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Investigation of Indoor Air Quality by Incorporating Sewage Sludge Waste into Fired Clay Brick

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Abstract. Generally, the production of sewage sludge waste has increased due to rapid growth of the population. Due to that, the disposal method has become crucial issues nowadays. Therefore, this research focuses on the investigation of indoor air quality of fired clay brick incorporating with sewage sludge. The bricks were incorporated with 0% and 5% of two type of sewage sludge and fired at 1050°C with heating rates 1°C/min. The experiment of Indoor Air Quality was obtained by measuring gases emissions of total volatile organic compound (TVOC), carbon dioxide (CO₂), carbon monoxide (CO), ozone (O₃), formaldehyde (HCHO) and particulate matter (PM₁₀) and were compared with Industry Code of Practice on Indoor Air Quality requirement standard. From the result shows that by incorporation of 5% of sewage sludge into fired clay brick complied with the standard requirement for building material usage with no negative effect to the environment. As the conclusions, the use of sewage sludge as clay replacement reduces the waste disposal in landfills and produce the low-cost building materials.

1. Introduction

Sewage sludge waste (SSW) is a sludge generated from wastewater treatment process during physical and chemical (primary), biological (secondary) and nutrient removal (tertiary) treatment [1,2]. A variety of biological, chemical, and physical pollutants found in sewage sludge are routinely digested at a municipal wastewater treatment plant (WWTP) [3]. Heavy metals elements like arsenic, lead, mercury, and nickel that are harmful to human health were present in sewage sludge waste [4-7]. Therefore, there is a significant issue of sludge remediation due to the huge production of the sewage sludge and the treating process is quite expensive [8]. The two most common disposal techniques used worldwide are landfill and distribute on reclaimed land [9,10]. This type of disposal have various degrees of environmental effect including groundwater pollution that occurs from landfill leachates, soil contamination as well as odour emissions [11,12].



Municipalities must manage the reuse, processing and disposal of sewage sludge effectively [13]. Previous research has shown that incorporating sewage sludge as the construction materials such as fired clay bricks is an alternative and effective method for reducing the hazards of sludge waste [14-17]. Clay bricks are made from natural resources, and their characteristics allow them to be combined with various types of sludge waste [18-24]. Other studies [25,26] show that incorporating sewage sludge into the production of fired clay bricks results in lighter bricks with better thermal, acoustical, and insulating properties than conventional bricks. As a result, it is clear that incorporating sewage sludge as a building and construction material is one of the potential methods of sludge disposal.

Many positive outcomes in terms of properties have been discovered when sewage sludge waste is incorporated into fired clay brick manufacturing. Nevertheless, indoor air quality assessment of the sewage sludge incorporated into fired clay brick receives less attention. Indoor air quality (IAQ) has received greater attention due to its importance in maintaining a healthy indoor environment. The standard that offers health protection to occupants of an enclosed or an indoor environment that served by air conditioning system as well as general mechanical ventilation was recommended by Industry Code of Practice on Indoor Air Quality (ICOP-IAQ) by the Department of Occupational Safety and Health, Ministry of Human Resources Malaysia. The factors in ICOP-IAQ is to determine whether an interior environment is safe and healthy or otherwise for the occupants. Carbon dioxide, formaldehyde, carbon monoxide and the environmental tobacco smoke (ETS) are the examples of chemical pollutants and physical conditions as humidity, air temperature and air velocity. Therefore, the goal of this research was to develop a better indoor air quality and better building materials for people as well as for the environment. In this study, the laboratory building size (cube, wall, and column) was conducted in a small chamber and the temperature and humidity controlled that comply with the Industry Code of Practice on Indoor Air Quality (ICOP-IAQ). Table 1 shows the list of indoor air parameters and the acceptable limits for ICOP-IAQ standard.

Table 1. Indoor air parameters and the acceptable limits (ICOP-IAQ, 2010)

Indoor Air Contaminants	Acceptable limits		
	ppm	mg/m ³	cfu/m ³
<u>Chemical contaminants</u>			
(a) Carbon monoxide	10	-	-
(b) Formaldehyde	0.1	-	-
(c) Ozone	0.05	-	-
(d) Respirable particulates	-	-	-
(e) Total volatile organic compounds (TVOC)	3	0.15	-

Notes:

- For chemical contaminants, the limits are eight-hour time-weighted average airborne concentrations.
- mg/m³ is milligrams per cubic meter of air at 25° Celsius and one atmosphere pressure.
- ppm is parts of vapour or gas per million parts of contaminated air by volume.

2. Methods

2.1. Raw materials preparation

The clay soil was obtained from a brick industry in Yong Peng, Johor. In the meanwhile, two types of sewage sludge were collected from the Indah Water Konsortium (IWK) in Batu Pahat, Johor. Clay soil and sewage sludge were through dry process in an oven at 105°C for 24hours to eliminate surplus moisture. After completely dry, the raw material was they were crushed and grind to make the sieving process easy. The 3.35-micron sieve was used for the sieving process.

2.2. Brick manufacturing

In this study, Control brick (CB) and Type A as well as Type B sewage sludge bricks are the three types of brick that were produced. The ratio mixture used in this study is shown in Table 2. The procedure of brick manufacturing began by combining clay soil with water. The procedure of mixing was carried out manually by hand. After being fully homogenized and compacted using an automated machine, the material was poured into the brick mould with the 215mm x 102mm x 65mm dimensions. The compacted brick through a drying process for 24 hours at 105°C in the oven. Brick production involves a final process called furnace firing. In this stage, the sample was fired in a lab furnace at a rate of 1°C per minute until it reached 1050°C.

Table 2. Mixture of brick manufactured

Mixture	Percentage (%)	Clay (g)	Sewage Sludge (g)	Water (ml)
Control brick (CB)	0	2800	0	476
Type A brick (A)	5	2660	140	510
Type B brick (B)	5	2660	140	507

2.3. Indoor Air Quality (IAQ)

In this study, IAQ was measured in the Walk in Stability Chamber (WiSC) that completely isolated from the outside air and gases. The Walk in Stability Chamber (WiSC) was designed to be utilized with the data logger device to regulated temperature and humidity and also insulated thermally. It has been designed to study on the indoor air quality, heat stress and thermal comfort assessment. The sample of building scaled fired clay brick has been built with a dimension of 1m x 1m x 1m for cube arrangement (Figure 1), 0.2m x 0.1m x 1.5m wall arrangement (Figure 2) and 0.5 m x 0.5 m x 1.5 m column arrangement (Figure 3). The parameters of air temperature and relative humidity were obtained in accordance with the standard requirements [27]. The gases that have been measured included the carbon monoxide (CO), carbon dioxide (CO₂), formaldehyde (HCHO), total volatile organic compound (TVOC), ozone (O₃) and particulate matter (PM₁₀). The average data collected was compared to the Industry Code of Practice on Indoor Air Quality after 8hours in the chamber [27].



Figure 1. Cube arrangement



Figure 2. Wall arrangement



Figure 3. Column arrangement

3. Results and Discussion

3.1. Total volatile organic compound (TVOC)

The effects of the tremendous abundance and accompanying health effects, particularly when present in enclosed spaces, TVOC have drawn a lot of attention. TVOC's short and long term negative effects on human health including irritation of throat, eyes, nose and membranes [28]. According to [27], the TVOC limit are 3ppm. Figure 4 illustrates TVOC against brick types in a wall, column, and cube arrangement. According to the graph, Type B brick emits the least amount of TVOC in the form of the wall arrangement with 0.10ppm, the column arrangement with 0.20ppm, and the cube arrangement with 0.10ppm. The Type A shows the higher TVOC emissions in the wall and cube arrangement with 0.40ppm and 0.50ppm as well as column arrangement at 0.30ppm respectively. In the meantime, CB

show the highest emissions in the column, with 0.50ppm. The TVOC emissions for all types of brick appeared to be low in all arrangement and below the 3ppm limit.

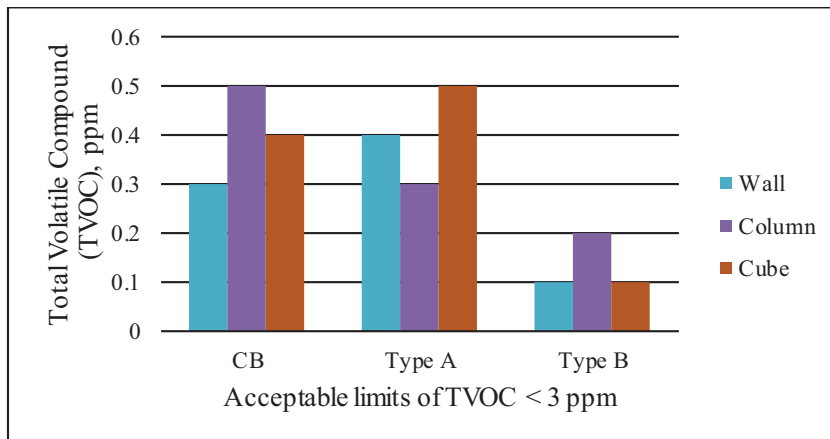


Figure 4. TVOC emission

3.2. Carbon dioxide (CO₂)

Carbon dioxide are typical air constituent that causes no concerns unless extremely high concentrations accumulate in the building. CO₂ is an odourless and colourless gas that is produced as a byproduct of human metabolic activity and can create the greenhouse effect, which increases global temperatures [29,30]. According to [27], the limitation of CO₂ level is 1000ppm. Figure 5 illustrates the CO₂ value for CB, Type A and Type B bricks. The results found that CB reached the peak of CO₂ in the shape of a wall at 504ppm, column at 621ppm, and cube at 598ppm. Meanwhile, the Type B column with 300ppm and the Type A wall arrangement with 323ppm demonstrating the lower of CO₂ result. As a conclusion, the production of fired clay brick is acceptable to use as building materials as well as below the 1000 ppm.

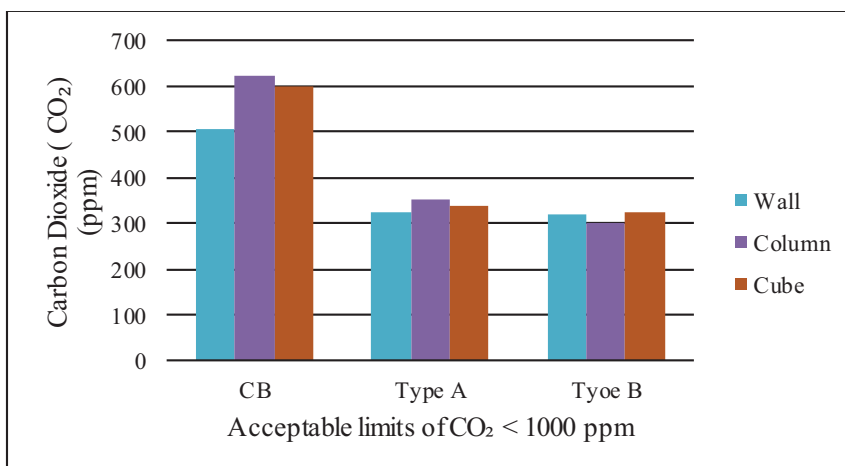


Figure 5. CO₂ emissions

3.3. Carbon monoxide (CO)

CO is a combustion product that indicates an issue with infiltration in the indoor environment. CO accumulation can trigger dizziness in building occupants [31]. According to [27], the CO limit is 10 ppm. Figure 6 illustrate the CO value for each brick sample. CB emits the most CO in the column and

cube, with 0.710ppm and 0.668ppm. In the meantime, CB release low CO at wall with 0.650ppm. Similar results are applicable for Type A and Type B bricks, with CO released in high concentrations in column of 0.697ppm and 0.659ppm, cube of 0.662ppm and 0.657ppm, and wall patterns of 0.653ppm and 0.648ppm respectively. Nevertheless, all of the bricks sample data are acceptable and pass the CO requirement of not exceeding 10 ppm.

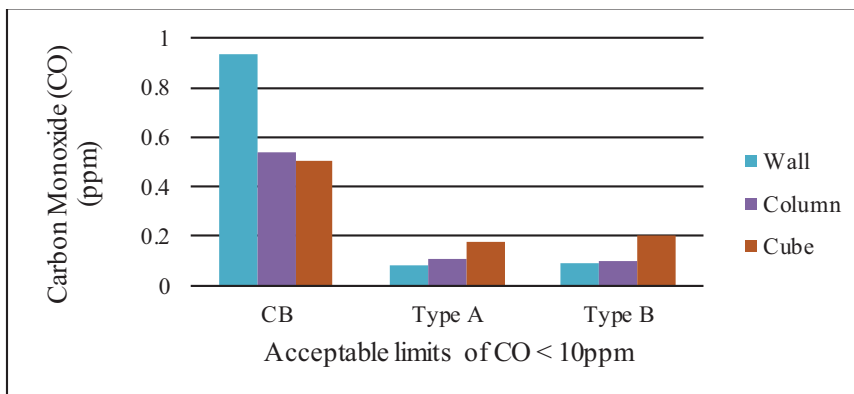


Figure 6. CO emission

3.4. Ozone (O₃)

Ozone (O₃) is a highly reactive gas that easily combines with unsaturated chemicals present in typical buildings. Exposure to O₃ emissions may provide a larger health risk [32]. The limitation standard for O₃ are 0.05ppm according to [27]. Figure 7 compares O₃ results for CB, Type A, and Type B. The results reveal that O₃ measured from CB has a consistent value of 0.01ppm of the wall, column, and cube arrangements. According to the graph, CB emitted the most O₃ compared to Type A and Type B sewage bricks. The lowest O₃ concentration with 0.005ppm was obtained in the Type B column arrangement. As a result, all samples meet the standard and do not exceed the limitation.

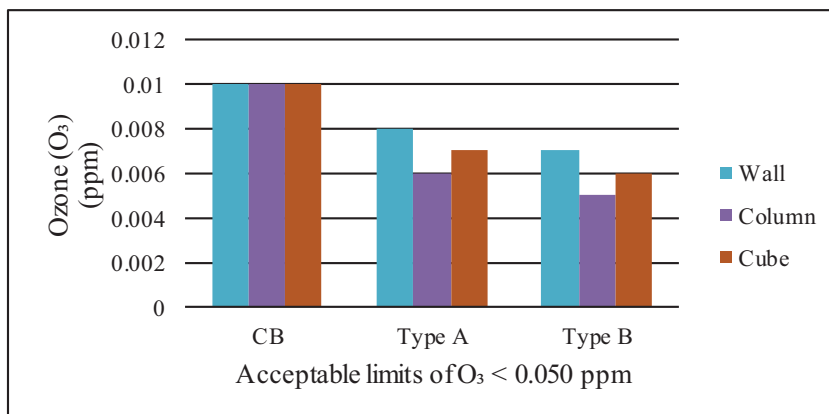


Figure 7. O₃ emissions

3.5. Formaldehyde (HCHO)

Formaldehyde (HCHO) is a gas formed by the oxidation of hydrocarbons. HCHO relates to the numerous chemical chemicals released by furniture in a building. HCHO is potential to irritate the eyes, nose, and respiratory system [33]. The acceptable limit of HCHO according to [27] is 0.100ppm. Figure 8 illustrates the HCHO of a CB, Type A and Type B brick sample. The graph shows that the highest

HCHO result was obtained from the CB, Type A, and Type B wall, with 0.01ppm, 0.011ppm, and 0.009ppm respectively. CB provides a constant value, while Type A and Type B decrease slightly within the arrangement of wall, column, and cube. According to the results, all types of brick samples produce the positive results with the lowest emission. Additionally, all of the bricks passed the standard limitation set by [27], which does not exceed 0.1 ppm of emission.

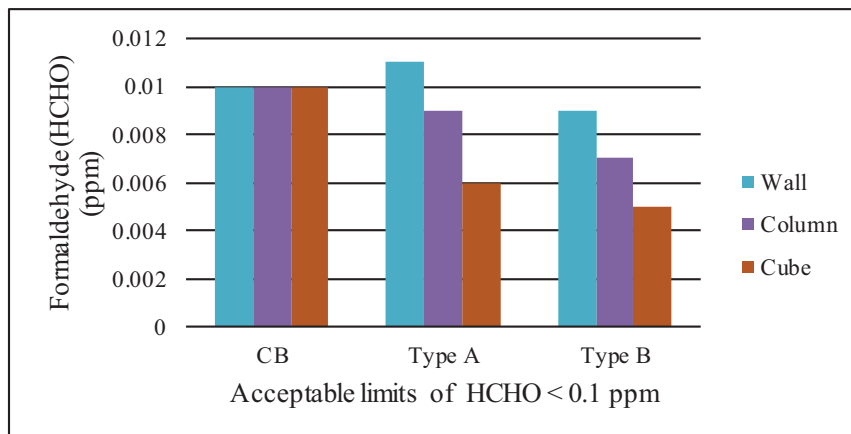


Figure 8. HCHO emissions

3.6. Particulate matter (PM_{10})

Particulate matter (PM_{10}), generally referred as particle pollution, is a mixture of solid and/or liquid particles suspended in the air. Building materials such as concrete, cement, wood, stone, and silica may provide a risk to human health related to PM_{10} . PM_{10} has a significant impact on health, including the lung and respiratory systems, the aggravation of existing respiratory and cardiovascular illness, lung tissue damage, and premature mortality [34]. The acceptable limit for PM_{10} is 0.150 mg/m^3 according to [27]. Figure 9 illustrated a graph for PM_{10} against all types of fired clay bricks. This value was measured in milligrams per cubic metre (mg/m^3). The result for the empty room (ER) was higher than the limit at 0.195 mg/m^3 , but the results for Type A and Type B show the same as the value hit the peak which was higher than acceptable limits. It rose up from 0.174 mg/m^3 to 0.230 mg/m^3 . According to the results, CB has the lowest emission and fulfills the requirements for wall at 0.109 mg/m^3 , column at 0.087 mg/m^3 , and cube at 0.095 mg/m^3 .

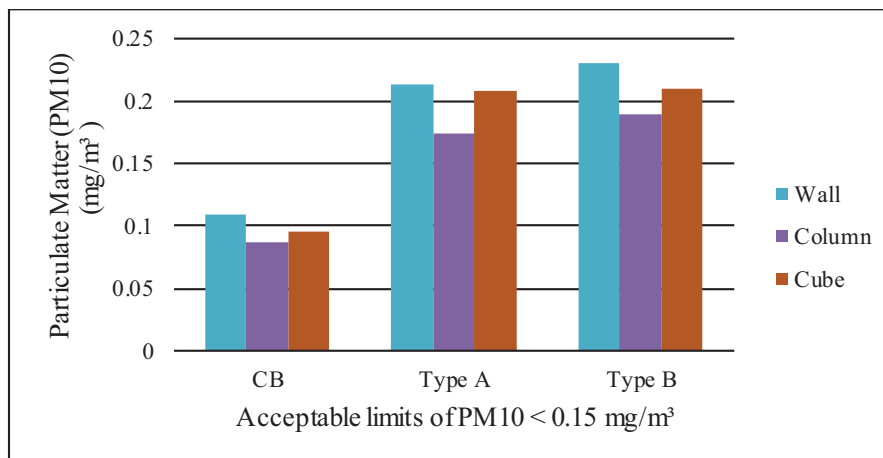


Figure 9. PM₁₀ emissions

4. Conclusions

The impact of incorporating 5% sewage sludge into fired clay bricks in term of indoor air quality (IAQ) assessment was investigated in this study. IAQ testing parameters included particulate matter (PM₁₀), carbon monoxide (CO), carbon dioxide (CO₂), ozone (O₃), formaldehyde (HCHO) and total volatile organic compound (TVOC) were based on standard of industry code of practice of indoor air quality (ICOP-IAQ). The results shows that with the exception of the PM₁₀ result, all values on Type A and Type B sewage bricks significantly lower in comparison to the CB results. The PM₁₀ result shows higher result than the limit and does not comply with the requirement. It is also already highly valued in empty room reading. This result might be related to a previous experiment conducted in the Walk in Stability Chamber (WiSC). However, the majority of parameters fulfill the requirements and are acceptable for use in indoor building material.

As a result, it is possible to conclude that utilizing sewage sludge as a partial replacement for clay in the manufacturing of fired clay bricks and as an alternative method of sewage sludge waste disposal is acceptable.

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