ATMOSPHERIC EMISSIONS FROM CLAMP KILNS IN THE SOUTH AFRICAN CLAY BRICK INDUSTRY

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The quantification of atmospheric emissions from clamp kilns in the South African clay brick industry has met with limited success. The pyramid-shaped, complex configuration of clamp kilns using coal or other carbonaceous fuels, as well as the uncertainty regarding combustion conditions within the kiln, has proven to be a hurdle in the measurement of emission parameters associated with gaseous and particulate pollutants.

To facilitate the measurement of these parameters, a model kiln was designed to fire bricks at operating conditions and configuration similar to a transverse slice of a full-scale clamp kiln used for brick firing in South Africa, but with a lower production capacity. The model kiln design ensures adequate confinement, capture and extraction of flue gases from the firing process with the aid of a bifurcated fan forcing the draft through to an extraction stack where monitoring takes place. The design provides adequate spacing to cater for packing and unpacking of bricks, and provides sufficient air for the combustion process, while still ensuring minimum losses of flue gas via the semi-enclosed sides.

Seven firing cycle have been completed so far, each within a period of 10 to 14 days. Hourly readings are recorded for PM_{10}, SO_2, NOx, NO, NO_2, CO concentrations and process parameters in the extraction stack.

Preliminary emission rate results from the monitoring program range from 1.25 $x10^{-1}$ – 2.45 $x10^{0}$ g/s for CO, 5.00 $x10^{-3}$ – 9.00 $x10^{-3}$ g/s for NO, 0 g/s for NO_2, 5.00 $x10^{-3}$ – 9.00 $x10^{-3}$ g/s for NOx, 2.9 $x10^{-2}$ – 8.50 $x10^{-2}$ for SO_2 and 7.00 $x10^{-3}$ – 1.40 $x10^{-2}$ for PM_{10}.

Keywords: stack monitoring**,** clamp kiln, emission rate, emission factor, model kiln design, clay brick emissions,

1. Introduction

1.1 Background

The clamp kiln for firing clay bricks is regarded as the major brick firing technique in South Africa. The bricks in a South African clamp kiln are packed in a pyramid-shaped formation with a layer of combustible material such as coke, cinder or coal at the base and after each layer of bricks; with additional coal already mixed into the clay during processing. Three layers of fired bricks (skinkle) are usually arranged to serve as receptacle to accommodate the base combustible material (CBA, 2002; 2005).

When the bottom layer of fuel is ignited, it sets the bricks on fire layer by layer until the whole kiln is ablaze. The kiln temperature rises gradually, igniting the fuel in the clay at about 800 ^{o}C and peaking at an average of 1200 ^{o}C to 1400 ^{o}C at the centre of the kiln (CBA, 2002; 2005 and Rajasthan State Control Board, 2011).

Clamp kiln technology in South Africa, at least in the formal brick production, has been developed to utilize much larger bricks than elsewhere, often containing several million bricks and because of its low capital cost has remained competitive (Figure 1). The technology produces about 70% of the total clay bricks production in South Africa, of the order of 3 billion bricks per annum, and operators employ approximately 12 000 people.

This method of firing bricks, globally regarded as an energy-inefficient process with a high potential for air pollution, is associated with the emission of pollutants such as particulate matter (PM), PM less than or equal to 10 microns in aerodynamic diameter (PM_{10}), PM less than or equal to 2.5 microns in aerodynamic diameter ($PM_{2.5}$), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), nitrogen oxide (NO), carbon monoxide (CO), carbon dioxide (CO_2), metals, total organic compounds (TOC) (including methane, ethane, volatile organic compounds [VOCs], and some hazardous air pollutants [HAPs], and fluorides), into the environment (USEPA, 1997 and Akinshipe 2013).

Figure 1: A typical kiln firing over seven million bricks in 21 days (Note: containment or extraction of emissions is not practicable)

The impact of these emissions on the immediate environment is amplified by the localization effect generated as a result of a relatively cool plume (when compared with other industrial processes) released into a low level "stable surface layer" where dispersion or mixing is limited, especially at night and during the winter season (DEA 2011, Irm 2011).

Consequently, "clamp kiln for brick production" in South Africa was listed as one of the activities (Listed Activity sub-category No. 5.3) that pose negative environmental effects as well as adverse health, social, economic and ecological impact (DEA 2013).

DEA (2013) identifies sulphur dioxide (SO_2) and particulate matter (dustfall) as emissions to be controlled by clamp kiln emitters and stipulates standards and methods by which ambient monitoring must be carried out. It also stipulates additional requirements where co-feeding with waste materials with calorific value allowed in terms of the Waste Disposal Standards published in terms of the Waste Act, 2008 occurs (sub-category 1.6).

The consequent stipulation of standards and methods by which ambient monitoring must be carried out for clamp kiln poses a problem for clamp kiln operators due to the following:

- The pyramid-shaped, complex configuration of clamp kilns using coal or other carbonaceous fuels, as well as the uncertainty regarding combustion conditions within the kiln, has proven to be a hurdle in the measurement of combustion rate, pollutants emission factors and emissions parameters (such as exit velocity, flowrate, flue gas temperature etc.) associated with gaseous and particulate pollutants (Cardenas et al. 2009, Umlauf et al. 2011, Akinshipe 2013);
- The lack of adequate emission control on clamp kilns, for all pollutant emissions (DEA 2011).

Previous work (Akinshipe, 2013) indicated that mass balance calculations were in most cases adequate for calculating SO_2 emissions from the clamp kilns, but that other sources located at brickmaking facilities also emitted particulate matter and nitrogen oxides, making assignment of these emissions to a particular source difficult.

This study aims to design and test a model kiln with capabilities to adequately fire bricks and effectively monitor gaseous pollutants and particulates specifically from the kiln. Effective monitoring of emissions will consequently facilitate the delineation of pollutant emission factors and emission parameters for South African clamp kilns.

2. Methodology

The approach to the study is divided into the following:

- Designing a model kiln with a point source stack configuration;
- Undertaking a series of stack monitoring campaigns on the model kiln using varying firing inputs; and
- Conducting laboratory and computational analysis of monitoring data in order to generate clamp kiln emission factors and other emission parameters.

2.1 Model Kiln Design

The model kiln is situated on a functional and accessible clamp kiln site. It is built in an isolated location in order to limit the influence of external air emission sources. The model kiln is designed with configurations similar to a transverse slice of a full-scale clamp kiln used for brick firing in South Africa, but with lesser production capacity ranging between 25 000 to 32 000 bricks per firing cycle (Figure 2).

Figure 2: Model kiln showing horizontal stack and mesh windscreen

A green-coloured fabric mesh wind screen is installed (5 metres away) to the north and northwest of the model kiln in order to shield prevalent airflow from the north and northwest of the region.

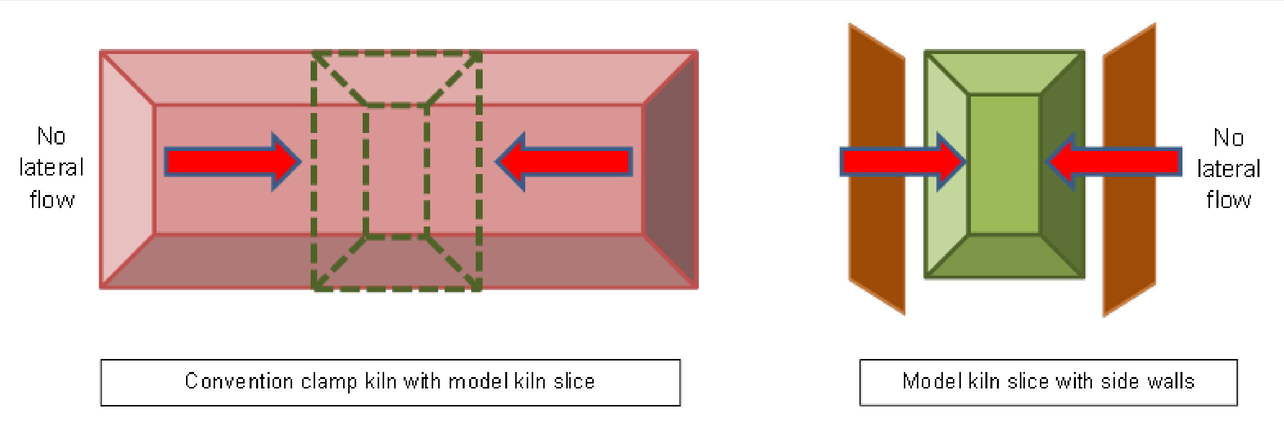

Figure 3: Illustration of air flow in a traditional South African clamp and the model kiln slice

Air flow in the model kiln is simulated to represent similar air flow in traditional full-sized kilns as illustrated in Figure 3.

The top of the kiln is hooded with an insulated cover bearing a horizontal stack outlet. The stack is equipped with a Bifurcated Case Axial fan channelling the flue gas through the stack where monitoring takes place. The design ensures efficient capture and channelling of the flue gas through the stack, with minimum losses experienced via the semi-enclosed sides (Figure 4).


Figure 4: On-going model kiln packing process

2.2 Stack Monitoring

A series of 7 model kiln firing and concurrent stack monitoring campaign was conducted in order to collect emissions data.

Hourly data recording was carried out for the entire duration for each firing campaign; which included readings for gaseous pollutants (CO, NO, NOx, NO_2 and SO_2), particulates (PM_{10}) and emission parameters (exit velocity, flowrate, flue gas temperature, combustion efficiency, excess air etc.). Measurements are also taken for the ambient air to allow for possible background input.

In measuring gaseous pollutants, the E INSTRUMENTS Model 5500 gas analyzer was utilized. The gas analyzer measures the afore-mentioned gaseous pollutants by means of electrochemical sensors (Figure 5). It also measures stack gas velocity, volumetric flow rate, excess air and combustion efficiency according to the EPA Method 2 or 2C (E Instruments, 2012).

PM_{10} measurement was undertaken using the Sidepak™ Personal Aerosol Monitor Model AM510 Figure 5). This is a laser photometer that measures airborne particle mass concentration with the aid of a built in sampling pump equipped with adjustable flow rate (TSI Incorporated, 2012). The Sidepak™ Personal Aerosol Monitor was considered adequate to measure particulate matter less than 10 micron in size. It has been shown (Lodge 1988; Harrison and Perry 1986) that the error for particles less than 10 micron in size rarely exceeds 10% only when the sampling velocity is a factor of 3 or more higher or lower than the velocity in the duct. In order to allow extended sampling, as well as the comparison of a large number of firing techniques to be compared, it was decided to accept this magnitude of error.

The Bifurcated Case Axial fan is a specially designed fan that has a split airway with a direct driven electric motor operating in ambient air within the motor compartment; and can handle air temperatures up to +200°C (Vent-Axia, 2010). This ensures effective capture and channeling of flue gas through the horizontal stack.


Figure 5: The E5500 Gas Analyser (left) and the SidePak Aerosol Monitor (right)

2.3 Firing and Energy Variables

Firing inputs that was varied over each monitoring campaign include:

- Source of "green" bricks – Dried bricks to be fired are obtained from different brick factories across South Africa;
- Method of bricks processing and packing – The bricks were processed, packed and fired in similar fashion to the technique employed at the source factory;
- Intrinsic properties of "green" bricks (such as moisture content and clay type) – These varies according to clay source; and
- Sulphur and energy content, and source of fuel used – Clamp kiln energy input parameter varies from one factory to another. The major source of fuel for South African clamp kiln is coal - small nuts coal, carbon fly ash (CFA) and duff coal (Lordan, 2011; CBA, 2002, 2005). Duff coal or CFA are used as "body fuel" (that is, are mixed into the clay during processing), while the small nuts or peas serve as the "external fuel" in the bottom ignition layer of the kiln (skinkle).

3. Results

The following sections provide the results of 7 firing and measurement campaigns undertaken.

3.1 Emission parameters and appearance

The flue-gas exit temperature and velocity profile for each batch of firing are shown in Figure 6 .

The batches show similar temperature trends (with the exception of batch 4 and 6). Temperatures generally initiate at near-ambient levels; gradually rising to a peak during the second and third quarter of the firing period; and dropping to near-ambient levels again towards the end of the cycle. The highest temperature of 409 ^{o}C was recorded during batch one firing. Batch 4 and 6 did not exhibit any consistent trend over the firing cycle.

The velocity profile does not exhibit any consistent trend over the firing cycle. Levels (ranging from about 3 m/s to 20 m/s) rose and fell over the firing period for all batches. This suggests that flue gas velocity at the stack is controlled by the extraction fan and environmental factors such as winds, rather than by convective processes inside the kiln.

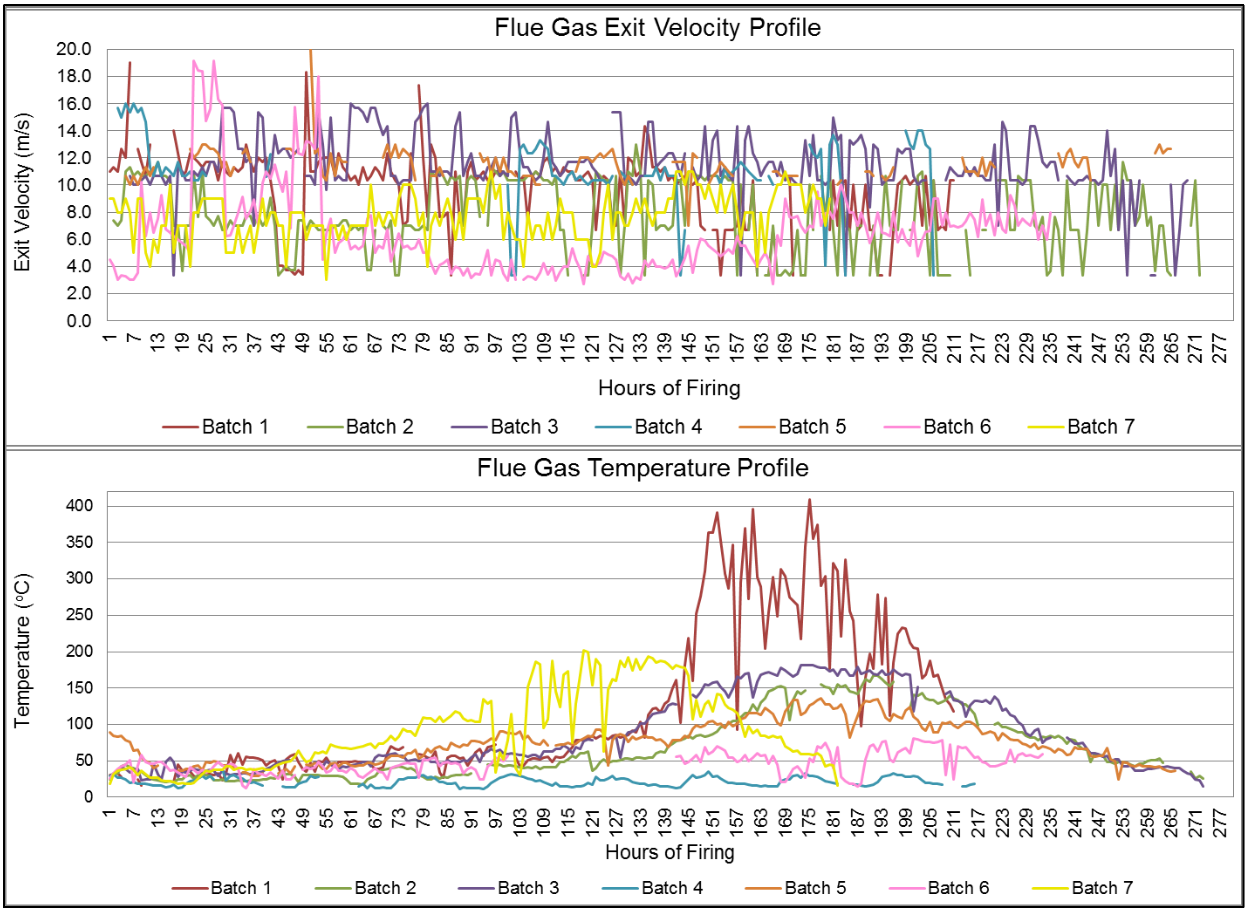

Figure 6: Flue gas velocity and temperature profile

At high wind speeds, visible smoke can be seen coming out from under the semi-enclosed air inlet at the opposing side to the wind direction.

From the outlet fan curve, the inlet velocity through the openings (with the “draught” doors closed) is of the order of 0.5 m/s, which is less than the normal wind velocities experienced by full-size kilns. The forced draught in the model kiln is therefore not expected to cause a material difference in air supply or flow conditions over the outside wall of the packed kiln. Hence, it is not anticipated that there would be significant difference between combustion conditions in the model kiln and a full-scale kiln.

Physical examination of fired bricks from the model kiln shows similar appearance with bricks fired in conventional clamp kilns. Also, the stack combustion efficiency measurements (which is a measure of the CO_2/CO ratio and the net temperature between the stack gas and ambient air) for each batch show results that are above established combustion requirements for kilns utilizing coal as fuel source (Biarnes, Freed, & Esteves, 2013). These suggest that the firing process in the model kiln is adequate to produce bricks with similar characteristics as those from conventional clamp kilns.

3.2 Emission Rate

Hourly emission rates were calculated for each batch and an average was obtained over the entire firing cycle (10 to 14 days), as shown in Table 1. It should be noted that the emission rates reported have not been standardized to account for occasional losses of flue gas from underneath the sliding boards, especially during extremely windy conditions. Batch 5 and 6 results are not included since their measurements were characterized with power failure and equipment malfunction.

Table 1: Average emission rate over the firing period

Emission rate (g/s)						
Batch	**CO**	**NO**	**NO_2**	**NOx**	**SO_2**	**PM_{10}**
Batch 1	2.454	0.009	0.000	0.009	0.085	0.014
Batch 2	0.204	0.005	0.000	0.005	0.030	0.006
Batch 3	0.744	0.005	0.000	0.005	0.029	0.011
Batch 4	0.125	0.005	0.000	0.005	0.025	0.010
Batch 7	0.649	0.007	0.000	0.007	0.054	0.007
Average[1]	0.835	0.006	0.000	0.006	0.045	0.010

NOTE: [1] This is the average without batch 5 and 6 measurement which was marred by power failure and equipment malfunction.

3.3 Emission Factors

Emission factors are given as gram of pollutant released per brick fired (g/brick). Emission factors were calculated from hourly emission rates; and they show similarity across firing campaigns. Batch 5 and 6 emission factors are excluded due to the afore-mentioned reason.

The calculated emission factors are presented in Table 2.

Table 2: Emission factors

Emission factors (g/brick)						
Batch	**CO**	**NO**	**NO_2**	**NOx**	**SO_2**	**PM_{10}**
Batch 1	52.45	0.19	0.00	0.19	1.81	0.31
Batch 2	6.46	0.15	0.00	0.15	0.96	0.20
Batch 3	22.31	0.15	0.00	0.15	0.88	0.32
Batch 4	1.76	0.07	0.00	0.07	0.36	0.14
Batch 7	14.93	0.16	0.00	0.16	1.24	0.15
Average[1]	19.58	0.14	0.00	0.14	1.05	0.22

NOTE: [1] This is the average without batch 5 and 6 measurement which was marred by power failure and equipment malfunction.

4. Conclusion

4.1 Main Findings

A model kiln for firing of bricks and effective monitoring of pollutants has been designed and tested using varying inputs. The model kiln was tested for its suitability in firing bricks similar to conventional South African clamp kilns, as well as its effectiveness in the capturing and channelling of flue gases through to a stack vent where monitoring of the flue gases takes place.

The model kiln has proven to be adequate in firing bricks. It also proved effective in emission monitoring for clamp kilns, which has met with limited success before now.

Significant findings from this preliminary study include the following:

- PM_{10} emissions are much lower (by a factor of 5 or more) than the value obtained from previous literature.
- Significant NO_2 is not emitted from a clamp kiln, contrary to existing literature. All of the NOx emitted is actually NO.
- The PM_{10} result has extended implications for dust management around brick yards – i.e good housekeeping, especially with regards to the roads, may have a much larger impact on PM emissions than measures taken on the kiln only.

4.2 Further Research

More firing and measurement campaigns are scheduled in order to generate more accurate emission factors.

Also, in order to account for losses due to the semi-closed sliding board, a thorough mass balance analysis is planned for SO_2, in order to compare to the measurement result. Thereafter, the monitoring results can be standardized for all other pollutants.

Furthermore, an attempt will be made to undertake an energy efficiency exercise, as well as develop an adequate air quality management plan and/or best industry practice for emission control at South African clamp kilns sites.

5. Acknowledgments

The Clay Brick Association funded part of the study and its members were generous with their time, products and site amenities.

6. References

Akinshipe, O. (2013). *The development of an 'emission inventory tool' for brick making clamp kilns.* Pretoria, South Africa: M.Sc. thesis, University of Pretoria.

Biarnes, M., Freed, B., & Esteves, J. (2013). *Combustion.* E Instruments International LLC.

Cardenas, B., Bouwman, H., Costner, P., Fiedler, H., Grochowalsky, A., Mirikau, C., et al. (2009). *Unintentional released POPs from brick production in developing countries.* Technical report, Joint Research Commission, European Commission.

Clay Brick Association. (2002). *Technical brochure on how to specify or build with clay brick.* Midrand, South Africa: CBA technical guide.

Clay Brick Association. (2005). The making of clay bricks. Midrand, South Africa.

DEA. (2011). *The Highveld Priority Area Air Quality Management Plan.* Pretoria, SA: Department of Environmental Affairs - Government Gazette.

DEA. (2013). *National Environment Management: Air Quality Act- List of activities which may result in atmospheric emissions which have or may have a significant detrimental effect on the environment, including health, social conditions, economic conditions ecological.* Pretoria, SA: Government Gazette No.33064. 537.

E Instruments. (2012). *E5500 Portable Industrial Integrated Emissions System Combustion Gas Analyzer - Instruction and Operations Manual.* Langhorne, PA, USA: E Instruments International LLC.

Harrison, R M, & Perry, R. (1986). *Handbook of air pollution analysis* (2nd ed.). London: Chapman and Hall.

Irm, F. (2011). *Impact of brick kiln emissions on the ambient air quality and vegetation - A case study of district Budgam.* Srinagar: M.Phil. Thesis, University of Kashmir.

Lodge, J. P. (1988). *Methods of air sampling and analysis* (3rd ed.). Boca Raton: CRC Press.

Lordan, P. (2011). *Technology Transfer mechanism – Introduction of Vertical Shaft Brick Kiln (VSBK) Technology at Vhavenda Brick, South Africa.* South Africa: Clean Development Mechanism, Project Design Document Form, CDM – Executive Board.

Rajasthan State Control Board. (2011). *Environmental guidance manual: Brick kilns.* India: Administrative Staff College report.

TSI Incorporated. (2012). *Sidepak™ Personal Aerosol Monitor Model AM510 - User Guide .* Shoreview, MN: TSI Incorporated.

Umlauf, G., Bouwman, H., Cardenas, B., Fiedler, H., Mariani, G., Mirikau, C., et al. (2011). "PCDD/F, PCB and HCB in soil and ash from brick production sites in Kenya, South Africa and Mexico". *Organohalogen Compounds, 73*, 1041-1045.

USEPA. (1997). *"Emission Factor Documentation for AP-42, Section 11.3, Brick and Structural Clay Products Manufacturing", Final report.* North Carolina, USA: United States Environmental Protection Agency, Research Triangle Park .

Vent-Axia. (2010). *Bifurcated Case Axial Fans (BIFA).* Retrieved July 25, 2015, from Vent-Axia Group Limited: http://www.vent-axia.com/range/bifurcated-case-axial-fans-bifa.html