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Research paper



Impact of Indoor Air Quality by Incorporating Agricultural Waste Into Fired Clay Brick

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Abstract

The demand for edible oil from all over the world has generated a huge amount of solid waste. Due to that, the problem of disposal method has become a constraint by the authorities. Therefore, this study is focusing on the incorporation of palm kernel shell (PKS) into fired clay brick in terms of indoor air quality assessment. The brick was incorporated with 0% and 5% of PKS and fired at 1050°C with heating rates of 1°C/min. Preliminary analysis was conducted with X-Ray Fluorescence test to determine chemical composition of raw materials used in the study. A further experiment of indoor air quality was obtained by measuring gases emission of total volatile organic compound (TVOC), carbon dioxide (CO_2), carbon monoxide (CO), ozone (O_3), formaldehyde (HCHO) and particulate matter (PM_{10}) in Walk in Stability Chamber with controlled temperature and relative humidity. All parameters were compared with Industry Code of Practice on Indoor Air Quality standard. The result shows that incorporation 5% of PKS into fired clay brick complied with the standard requirement for use as building materials. As the conclusion, the use of palm kernel shell as clay replacement could reduce the waste disposal in landfills whilst providing low-cost building materials.

Keywords: *Agricultural waste; fired clay brick; indoor air quality; palm kernel shell.*

1. Introduction

Palm oil production in Malaysia is a second largest producer after Indonesia [1]. According [2], the expanded manufacturing of palm oil has brought tons of palm oil waste in Malaysia. The process from fresh fruit bunches (FFB) consist of crude palm oil and palm kennel, most of the biomass residues in palm fibres, palm kernel shells and empty bunches are higher in fibre content was produced by palm oil manufacturer [2]. The effect of production of palm oil leads to major waste disposal that consists of empty fruit bunch (EFB), palm kernel shell (PKS), mesocarp fibre (MF), oil palm fond (OPF) and palm oil trunk (POT) which collected from milling process and cultivation results [3].

Most of Palm kernel shell (PKS) in Malaysia was utilized as a material for activated carbon production [4]. Moreover, in comparison of PKS with others solid waste, PKS is more decent because of its high chemical stability, porous surface, high mechanical strength, various surface functional groups, and insolubility in water [4]. Many researchers previously utilize palm oil waste for production of biofuel which using torrefaction technology for improvement of fuel characteristics and also renewable energy source [5]. Therefore, this concludes that the disposal of PKS as open burning and dumping is unacceptable method, thus more researchers are interested to develop new alternative of application for this waste.

Bricks are one of the oldest and constructing materials that have been used for an extended period of time [6]. Brick is typically used for major construction for civil engineering work in making walls, pavements and others in the construction of masonry [7]. Due to its strength, durability, weather resistance, simplicity and durability, brick has been practised extensively and have been given a place in history [8, 9]. Fired clay bricks are one of the toughest building components and it is known as engineering brick.

According to [10], the manufactured bricks is important due to its availability, low-cost production and one of the strongest material and high durability that is made from local sources. Moreover, building brick are commonly made from a mixture of clay that has been subjected to certain processes, varying by material type, manufacturing method and finished product properties. Many types of brick that have been used in construction work such as heavy-duty building brick, perforated building, building brick, facing brick, hollow brick, sewer or acid brick, paving brick, special brick, fly ash brick and fired clay brick [11].

Many promising results in terms of properties have been observed, however, less attention is focused on the indoor air quality (IAQ) of the fired clay brick manufactured. IAQ refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants. A good indoor air quality can contribute a quality and productivity to the human surrounding. Therefore, this study was conducted to access environmental impact of fired clay bricks in terms of indoor air quality.

2. Materials and Method

2.1. Raw materials preparation

Clay soil was supplied by a brick company located in Yong Peng, Johor. Meanwhile, palm kernel shell (PKS) was obtained from the palm oil plantation located in Kluang, Johor. Upon arrival, clay soil and PKS was dried in a mechanical oven for 24 hours at

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105°C to remove excess water content in the raw materials. After completely dry, both raw materials were grounded and crushed to facilitate the sieving process. The sieve with size of 2 mm aperture was used to yield homogenous size. Fig 1a and Fig 1b show the raw materials after sieving process.

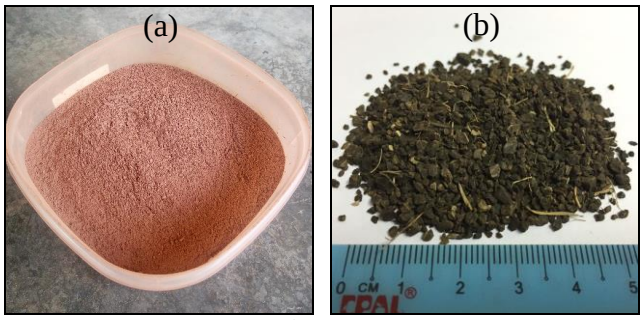

Fig. 1: Grinded of (a) clay soil and (b) PKS

2.2. Chemical and geotechnical analysis of raw material

X-Ray Fluorescence (XRF) was used to determine the chemical composition of clay soil and palm kernel shell.
Geotechnical test such as Atterberg limit test and specific gravity test was conducted according to [12]. In the meantime, standard proctor test was performed according to [13] in order to determine optimum moisture content of control brick (CB) and palm kernel shell brick (PKSB) during mixing process.

2.3. Brick manufacturing

Two types of brick were manufactured which are control brick (CB) and palm kernel shell brick (PKSB). Table 1 show the ratio mixture used in this study. The process started by mixing clay soil with predetermined water as mention in Table 1. Mechanical mixer with 10 L capacity was used during mixing process. After satisfactorily homogenized, the mixture was placed into following size of mould (215 mm x 102 mm x 65 mm) and compressed with automated brick machine. The compacted brick was then left for natural drying at room temperature for 24 hours to remove its initial moisture. The next 24 hours passed, the brick was dried for another 24 hours in a ventilated oven at 105°C in order to allow slow loss of moisture from brick. A final step for manufacturing brick is fired in a furnace. In this study, laboratory furnace was used to fire brick with heating rates set to 1°C/min until reached 1050°C of final temperature.
The same manufacturing method was also applied for PKSB with ratio mixture according to Table 1.

Table 1: Ratio mixture used

Mixture	Percentage (%)	Clay (g)	PKS (g)	Water (mL)
Control brick	0	2800	0	476
PKSB	5	2710	90	518

Indoor air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants. A good indoor air quality can contribute a quality and productivity to the human surrounding. In this experiment, IAQ was conducted in the Walk in Stability Chamber (WiSC) that is isolated from outside air and gases. The Walk in Stability Chamber (WiSC) was thermally insulated designed to be used with a controlled temperature and humidity with the data logger system. It has been designed to study on thermal comfort, heat stress and indoor air quality. The sample of building scaled fired clay brick has been built with a dimension of 1 m x 1 m x 1 m cube (Fig. 2), 0.2 m x 0.1 m x 1.5 m wall (Fig. 3) and 0.5 m x 0.5 m x 1.5 m column (Fig. 4). The data of a sample building scaled fired brick built was collected by using Indoor Environmental Quality Monitor (IEQ). The properties of air temperature, relative humidity and air movement were determined according to [14]. The gases that have been measured were carbon monoxide (CO), carbon dioxide (CO_2), formaldehyde (HCHO), total volatile organic compound (TVOC), ozone (O_3) and particulate matter (PM_{10}). After eight hours in the chamber, the data was collected on average and it has been compared with the standards Industry Code of Practice on Indoor Air Quality [14].



Fig. 2: Cube pattern



Fig. 3: Wall pattern

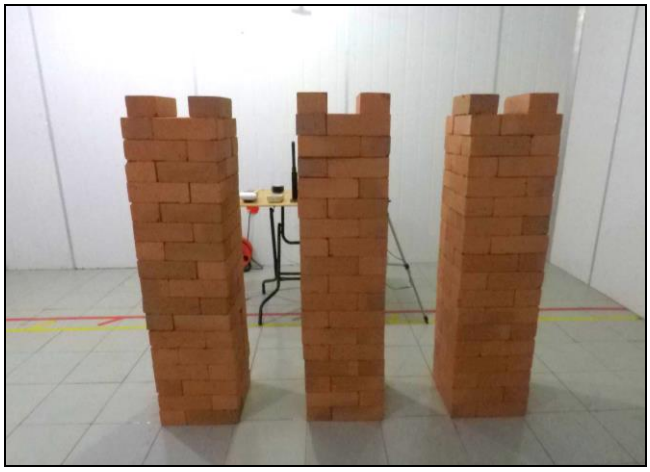

Fig. 4: Column pattern

3. Result and discussion

X-Ray Fluorescence (XRF) analysis and indoor air quality (IAQ) were the testing parameters conducted in this study. The results for the testing were discussed accordingly.

3.1. Properties of raw materials

The characteristic of raw materials has been obtained using XRF. Table 2 shows the chemical composition of clay soil and palm kernel shell (PKS) from X-Ray Fluorescence (XRF) test. The highest percentage of chemical composition for clay soil is silicon dioxide (SiO_2) with 55.7%, aluminium oxide (Al_2O_3) with 24.4% and iron oxide (Fe_2O_3) with 4.46%. Meanwhile, minor composition in clay soil is manganese oxide (MnO), calcium oxide (CaO) and sodium oxide (Na_2O) with 0.04%, 0.25% and 0.30%, respectively.

The highest percentage of chemical composition for PKS is silicon dioxide (SiO_2) with 47.10%, aluminium oxide (Al_2O_3) with 16.19% and iron oxide (Fe_2O_3) with 10.59%. Meanwhile, calcium oxide (CaO), potassium oxide (K_2O) and titanium dioxide (TiO) are the lowest element in palm kernel shell with 0.20%, 0.25% and 0.79%, respectively.

The loss of ignition for clay soil and PKS is low in organic matter with 7.3% and 9.21%, respectively. The loss of ignition of this clay soil and PKS was low in organic matter however PKS is compatible to replace clay soil in brick production.

Table 2: Chemical composition of raw material

Oxide content	Concentration (%)	
	Clay soil	PKS
SiO_2	55.70	47.10
Al_2O_3	24.40	16.19
Na_2O	0.30	0.94
K_2O	2.24	0.25
Fe_2O_3	4.46	10.59
CaO	0.25	0.20
MgO	1.20	0.93
P_2O_5	n.a	0.88
TiO_2	0.94	0.79
MnO	0.04	1.16
SO_3	n.a	1.56
Cr_2O_3	n.a	2.2
ZnO	n.a	1.57
LOI	7.30	9.21
n.a = not availabe		

3.2. Indoor air quality of manufactured brick

3.2.1. Total Volatile Organic Compound (TVOC)

TVOC has emitted gases from particular liquids or solids. Other substances that can contribute to a high of TVOC such as paints, varnishes, wax and fuels and expose to TVOC can cause health problem and cancer. According to [14], the acceptable limits for TVOC is 3 ppm. Fig. 5 shows the TVOC emission from CB and PKSB. From the result, it shows that CB released the lowest TVOC in the form of cube (0.266 ppm), followed by wall (0.287 ppm) and column (0.298 ppm). Another observation for PKSB has shown that wall pattern released lower TVOC compared to cube and column pattern with 0.266 ppm, 0.307 ppm and 0.316 ppm, respectively. As a conclusion, the incorporation 5% of PKS into fired clay brick still does not release high TVOC gases and PKSB is safe to be used as an indoor building material.

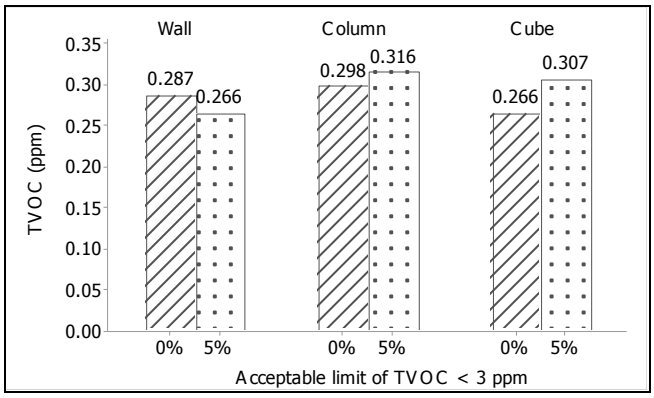

Fig. 5: TVOC emission

3.2.2. Carbon Dioxide (CO_2)

Carbon dioxide (CO_2) is a colourless gas with a density of about 60% higher than dry air and it usually produced respiratory human activities. The excessive CO_2 gases can cause the greenhouse effect that increased earth temperature. According to [14], the acceptable limits for CO_2 are 1000 ppm. Fig. 6 shows the value of CO_2 for the CB and PKSB. Overall, CB0% releases high concentration of CO_2 in column and wall pattern with 879 ppm and 805 ppm, respectively. Meanwhile, CB0% releases low CO_2 at 704 ppm (wall pattern). Contrary to PKSB, CO_2 released high concentration in wall pattern, followed by column and cube pattern with 873 ppm, 852 ppm and 650 ppm, respectively. As a conclusion, all bricks manufactured in this study are safe to be used as building materials in closed structures and meet standard limits below 1000 ppm.

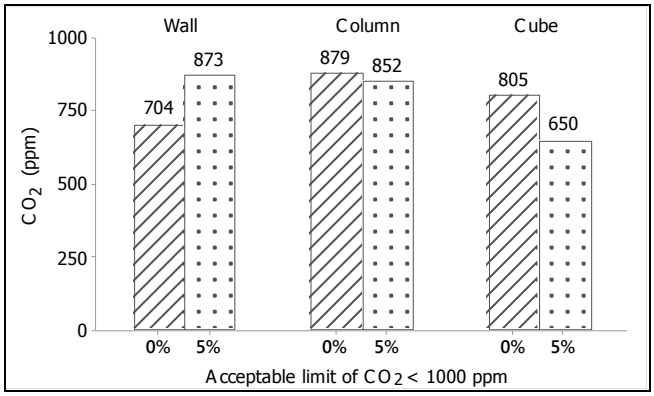

Fig. 6: CO_2 emission

3.2.3. Carbon Monoxide (CO)

Carbon Monoxide (CO) is a colourless, odourless, and tasteless gas and slightly less dense than air. According to [14], the acceptable limits for CO is 10 ppm. Fig. 7 shows the CO graph value for the CB and PKSB. The result showed that CB has the lowest emissions of CO gases in the form of wall and column pattern with 0.644 ppm and 0.642 ppm, respectively. However, the cube pattern shows the highest release with 0.700 ppm for CB. Meanwhile, analysis for PKSB has shown that the released of CO gases is high in column pattern, followed by wall and cube with 0.690 ppm, 0.664 ppm and 0.603 ppm. Therefore, all pattern for both manufactured bricks did not exceed the allowable limit.

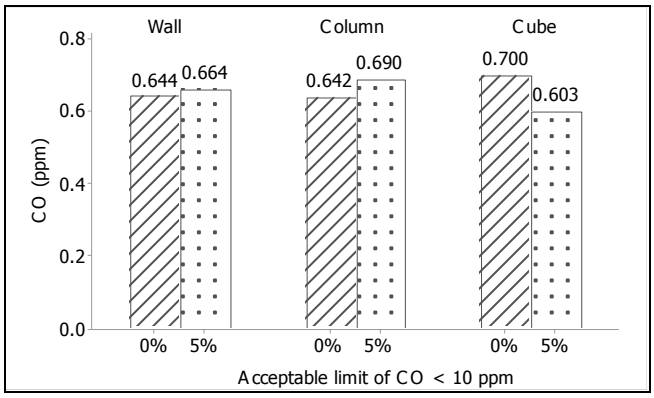

Fig. 7: CO emission

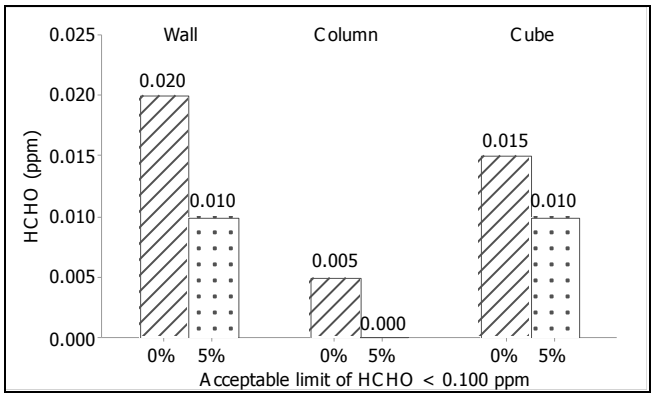

Fig. 9: HCHO emission

3.2.4. Ozone (O_3)

Ozone (O_3) is an inorganic molecule and it is a pale blue gas with a distinctively pungent smell. It also can be found in man-made or their natural state. According to [14], the acceptable limits for O_3 is 0.050 ppm. Fig. 8 shows the comparison of O_3 gases for CB and PKSB. The result shows that CB and PKSB released same level of O_3 gases for both wall and cube pattern with 0.014 ppm and 0.015 ppm, accordingly. Meanwhile, in the form of column pattern, CB released high O_3 compared to PKSB with 0.013 ppm. From this result, the emission of CB in wall and cube from has a constant value. Based on the data obtained, all types of brick samples showed the best results with the lowest emissions. In addition, all the bricks are in compliance with the standards by DOSH (2010) which does not exceed 0.050 ppm.

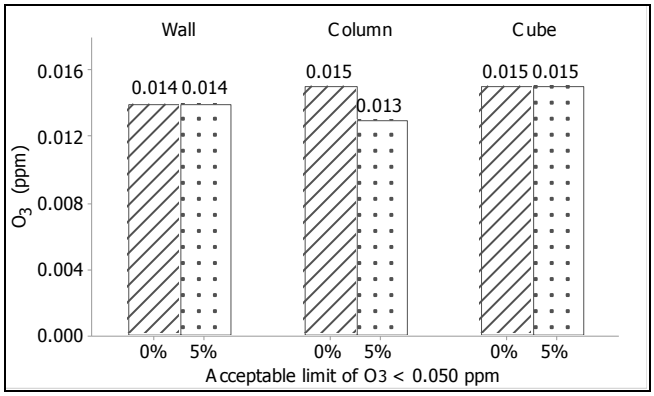

Fig. 8: O_3 emission

3.2.5. Formaldehyde (HCHO)

Formaldehyde (HCHO) is a naturally occurring organic compound and it is one of the gases that composed of hydrocarbons and oxidation. According to [14], the acceptable limits of HCHO is 0.100 ppm. Fig. 9 shows the comparison of HCHO released from CB and PKSB. The graph clearly shows that PKSB released the lowest HCHO gas on wall and cube pattern with 0.010 ppm while no gas is released on column pattern. Meanwhile, CB released highest HCHO gases in wall pattern followed by cube and column pattern with 0.020 ppm, 0.015 ppm and 0.005 ppm, respectively. From the result obtained, it was determined that the incorporation of PKS into fired clay brick could reduce the amount of HCHO. However, all bricks are complied with the standards and are safe to be used as indoor building materials.

3.2.6. Particulate Matter (PM_{10})

Particulate matter (PM_{10}) is the total of liquid and solid particles suspended in air. This complex mixture includes both inorganic and organic particles such as dust, soot, smoke, pollen, liquid droplets and soot. It came from the industrial activities and open burning as pollutant gases. According to [14], the acceptable limits for PM_{10} is 0.150 mg/m^3. Fig. 10 shows the PM_{10} for CB and PKSB. From the result, it shows that CB has the highest emissions of PM_{10} in the cube pattern at 0.197 mg/m^3 followed by column and wall pattern with 0.194 mg/m^3 and 0.159 mg/m^3. Contrary to PKSB, column released high PM_{10} with 0.192 mg/m^3 followed by cube (0.186 mg/m^3) and wall (0.159 mg/m^3). All the result of PM_{10} in CB and PKSB is higher than acceptable limit due to result of empty room (ER) that already higher than acceptable limit.

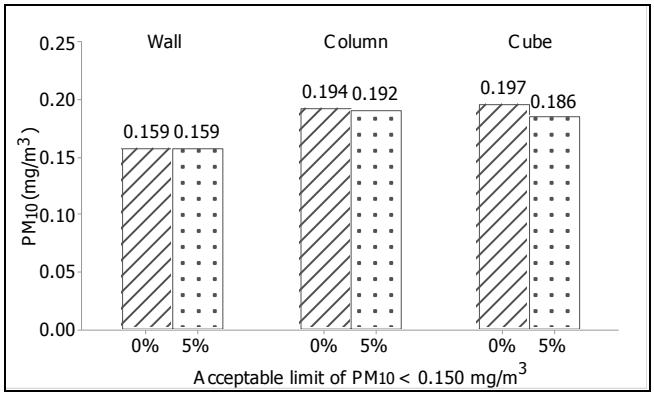

Fig. 10: PM_{10} emission

4. Conclusion

The characteristic of clay soil and PKS were determined and the comparison between this two materials has been done. The 5% was selected to be carried out in third stage for indoor air quality (IAQ) assessment. All the parameters that have been tested that included the total volatile organic compound (TVOC), carbon dioxide (CO_2), carbon monoxide (CO), ozone (O_2) and formaldehyde (HCHO) and particulate matter (PM_{10}) were based on standards of Industry Code of Practice on Indoor Air Quality. From the result, it shows that all the parameter of gases on PKSB were comply with the standard except for particulate matter (PM_{10}). The PM_{10} emission value is higher than the limit due to an already saturated (ER) room with PM_{10}. The possible cause of this result may be from previous experiment conducted in the Walk in Stability Chamber (WiSC). However, the majority of the parameters are in compliance with the standard and safe to be used as indoor building material.

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