioxide (CO_2) is odourless, colourless gas that is formed from burned carbon containing substances. It also produces by human metabolism and exhaled through lungs. CO_2 is normal constituent of the earth's atmosphere. The presence of high

CO_2 gases is high in the air may cause headaches, loss of judgment, dizziness, drowsiness and rapid breathing.

2.8.1.3 Carbon Monoxide (CO)

Carbon Monoxide (CO) is an odourless, tasteless and colourless gas. It is an unreactive gas and readily penetrates from outdoor without undergoing significant depletion by physical and chemical processes other than by dilution through air exchange. According to Jantunen (2006), CO may be generated from incomplete combustion due to low quality fuel, poor mixing or low combustion. Once CO presents in indoor air or outdoor air, it can be removed only by exchange with fresh air. CO can cause irreversible brain damage, coma and even death when exposed to high concentration.

2.8.1.4 Ozone (O_3)

Ozone (O_3) reactions that occur on material surfaces can lead to elevated concentrations of oxidized products in the occupied space of buildings. It is very reactive and easily reacts with unsaturated compounds that are commonly found in typical buildings (Levin, 2008). A study by Morrison and Nazaroff (2002) found that O_3 also react with oils found in linseed oil which is composed primarily of esters of linolenic, linoleic and oleic acids. Exposure to O_3 emission may pose a greater health hazard than the chemicals from which they are formed (Weschler, 2006).

2.8.1.5 Formaldehyde (HCHO)

Over the years, the release of HCHO in ambient air especially from building products has been continuously decreased. At room temperature, HCHO is colourless gas that is flammable and highly reactive. Sources of HCHO including building materials including wood products (plywood wall paneling, particleboard, and fiberboard), combustion sources, environmental tobacco smoke (ETS), durable press drapes, textiles and glues (Salthammer *et al*., 2010).

2.8.1.6 Particulate Matter (PM_{10})

Particulate Matter (PM_{10}) has been analyzed for several years. According to Vitez and Travnicek (2010), particle size is important physical properties of solids which are used in many fields of human activity. A study by Branis *et al*. (2005) found that sources of particulate matter not only from indoor activities, but also from outdoor activities. PM_{10} will affect significant health that include effects on the breathing and respiratory systems, the aggravation of existing respiratory and cardiovascular diseases, damage to lung tissues and premature mortality (Jimoda, 2012).

2.8.2 Emission from Building Materials

The building must fulfill a healthy and comfortable indoor climate to the people using it or otherwise, it has potential to affect health and well-being of occupants. Particularly, interest has been shown to the emissions from building material in response to the requirements of Industry Code of practice on Indoor Air Quality (ICOP-IAQ: 2012). Building materials emit a wide variety of indoor pollutants such as Total Volatile Organic Compound (TVOC), Carbon Monoxide (CO), Carbon Dioxide (CO_2), Ozone (O_3), Formaldehyde (HCHO) and particulate matter (PM_{10}). Present available data on gas emissions are insufficient to assist the researcher to make informed selections of materials. There are too few emissions tests results are available because of the lack requirements for emission testing.

Certainly, there is a need to develop tests that can be used by several researchers. Recently, environmental chamber testing is a practical solution that can be conducted to identify products that may emit significant quantities of toxic, irritating or odorous compound where environmental simulation is needed (Huang *et al*., 2013; Järnström, 2007; Levin and Hodgson, 1996). The environmental chamber can stimulate virtually types of environmental condition include temperature, relative humidity and air exchange rate. It varies from small size chambers to large scale size chambers.

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