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CONSERVATION OF NATURAL RESOURCES: UTILIZATION OF SEWAGE SLUDGE IN BRICK AND ITS IMPACT ON GAS EMISSIONS AND INDOOR AIR QUALITY

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Abstract

As the production of sewage sludge waste has increased, sewage sludge disposal has become a critical concern. The increase in sludge waste will have a substantial effect on energy conservation and the environment. From a recycling perspective, the conversion of sewage sludge into construction materials is considered a rational solution. By incorporating the sewage sludge into fired clay bricks, it is expected to conserve non-renewable resources, be cost-effective, and minimise the quantity of sludge waste disposed in landfills. However, the application might pose a threat to the environment and human health. Therefore, this research focus on the investigation of pollutant gases during the firing process and the indoor air quality of the manufactured fired clay brick incorporated with sewage sludge. The bricks were incorporated with two types of sewage sludge (0% and 5%), fired at 1050ºC with 1ºC/min as its heating rate. The X-ray fluorescence (XRF) test was conducted to determine the characteristics of the sewage sludge and clay soil. The gas emissions measured during the firing process include carbon monoxide (CO), carbon dioxide (CO2), nitrogen oxide (NO), and sulphur oxide (SO2). As for the Indoor Air Quality, the measured gas emissions were total volatile organic compounds (TVOC), carbon dioxide (CO2), carbon monoxide (CO), ozone (O3), formaldehyde (HCHO), and particulate matter (PM10). All the gases were compared with Industry Code of Practice on Indoor Air Quality requirement standard. The results show that the incorporation of 5% sewage sludge into fired clay brick complied with the standard requirement for building material usage with no negative effect towards the environment.

Keywords*: Sewage sludge waste; Fired clay brick; Gas emissions; Indoor air quality; Waste management*

Introduction

Sewage sludge is generated every year due to the rapid growth of the population and urbanisation. In general, the municipal wastewater treatment plant (WWTP) receives approximately ten thousand to millions of cubic metres of domestic sewage daily and digests a different range of physical, chemical, and biological contaminants in the sludge [1]. In Malaysia, about 5.3 million m^3 per year of sewage sludge was produced by national sewage companies such

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as Indah Water Konsortium, which is expected to generate up to 7 million cubic metres by the year 2020 [2, 3]. According to previous studies, sewage sludge waste contained heavy metals such as arsenic, lead, mercury, and nickel that can be dangerous for human health [4-7]. The effect of high production of sewage sludge has led to major sludge disposal problems. Moreover, the cost to treat the sludge is very high, and it takes a long time to deal with the sludge [8]. Most current sludge disposal methods worldwide are landfilling and spreading on reclaimed land [9, 10]. However, these methods of disposal have varying degrees of environmental impact, such as groundwater pollution from landfill leachate, odour emissions, and soil contaminants [11, 12].

Therefore, immobilising the heavy metals in sewage sludge is an important factor in disposing of the sludge waste. The processing, reuse, and disposal of sewage sludge must be managed by municipal authorities in an effective way [13]. According to several previous studies, by valorization the sewage sludge waste into construction material such as fired clay bricks has proven to be an alternative and effective method to reduce the potential hazard of the sludge waste [14-17]. Clay bricks are produced by using existing natural resources; the properties of clay allow their combination with different types of sludge waste [18-21]. This has also been supported by Wiemes *et al.* [22] and Samadikun *et al.* [23] which stated that the chemical composition of sewage sludge is extremely similar to the clay brick and could be a potential substitute for clay brick. Other than that, a study by Liew *et al.* [24] and Zhang *et al.* [25] shows that by incorporating sewage sludge into fired clay bricks, manufactured bricks has produced lighter bricks with better thermal, acoustical, and insulating properties compared to conventional bricks. Therefore, it seems evident that the incorporation of sludge waste as a building and construction material can be considered one of the most promising disposal methods for sludge waste.

However, the rapid growth of the brick industry all over the world has resulted in some pollutant gases being released from brick manufacturing industries. Brick industries have been one of the major sources of greenhouse emissions in the world [26, 27]. During the firing process of brick manufacturing, pollutant gases may derive, such as carbon dioxide, nitrogen oxide, sulphur oxide, inorganic fluorine and chlorine compounds, and also organic compounds [28-30]. These pollutant gases have a negative impact not only on the environment but also on human health.

Other than that, indoor environmental quality, especially indoor air quality, has been a growing concern because the majority of individuals spend most of their time in indoor environments. With the introduction of chemical pollutants in the building industry, the coexistence of materials in the indoor environment exposes individuals to the complex composition of air pollutants [31, 32]. Indoor air pollution is generally comprised of a mixture of particulate matter (PM_{10}), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and volatile organic compounds (VOCs) [33, 34]. The main health effects of indoor air pollution include irritation, respiratory infection, and Sick Building Syndrome (SBS), among others [35]. In order to ensure the occupants of buildings are protected from poor indoor air quality that could adversely affect their health and reduce productivity, the Ministry of Human Resources in Malaysia introduced the Code of Practise on Indoor Air Quality by the Department of Occupational Safety and Health in 2005 [36] to protect an indoor or enclosed environment.

Many promising results in terms of properties have been observed with the incorporation of sewage sludge waste in fired clay brick manufactured; however, less attention is focused on the gas emissions during firing and indoor air quality of the brick. Therefore, this study will focus on the gases that will be emitted during the manufacturing of the brick and the environmental impact of fired clay bricks in terms of indoor air quality.

Experimental part

Materials

Clay soil was collected from the Brick Company located in Yong Peng, Johor. Meanwhile, sewage sludge was obtained from the Indah Water Konsortium (IWK), which is located at Batu Pahat, Johor. Upon arrival, clay soil and sewage sludge were dried in an oven for 24 hours at 105ºC to remove the excess water content in the raw materials. Both raw materials were grinded and crushed to make the sieving process easier after they were completely dry. A passing sieve of 3.35 microns was used to manufacture a clay brick. Figure 1 shows the raw materials after the sieving process.

Fig. 1. Grinded of clay soil (left) and sewage sludge (right)

X-Ray fluorescence (XRF) was used to determine the chemical composition and heavy metal concentration of both clay soil and sewage sludge. The Atterberg limit test and specific gravity test were conducted according to British Standard (BS) [37] for geotechnical tests. Other than that, in order to determine the optimum moisture content of control brick (CB), sewage brick A (SBA), and sewage brick B (SBB) during the mixing process, a standard proctor test was conducted according to BS [38].

Methods

Brick manufacturing

There are three types of brick that were manufactured: control brick (CB), and Sewage brick A (SBA), and Sewage brick B (SBB). Table 1 shows the ratio mixture for this study. The process started by mixing clay soil with water, as mentioned in Table 1, for a control and sludge brick. The mixing process was conducted manually. The mixture was placed into the following size brick mould (215 x 102 x 65mm) after being completely homogenised and compressed with an automatic machine. The compacted brick was dried for 24 hours in an oven at 105°C. A final step in manufacturing brick is firing it in a furnace. In this study, a laboratory furnace was used, heating rates at 1°C/min until the final temperature reached 1050°C.

Table 1. Ratio mixture of CB, SBA and SBB

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

Gas emissions during firing

Emissions from the brick samples were measured directly from the furnace using a connector from the gas detector, as illustrated in figure 2. The gas detector (YES Air Gas Detector) was equipped with sensors for carbon monoxide (CO), carbon dioxide (CO_2), nitric oxide (NO), and sulphur dioxide (SO_2) to measure the emissions. Gas measurements were recorded at 5-minute intervals at each specified temperature, specifically at 200, 250, 300, 400, 500, 600, 700, 800, 900, 1000, and 1050ºC. The initial reading at 100°C should not be taken as allowing water vapour to be released from the brick body. 1°C/min heating rate were applied during the firing process. The final temperature was set to 1050°C with 2 hours of soaking time. The emissions from the brick firing process with 1°C/min heating rates were measured and subtracted from the sample data.

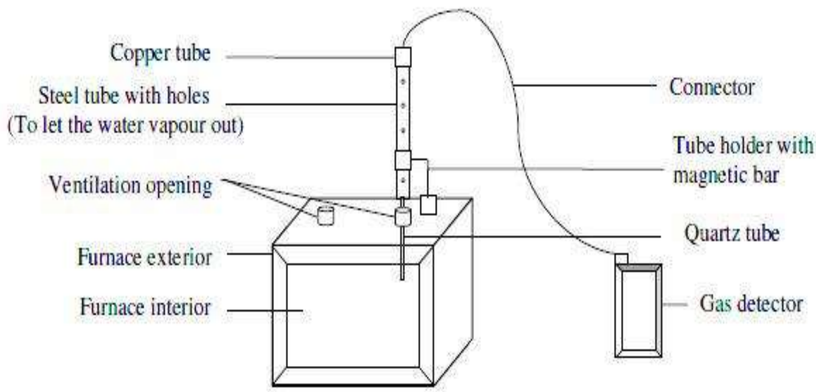

Fig. 2. Experimental set-up for measuring the concentration of gas emissions

Indoor Air Quality

In this study, IAQ was conducted in the Walk in Stability Chamber (WiSC), which is isolated from outside air and gases. The Walk in Stability Chamber (WiSC) was thermally insulated and designed to be used at a controlled temperature and humidity with the data logger system. It has been designed to study thermal comfort, heat stress, and indoor air quality. The sample of building scaled fired clay brick has been built with a dimension of 1.0×1.0×1.0m^3 (Fig. 3), 0.2×0.1×1.5m wall (Fig. 4), and 0.5×0.5×1.5m column (Fig. 5). The properties of air temperature and relative humidity were determined according to the standard requirements [36]. The gases that have been measured are carbon monoxide (CO), carbon dioxide (CO_2), formaldehyde (HCHO), total volatile organic compounds (TVOC), ozone (O_3), and particulate matter (PM_{10}). After eight hours in the chamber, the data that was collected on average has been compared with the standards of the industry code of practise on indoor air quality [36].

Fig. 3. Cube pattern

Fig. 4. Wall pattern

Fig. 5. Column pattern

Results and discussion

X-Ray fluorescence (XRF) analysis, compressive strength, and indoor air quality (IAQ) were testing parameters conducted in this study. The results of the testing were discussed thoroughly.

Properties of raw materials

The characteristics of raw materials have been obtained using XRF. Table 2 shows the chemical composition of clay soil and sewage sludge. From the results, it shows that the highest percentage of chemical composition for clay soil is silicon dioxide (SiO_2) with 49.30%, aluminium oxide (Al_2O_3) with 18.40%, and iron oxide (Fe_2O_3) with 6.78%. Meanwhile, the minor composition in clay soil is magnesium oxide (MgO) with 0.80%, titanium oxide (TiO_2) with 0.94, and manganese oxide (MnO) with 0.4%.

Table 2. Chemical composition of raw materials

Element	Chemical composition		
	Clay soil	**Type A sewage sludge**	**Type B sewage sludge**
SiO_2	49.30	14.30	16.30
Al_2O_3	18.40	6.66	4.79
Na_2O	n.a	0.23	n.a
K_2O	3.09	0.71	1.07
Fe_2O_3	6.78	9.85	9.35
CaO	n.a	6.55	2.40
MgO	0.80	1.15	0.85
P_2O_5	n.a	5.58	6.68
TiO_2	0.94	0.50	0.52
MnO	0.4	0.6	0.5
SO_3	n.a	9.20	4.61

n.a = not available

Other than that, the result shows that the highest chemical composition in sewage sludge is silicon dioxide (SiO_2), with 14.30% for type A sludge and 16.30% for type B sludge. Other higher compositions in type A and type B sludge are aluminium oxide (Al_2O_3) with 8.98% and 9.79% and iron oxide (Fe_2O_3) with 9.85% for type A and 9.35% for type B sludge, respectively.

Meanwhile, nitric oxide (Na_2O), titanium oxide (TiO_2), and manganese oxide (MnO) show the lowest composition in both types of sludge.

As can be seen from the result, the composition of sewage sludge and clay soil was similar, so the sludge is very reliable as a replacement for clay soil. *Hegazy et al.* [39] stated that sewage sludge can be successfully incorporated into clay brick due to the high silica content that can enhance the physical properties of brick.

Gas emission during firing process of brick

Emission of carbon monoxide (CO)

Carbon monoxide (CO) is a toxic gas that is produced during combustion. Complete combustion of carbon produces carbon dioxide, but incomplete combustion produces largely CO [40]. Figure 6 shows the emission of CO from all types of brick.

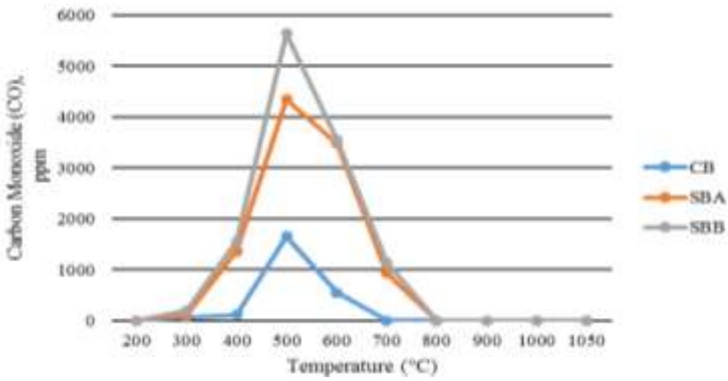

Fig. 6. Variation of CO emissions

A study by Akinshipe and Kornelius [27] described that carbonaceous matter in clay starts to burn out at about 200-350°C to form hydrocarbons and more carbonaceous residues that combusted to emit CO. The same result was obtained in this study, which shows the emissions of CO start to release from 300 to 700°C with a high peak of emission at 500°C. The highest emission of CO was recorded from sewage brick B (SBB), followed by sewage brick A (SBA) and control brick (CB) with 5642, 4347, and 1660ppm, respectively. According to Batistella *et al.* [41], the high CO concentration found in high organic matter such as SBA and SBB in this study contributed to the high oxygen content and high temperature that may have promoted the initiation of organic matter oxidation. After 700°C, CO starts to decrease since the oxidation of carbonaceous matter is complete.

Emission of carbon dioxide (CO_2)

The release of CO_2 is due to the combustion of carbonates and carbonaceous matter contained in brick [42]. Figure 7 shows the gas emissions of carbon dioxide for all types of brick. From the graph, it shows that the peak pattern of emissions occurred between 200°C to 700°C with the highest peak emissions at 400°C from CB, SBA, and SBB. A low concentration was recorded by CB with 2459ppm. Meanwhile, 5% of SBA and SBB have increased CO_2 emissions to 6345 and 7632ppm, respectively. After 1000°C, the CO_2 for all types of bricks has reached zero emissions. The result indicates that incorporating sewage sludge into brick production released high CO_2 levels during the firing process. The same result was obtained by Chen and Kuo [43], which shows the higher CO_2 released during the firing process when reusing the sewage sludge into brick production compared to conventional brick.

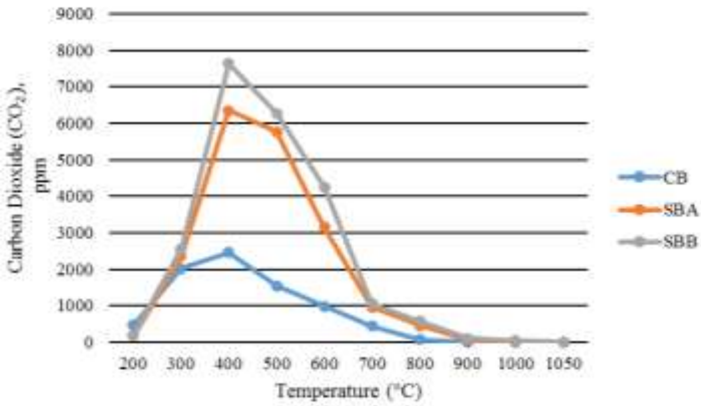

Fig. 7. Variation of CO_2 emissions

Emission of nitrogen oxide (NO)

Gases emissions of Nitrogen Oxide (NO) from all types of bricks are presented in figure 8. NO is released to the atmosphere potentially because of the oxidation of nitrogen by burning at high temperatures [44]. The result shows that the NO emissions for CB, SBA, and SBB were between 400 and 900°C with a high peak of emissions at 700°C. By comparing the emission from the different types of brick, CB released low NO with 18.5ppm in contrast to SBB and SBA with 20.7 and 20.1ppm, respectively.

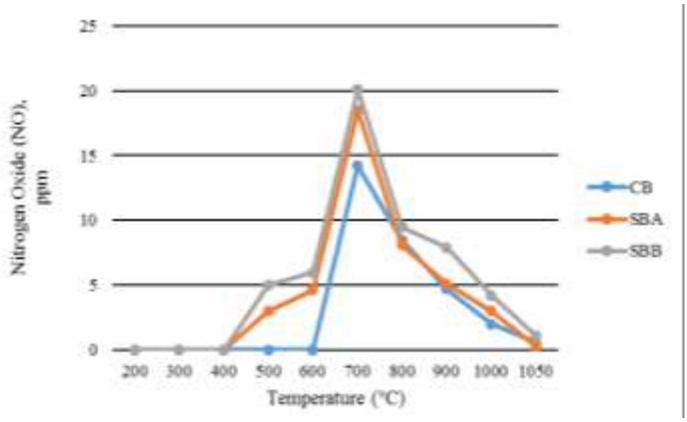

Fig. 8. Variation of NO emissions

Emission of sulphur dioxide (SO_2)

Figure 9 presents the gas emissions of SO_2 for CB, SBA, and SBB. The combustion of sulphur contained in brick may derived the SO_2 [45]. From the result, it shows that the dominant emissions of SO_2 are from CB in the range between 200 and 500°C with a high peak of 400°C. Different patterns of SO_2 peak emission for SBA and SBB are between 400 and 700°C with a high peak of 500°C. By comparing the emission from different types of brick, SBA releases the lowest SO_2 compared to CB and SBB with 0.3 ppm, 0.4 ppm, and 0.86 ppm, respectively. The same result has been obtained by another researcher, who stated that oxidation of sulphate compounds occurred at a temperature of 400°C [46].

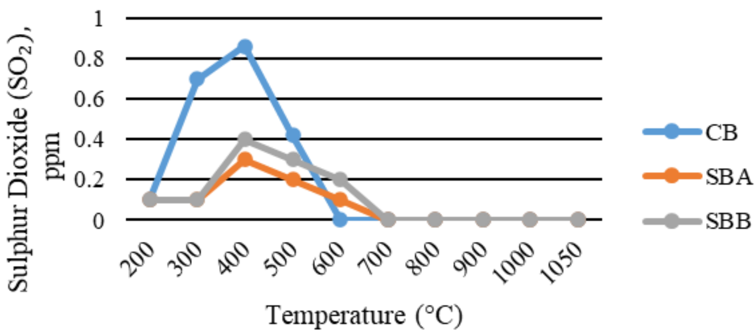

Fig. 9. Variation of SO_2 emissions

Indoor air quality of brick (IAQ)

Total Volatile Organic Compound (TVOC)

The amount of volatile organic compounds obtained from indoor air is often called the "total volatile organic compound," or TVOC. Sources of TVOC include carpet, wood panels, paint, occupants, pets, and other sources. TVOC have received great attention due to its high abundance and associated impact on health, especially in indoor environments. TVOC has a short-term and long-term adverse effect on human health, including irritation of membranes, eyes, nose, and throat [47]. According to the Department of Safety and Health Malaysia [36], the limitation for TVOC is 3 ppm. Figure 10 shows TVOC values against types of bricks in the pattern of wall, column, and cube.

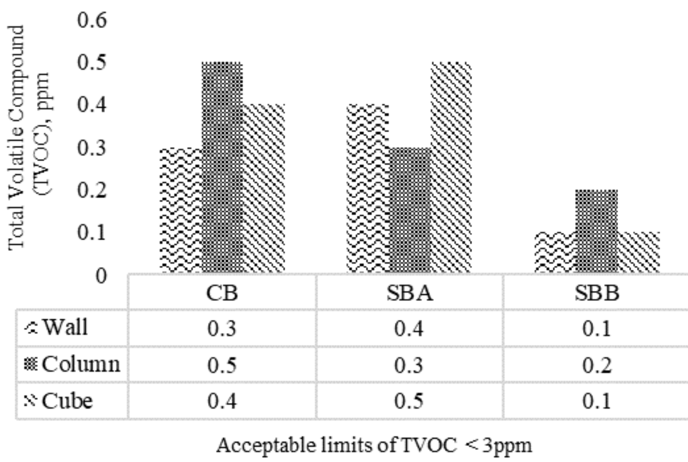

Fig. 10. TVOC emission

The graph shows that SBB releases the lowest emissions in the form of a wall at 0.10 ppm, a column at 0.20ppm and a cube at 0.10ppm. For the SBA, it received the majority of the highest emissions of TVOC in the form of walls and cubes at 0.40 and 0.50ppm and columns at 0.30ppm. On the other hand, in the column pattern, CB has the highest emissions, rather than SBA and SBB with 0.50ppm. The TVOC level for CB, SBA, and SBB appeared to be minimum in every pattern and below the limit, which is 3ppm.

Carbon dioxide (CO_2)

Carbon dioxide (CO_2) is a common air element and does not cause problems except at very high concentrations accumulated in the building. CO_2 is an odourless and colourless gases that is a by-product of human metabolic activity. The high CO_2 gases can cause the greenhouse effect, which increases the earth's temperature [48, 49]. Based on the limitation from the standard [36], the CO_2 is about 1000ppm. Figure 11 shows the values of CO_2 for CB, SBA, and SBB. The result shows that CB (0%) hit the peak of CO_2 in the form of a wall, column, and cube at 504, 621, and 598ppm respectively. Meanwhile, the SBA (5%) and SBB (5%) obtained lower results in each form, with the SBB column at 300ppm and the SBA wall at 323ppm showing the lowest CO_2 emissions. As a conclusion, bricks manufactured from fired clay are safe to be used as building materials and have passed the below limitation, which is 1000ppm.

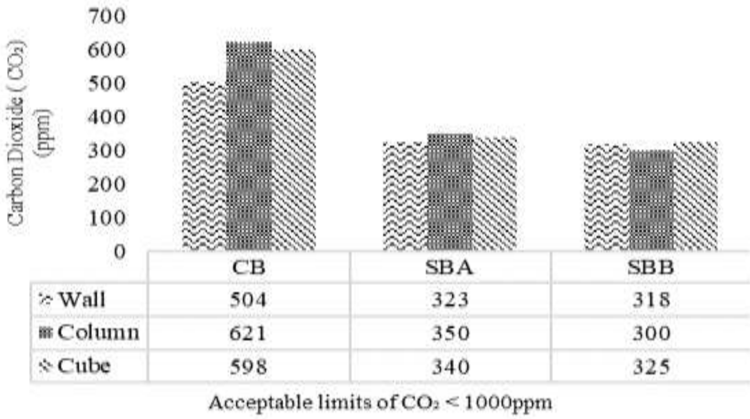

Fig. 11. CO_2 emissions

Carbon monoxide (CO)

Carbon monoxide (CO) is a gas that is colourless, odourless, and tasteless. CO is part of the combustion product and indicates the infiltration issue in the indoor environment. The high accumulation of CO can cause dizziness in building occupants [50]. Nevertheless, the limitation of CO is 10ppm, according to the standard [36]. Figure 12 shows the value of CO for the CB, SBA, and SBB. Overall, CB releases the highest emissions of CO in the column and cube patterns, with 0.710ppm and 0.668ppm, respectively. Meanwhile, CB releases low CO at the wall pattern at 0.650ppm. Same goes to SBA and SBB; CO released high concentrations in column patterns with 0.697ppm and 0.659ppm, cube patterns with 0.662ppm and 0.657ppm, also followed by wall patterns with 0.653 and 0.648ppm, respectively. Nevertheless, all the data for CB, SBA, and SBB still satisfy and comply with the standard of CO, which did not exceed 10 ppm.

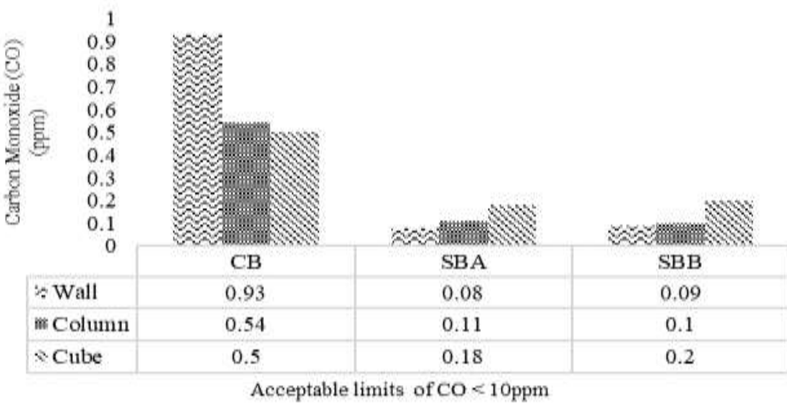

Fig. 12. CO emission

Ozone (O_3)

Ozone (O_3), formerly known as ozone, is a colourless gas. It is very reactive and easily reacts with unsaturated compounds that are commonly found in typical buildings. Exposure to O_3 emissions may pose a greater health hazard [51]. According to industry code of practice on indoor air quality [36], the acceptable limit for O_3 is 0.05 ppm. Figure 13 shows the comparison of O_3 gases for CB, SBA, and SBB. The result shows that O_3 measured from CB demonstrated a constant value in the form of a wall, column, and cube at 0.01 ppm. However, based on the graph, CB demonstrated the highest O_3 emissions compared to SBA and SBB. The lowest O_3 value was obtained in the SBB column pattern with 0.005 ppm. Thus, all samples comply with the standard, which does not exceed the limitation from the standard requirement.

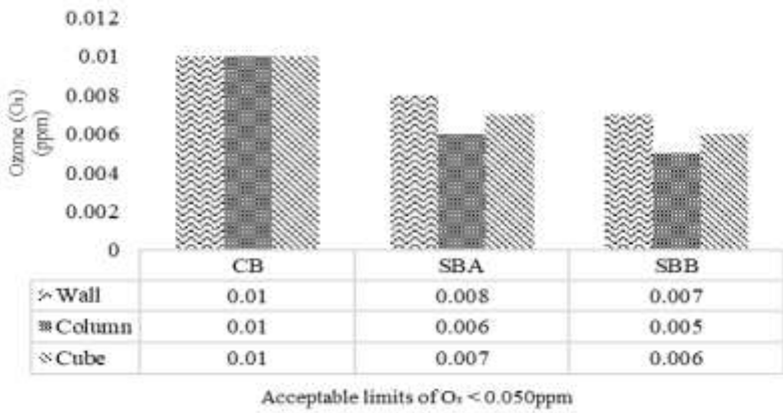

Fig. 13. O_3 emissions

Formaldehyde (HCHO)

Formaldehyde (HCHO) is a gas that is composed of hydrocarbons and oxidation. HCHO is one of the various chemical substances in buildings that are emitted from furnishings. The effect of HCHO is likely irritating to the eyes, nose, and respiratory system [33]. According to industry code of practice on indoor air quality [36], the acceptable limit of HCHO is 0.100ppm. Figure 14 shows the results of HCHO for CB, SBA, and SBB. The graph clearly shows that the highest HCHO result obtained from the wall patterns of CB, SBA, and SBB was 0.01, 0.011, and 0.009ppm, respectively. The CB gives a constant value, while SBA and SBB slightly decrease within the form of arrangement by wall, column, and cube. Based on the data obtained, all types of brick samples show the best result with the lowest emission. In addition, all the bricks were complying with the standard limitation [36], which does not exceed 0.1ppm of emission.

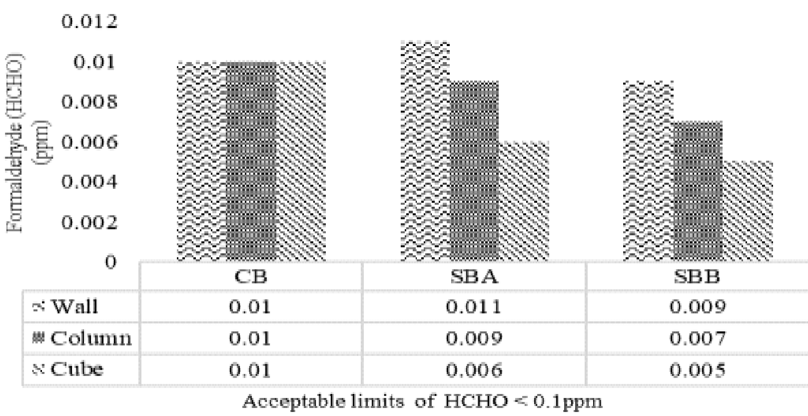

Fig. 14. HCHO emissions

Particulate matter (PM_{10})

Particulate matter (PM_{10}), also referred to as "particle pollution," is a mixture of solids and/or liquids suspended in the air. Potential hazard of building materials such as concrete, cement, wood, stone, and silica to human health-related PM_{10}. PM_{10} affects significant health outcomes that include the breathing and respiratory systems, the aggravation of existing respiratory and cardiovascular disease, damage to lung tissue, and premature mortality [52]. According to the standards of the industry code of practise on indoor air quality [36], the acceptable limit for PM_{10} is 0.150mg/m^3. Figure 15 shows the graph for PM_{10} against types of fired clay bricks. This parameter was measured in milligrammes per metre cube (mg/m^3).

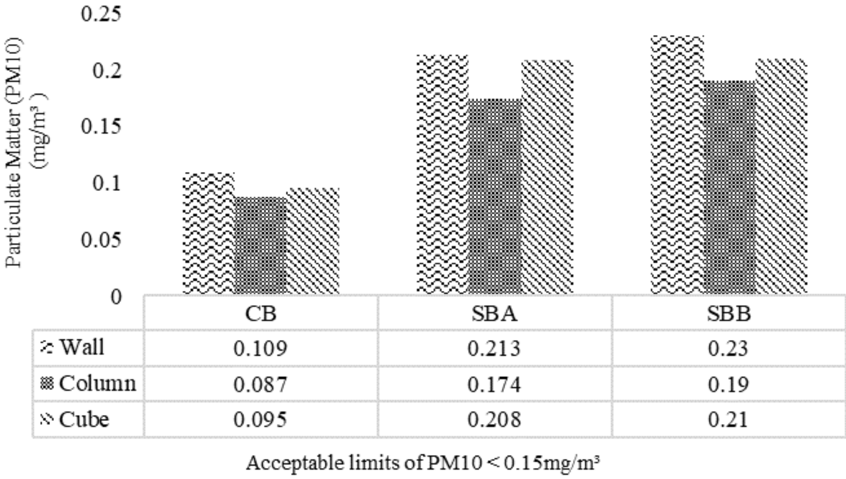

Fig. 15. PM_{10} emissions

Empty room (ER) result shown greater values than the limitation provided with 0.195mg/m³. SBA and SBB results also indicate the same pattern as the values recorded were higher than the acceptable limits. The increased values range from 0.174mg/m³ to 0.230mg/m³. From the results obtained, CB shows the lowest emission and complies with the standard provided for wall at 0.109mg/m^3, column at 0.087mg/m^3 and cube at 0.095mg/m^3 respectively. In conclusion, in terms of particulate matter (PM_{10}), the incorporated sewage sludge with fired clay brick demonstrated higher value than the acceptable limits provided.

Conclusions

This study investigated the effect of incorporating 5% of sewage sludge into fired clay bricks on the gas emissions during the firing process and indoor air quality (IAQ) assessment of the manufactured bricks. As for the gas emission experiment, the results showed that the incorporation of sewage sludge significantly increased CO, CO_2, and NO emissions. Moreover, the results indicated that the SO_2 emissions from SBA and SBB were relatively low compared to other emissions but much higher in CB. This result was also supported by Ukwatta and Mohajerani [53], who stated that the increasing organic content in bricks could contribute to higher gas emissions during the firing process of bricks.

As for the IAQ assessment, all the parameters that have been tested, including total volatile organic compounds (TVOC), carbon dioxide (CO_2), carbon monoxide (CO), ozone (O_3), formaldehyde (HCHO), and particulate matter (PM_{10}), were based on the standard of the industry code of practise for indoor air quality (ICOP-IAQ). From the result, it shows that all parameters of gas on SBA and SBB were lower compared to CB except for the PM_{10} result. The PM_{10} result is higher than the limit and does not comply with the standard. Worth to mention, the PM_{10} value recorded in an empty-room reading is also quite high that might due to uncertain circumstances in the Walk in Stability Chamber (WiSC). However, the majority of parameters were in compliance with the standard and safe to be used in indoor building materials.

Therefore, it can be concluded that the utilisation of sewage sludge could be a compatible partial replacement material for clay in fired clay brick manufacturing. In addition, it will also provide alternative methods for disposing of the sludge waste. The findings also demonstrated that sewage sludge brick production has a low environmental impact and complies with the standards used in this study. Therefore, sewage sludge has the potential to become an environmentally friendly construction material while also contributing to the conservation of natural resources.

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