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Research paper

Effect of heating rate on gas emissions and properties of fired clay bricks and fired clay bricks incorporated with cigarette butts

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ABSTRACT

In general, the firing process of clay bricks generates a range of gas emissions into the atmosphere. At high concentrations, these volatile emissions can be a serious source of environmental pollutions. The main purpose of this study was to evaluate the effect of different heating rates on gas emissions and properties during the firing of clay bricks and clay bricks incorporated with cigarette butts (CBs). In this investigation, four different heating rates were used: 0.7 °C min^{-1}, 2 °C min^{-1}, 5 °C min^{-1} and 10 °C min^{-1}. The samples were fired in solid form from room temperature to 1050 °C. During the firing cycles, carbon monoxide, carbon dioxide, nitrogen oxides, hydrogen cyanide and chlorine emissions were measured at different heating rates. All bricks were also tested for their physical and mechanical properties including dry density, compressive strength, tensile strength, water absorption and initial rate of absorption. Results show that gas emissions were reduced significantly with higher heating rates (10 °C min) followed by 5 °C min^{-1} and 2 °C min^{-1} for both types of brick samples. Higher heating rates also decrease the compressive strength and tensile strength value but demonstrate an insignificant effect on the water absorption properties respectively. In conclusion, a higher heating rate is preferable in terms of decreasing gas emissions and it is also able to produce adequate physical and mechanical properties especially for the CB brick.

1. Introduction

Brick is one of the most accommodating masonry units due to its properties. The firing process of clay bricks generates a range of gas emissions into the atmosphere. These gases include water vapour (H_2O), oxygen (O_2), carbon monoxide (CO), carbon dioxide (CO_2), sulphur dioxide (SO_2), ammonia (NH_3), chlorine (Cl_2) and fluorine (F). At high concentrations, these volatile emissions can be serious sources of environmental pollutions (Morgan, 1993). Therefore, innovation in the firing process is essential to prevent the environmental impact of the brick manufacturing process.

Many studies have been carried out to investigate the evolved gas from fired clay bricks. Attempts have been made to investigate the volumes of gases released at different temperatures and their correlations with the clay properties; see for example the studies by Parsons et al. (1997), Santos et al. (2003) and Toledo et al. (2004). In particular, Dunham et al. (2001) and Rasmussen et al. (2012) investigated shorter firing times in the manufacturing of clay bricks while Dondi et al. (1999) compared the influences of fast firing and traditional firing on physical and mechanical properties of clay bricks. Gonzalez et al. (2002), Cusido et al. (2003), Gonzalez et al. (2006), Gonzalez et al. (2011) and Shen et al. (2013) emphasised the reduction of gas emissions, specifically of fluorine, chlorine and sulphur, by controlling the firing temperature and mineral contents of the clay during the manufacturing process. Nevertheless, previous research provided very limited discussion on the effect of different heating rates, particularly on the gas emissions and on physical–mechanical properties of manufactured fired clay bricks. In this study, two types of brick samples were used: the clay bricks and clay bricks incorporated with cigarette butts (CBs). Recycling cigarette butts as an inert component into clay bricks can be a practical solution to one of the important pollution problems in the world (Abdul Kadir and Mohajerani, 2010, 2011; Abdul Kadir et al., 2010). The main purpose of this study is to evaluate the effect of different heating rates on gas emissions during firing as well as the properties of clay bricks and bricks incorporated with CB. In this investigation, the gas emissions are presented as Estimated Total Emission (ETE). The ETE is the estimated total gas emission from the fired brick samples during the heating period.

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2. Materials and methods

In this study, in order to investigate the evolved gas released under conditions analogous to the actual clay brick firing process, clay brick and CB brick samples are prepared in extruded forms. The chemical composition of the raw clay samples was determined using an X-ray fluorescence analyser (XRF) and the major crystalline phases of silt and clay fraction of the brick soil were examined using a Bruker X-ray diffractometer (XRD).

The preparation of the manufacturing fired clay brick and CB brick samples was explained in detail in previous studies (Abdul Kadir and Mohajerani, 2010, 2011; Abdul Kadir et al., 2010). In this investigation, clay brick and fired clay brick samples with 5% of CB content were prepared. The brick samples were manufactured in three different sizes: cube (100 mm × 100 mm × 100 mm), brick (225 mm × 110 mm × 75 mm) and beam (300 mm × 100 mm × 50 mm), in compliance with the minimum requirements for testing under the relevant Australian/New Zealand Standards (AS/NZS 4456.1, 2003). The mixes were made using a Hobart mechanical mixer with a 10 l capacity for 5 min. In order to achieve uniform distribution of CBs, they were initially mixed with dry soil in the mixer and then water was gradually added to the mix. Potable water was used for the optimum moisture content in order to make high dry density brick samples. Before compaction, the test mould was sprayed with oil to prevent any effect of the mould inner wall on the sample. The samples were compacted manually by pressing and kneading the mixes in the respective moulds using predetermined masses corresponding to the maximum dry density. The brick samples were dried in an oven at 105 °C for 24 h prior to heating experiments.

Four different heating rates were used: 0.7 °C min^{-1}, 2 °C min^{-1}, 5 °C min^{-1} and 10 °C min^{-1}. The samples were fired in solid forms from room temperature to 1050 °C. The procedure developed is shown in the following flow diagram (Fig. 1). The gas detector (Industrial Scientific iBrid Multi-Gas sensors) used in this study was equipped with five gas sensors for carbon monoxide (CO), carbon dioxide (CO_2), chlorine (Cl_2), nitrogen oxide (NO) and hydrogen cyanide (HCN). These gases are the expected main gases emitted from fired clay bricks. The iBrid Multi-Gas sensors are temperature-compensated using an on board temperature sensor that enables accurate readings across the full temperature range of the instrument. Furthermore, an internal gas-permeable filter is provided to limit the amount of dust and contaminants that may enter the internal sensor chamber and affect the sensor readings. The instrument also alerts the user audibly and visually if over-range values are detected. Over-range values are those values outside the normal operating ranges of the sensors. Moreover, the iBrid instrument utilises optical media interfaces for infrared data transmission (IrDA) at a speed of 115,200 bytes/s and can save up to three months of data collected at 1 minute intervals for five sensors simultaneously. The detection limit range for CO is from 0 ppm to 1500 ppm, CO_2 is from 0% to 5% by volume, Cl_2 is from 0 ppm to 50 ppm, NO is from 0 ppm to 1000 ppm and HCN is from 0 ppm to 30 ppm. The principal means used to determine CO, Cl_2, NO and HCN is by using an electrochemical sensor while for CO_2 an infrared sensor is used.

2.1. Estimated Total Emission (ETE)

In this investigation, the effects of different heating rates on Estimated Total Emission (ETE) were determined. The ETE from the fired brick samples during the heating period was approximated by calculating the total area under the curve from the 'Gas emissions per unit mass of brick' (ppm kg^{-1}) versus the 'Heating time (hour)'. These values could be obtained by employing the trapezoidal method, in ppm·hr·kg^{-1}. The ETE values obtained are indicative of the total gas emissions under the conditions applicable to this study. Example calculations to determine ETE are shown in Eq. (1) based on data provided in Table 1. The mass of the fired CB brick used is 2.72 kg.

$$\begin{aligned} ETE = \frac{1}{2.72\text{kg}}\Big[&\left(\frac{0+12\text{ppm}}{2}\right)4.75\text{hr} + \left(\frac{12+28\text{ppm}}{2}\right)1.20\text{hr} \\ &+ \left(\frac{128+1500\text{ppm}}{2}\right)1.18\text{hr} + \left(\frac{1500+429\text{ppm}}{2}\right)2.39\text{hr} \\ &+ \left(\frac{429+122\text{ppm}}{2}\right)2.38\text{hr} + \left(\frac{122+20\text{ppm}}{2}\right)2.38\text{hr} \\ &+ \left(\frac{20+12\text{ppm}}{2}\right)2.39\text{hr} + \left(\frac{12+8\text{ppm}}{2.}\right)2.36\text{hr} \\ &+ \left(\frac{8+8\text{ppm}}{2}\right)2.39\text{hr} + \left(\frac{7+7\text{ppm}}{2}\right)2.38\text{hr} \\ &+ \left(\frac{7+7\text{ppm}}{2}\right)1.2\text{hr}\Big] = 1583.80\text{ppm}\cdot\text{hr}/\text{kg}. \end{aligned} \quad (1)$$

A gas measurement set-up was developed at this stage to measure ETE, as shown in Fig. 2. Emissions from the brick samples were measured

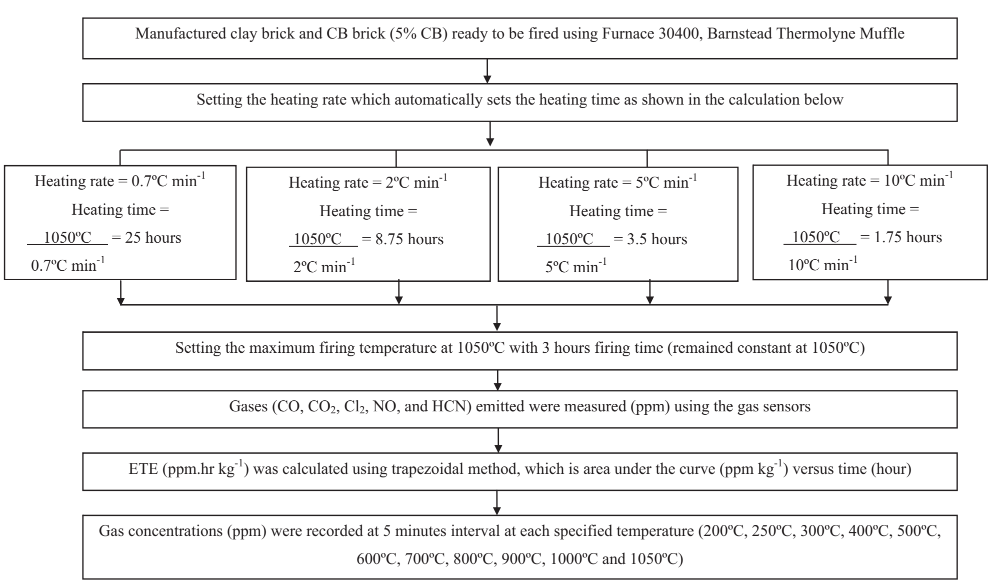

Fig. 1. Flow diagram for measuring Estimated Total Emission (ETE).