PERFORMANCE OPTIMIZATION OF KILN THERMAL DISTRIBUTION UNDER IMPROVED COOKSTOVE PRODUCTION (ICS)

J.S NYARERU[a], P. M. Kimari[a,b], D.K Nyamu [a], J.N Karuri[a,b], I.O Otieno[a,b], S.N Muriithi[a,b]

[a]*Centre for Biomass Energy Studies, Dedan Kimathi University of Technology, Nyeri, Kenya*

[b]*Department of Mechanical Engineering, Dedan Kimathi University of Technology, Nyeri, Kenya*

Abstract

Production of green-quality liners has been a major concern in Kenya for a while now. Most local producers depend on traditional kilns for the burning process using firewood. To produce high-quality green liners, a better burning process is required within the kiln. These kilns suffer higher fuel consumption, and heat loss majorly attributed to lack of insulation, poor ware strength and extensive breakage. Accounting for the demerits of the traditional one has led to the development of a downdraught kiln with a firebox that operates with the working principle of a boiler in this project. The purpose of the project is to perform a thermal analysis of the firing process to achieve an optimum uniform temperature distribution within the kiln of about 900℃ to 1000 ℃ and decrease the fuel consumption through better distribution of input heat. The analysis involves the variation of the target or firewall height, the dome radius and the chimney height and internal geometry. This procedure helps in determining the optimal firewall height, dome radius and chimney height and internal geometry. Furthermore, the critical radius for insulation at different parts of the kiln experiencing different thermal stresses is to be determined. This aims at reducing material wastage and preventing heat loss to the surrounding. For this reason, the downdraught kiln is modelled and simulated on the computer by using computational fluid dynamics and heat transfer.

Keywords: ICS, kiln design,

1.0 INTRODUCTION

Upgrading the rural industrial sector is critical to the growth of our rural masses, and technology inputs are critical for lowering production costs, increasing productivity and enhancing product quality. The pottery industry is one of our country's rural industrial sectors. This industry has been sustained by working experiences, which have rendered it weak and ineffective. Furthermore, this limits quality control and assurance for the products. Traditional pottery craftsmen use traditional manufacturing methods for production. As a result, these products cannot compete in the market with high-quality pottery products [1].

Traditional kilns built up of clay and reinforced with thatches have been in use around major ICS production centres in the country. These kilns have been widely incorporated due to the availability of the skill to build them and the resources used to prepare them. These traditional kilns however start with lower fuel efficiency and gradually get worse as the exterior and interior walls break due to the high temperatures.

The combustion process of traditional kilns has been hazardous due to the excessive smoke sprayed out through a rather undesigned firing chamber as well as providing inefficient combustion. These factors have caused the traditional kilns to be expensive to maintain and run in these centres. The kilns are based on designs that do not take into effect uniform distribution of heat thus causing the clay liners preparation efficiency to drop down to around 65%. This in general leads to the production being expensive thus driving the cost of clay liners to the roof.

With better efficiency of combustion and heat distribution lesser biomass fuel is consumed and more clay liners are produced simultaneously. Secondary effects of such efficiency include lesser CO_2 emissions contributing to the reduction of global warming.

The high-efficiency pottery kilns used in the organised sector are too expensive to be affordable by the small-scale sector. To improve the quality of the products and decrease the cost of production it is needed to optimize the burning process in traditional kilns.

2.0 METHODOLOGY

2.1 KILN SECTIONS

The kiln shown in Figure 1 was designed to provide room for a limited number of ICS clay liners. It was comprised of three regions: the firing chamber, the kiln and the chimney. Different sections are subjected to different peak temperatures and each part served a unique purpose to the general objective of the kiln. The study carried out was based on the downdraft design of kilns after its preference against updraft design due to its higher fuel efficiency results [2].

The following are the factors affecting the performance of the kiln [3]

- Firewall height
- Dome radius
- Chimney height
- Flue vent connector length

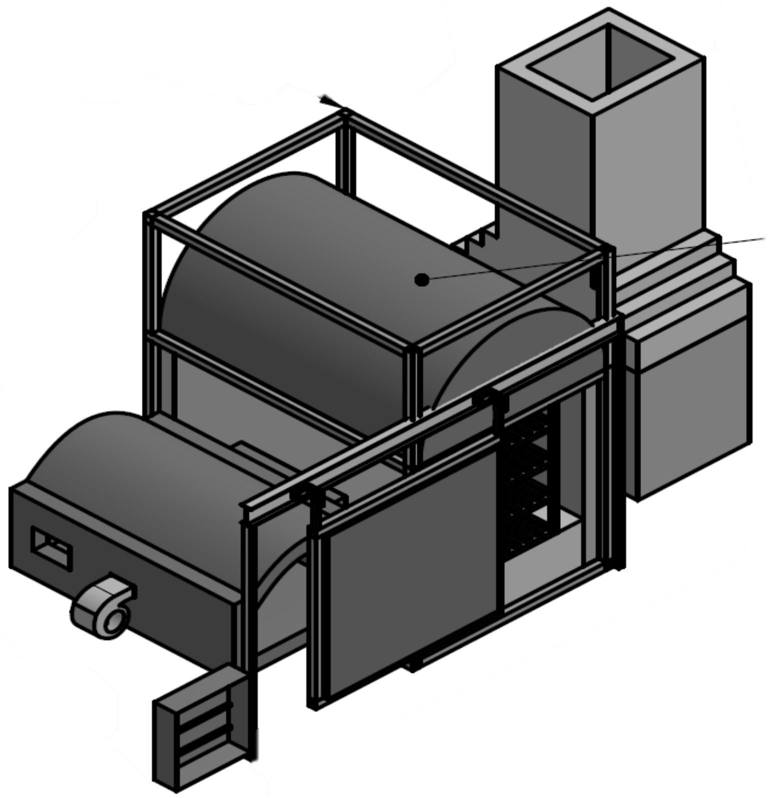

Figure 1: ICS Production Kiln

2.2 KILN SIMULATION

2.2.1 Effect of changing the firewall height on temperature distribution

Simulation of airflow through the kiln was done using SolidWorks software. This was done by inputting boundary conditions such as pressure, temperature, and volume flow rate. The height of the firewall and dome radius considered in this design is 1500mm and 1046.8mm respectively. The firewall for this design has no perforations.

2.2.2 Effect of changing dome height on the temperature distribution

For this simulation, the original firewall height, 1500mm, was maintained. The dome radius was increased from 1046.8mm to 2000mm and the firewall was perforated, and the results were studied.

2.2.3 Effect of changing both firewall height and dome radius

Both the firewall height and dome radius were changed to 1000mm and 2000mm respectively. It is important to note that for this design the firewall had no perforations. The following temperature distribution was obtained.

2.2.4 Effect of changing chimney's height and cross-sectional area and flue vent connector's length

After settling on a firewall height of 1250mm and a dome radius of 2000mm, the next step was to optimize the chimney's parameters and the length of the flue vent connector. The initial height of the chimney was 3000mm, the top and bottom cross-section area were 3750mm2 and the flue vent connector length was 800mm. For the first simulation, these parameters were adjusted to 5000mm chimney height, 294000mm2 and 1600000mm2 top and bottom cross-section area respectively and 1600mm flue vent connector length.

3. RESULTS AND DISCUSSION

3.1 Effect of changing the firewall height on temperature distribution

The picture and graph below show the temperature distribution throughout the kiln.

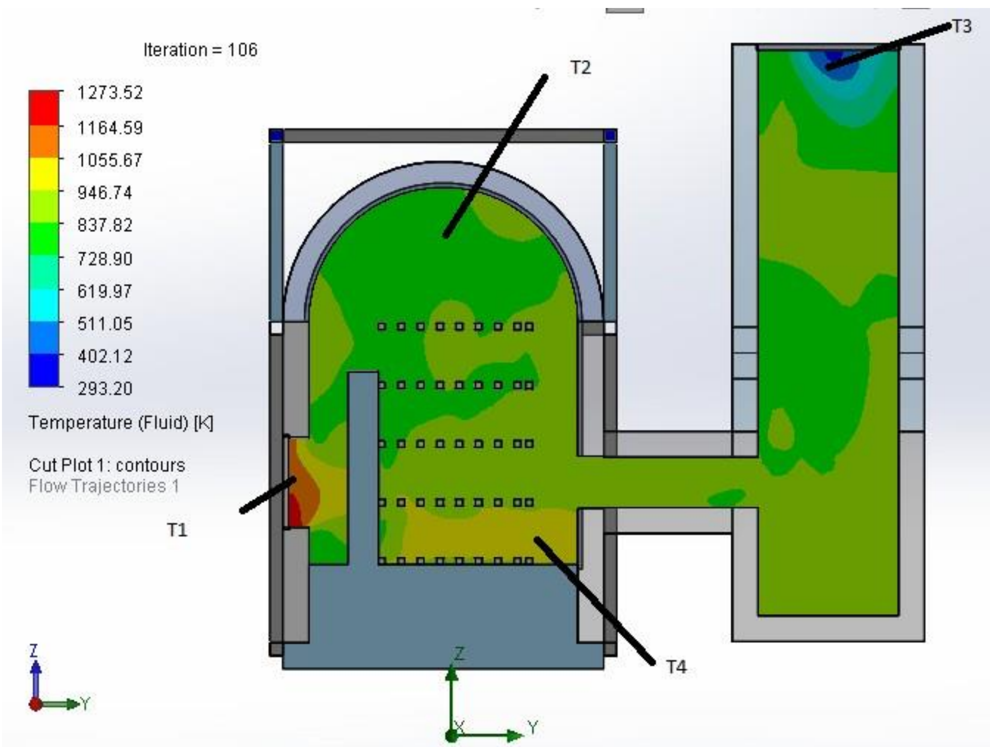

Figure 2: Temperature distribution inside the kiln at 1500mm firewall height

From the analysis, the temperature distribution varies throughout the kiln. T1, the temperature at the entrance is 1164.59, T2, at the top of the kiln is 837.82 K, T4, at the bottom of the kiln is 1055.67K and T3, at the exit of the chimney is 293.20K.

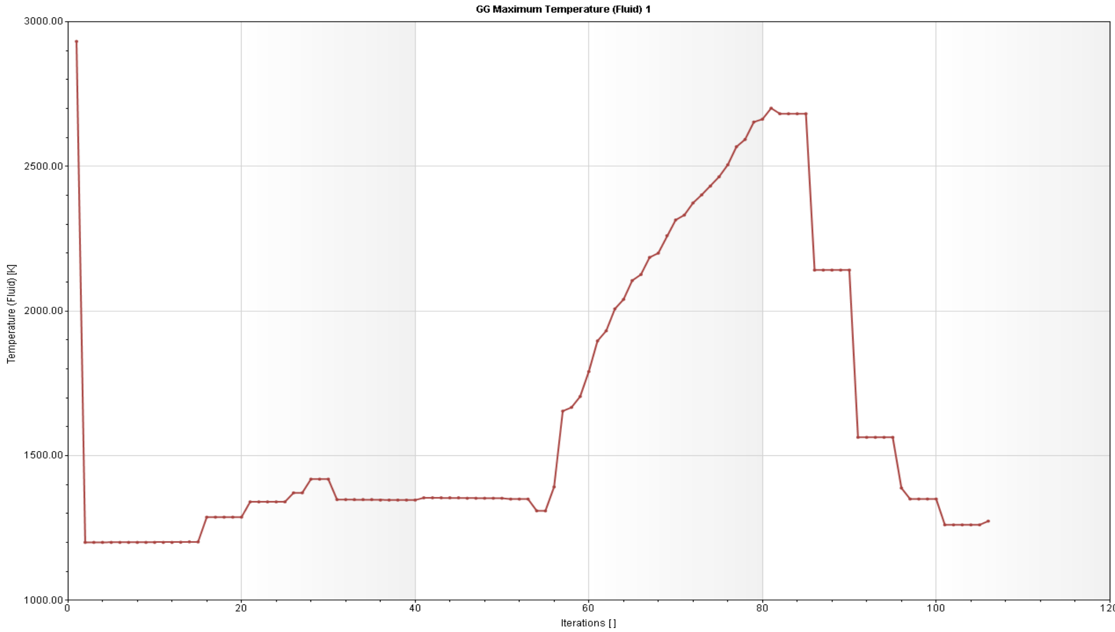

Figure 3: Temperature profile of kiln at 1500mm firewall height

The firewall height was changed to 1250mm for this simulation with the dome radius kept constant at 1046.8mm. The temperature distribution was as shown below:

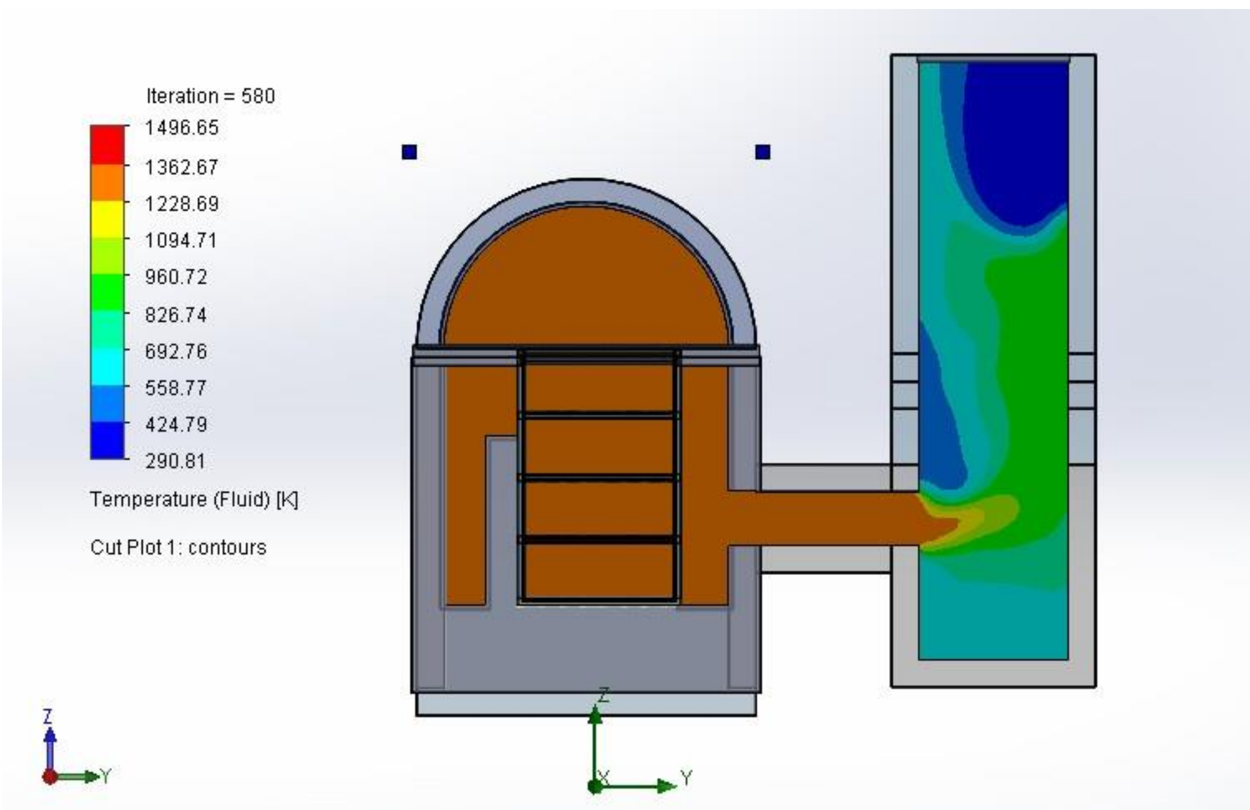

Figure 4: Temperature distribution of the kiln at 1250mm firewall height

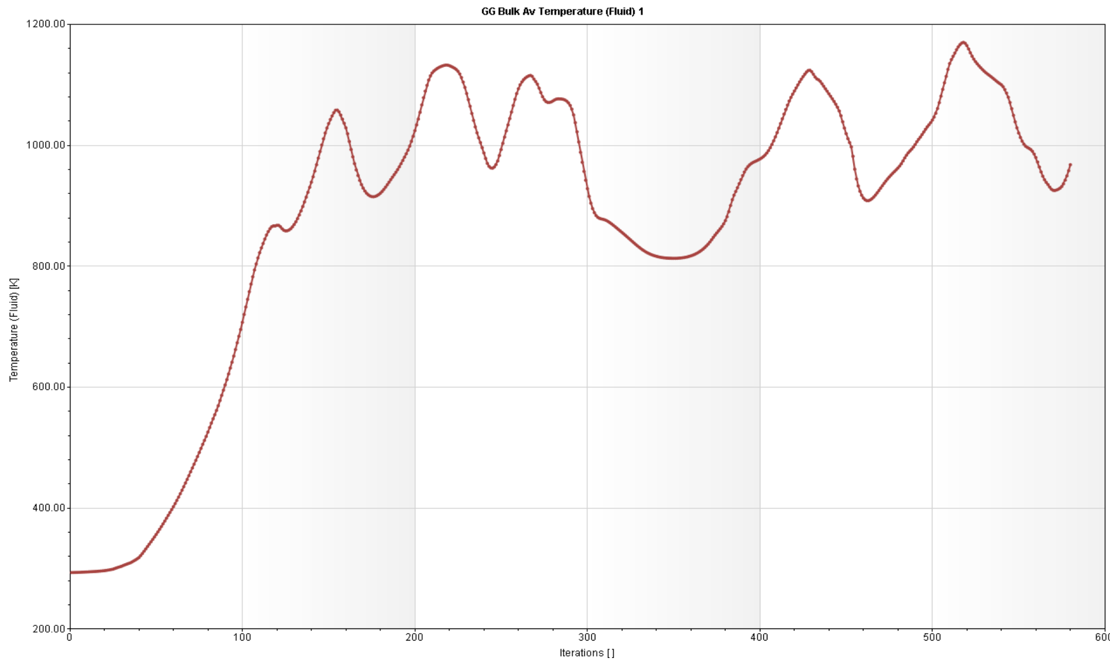

Figure 5: Temperature profile of kiln at 1250mm firewall height

The temperature distribution in the kiln was constant at1362.67K and the chimneys ranged between 290.81K and 960.72K.

When the firewall height was changed to 1000mm and the dome radius was kept constant, the kiln temperature increased to 1206.75K while the chimney temperature ranged between 293.19K- 699.22K

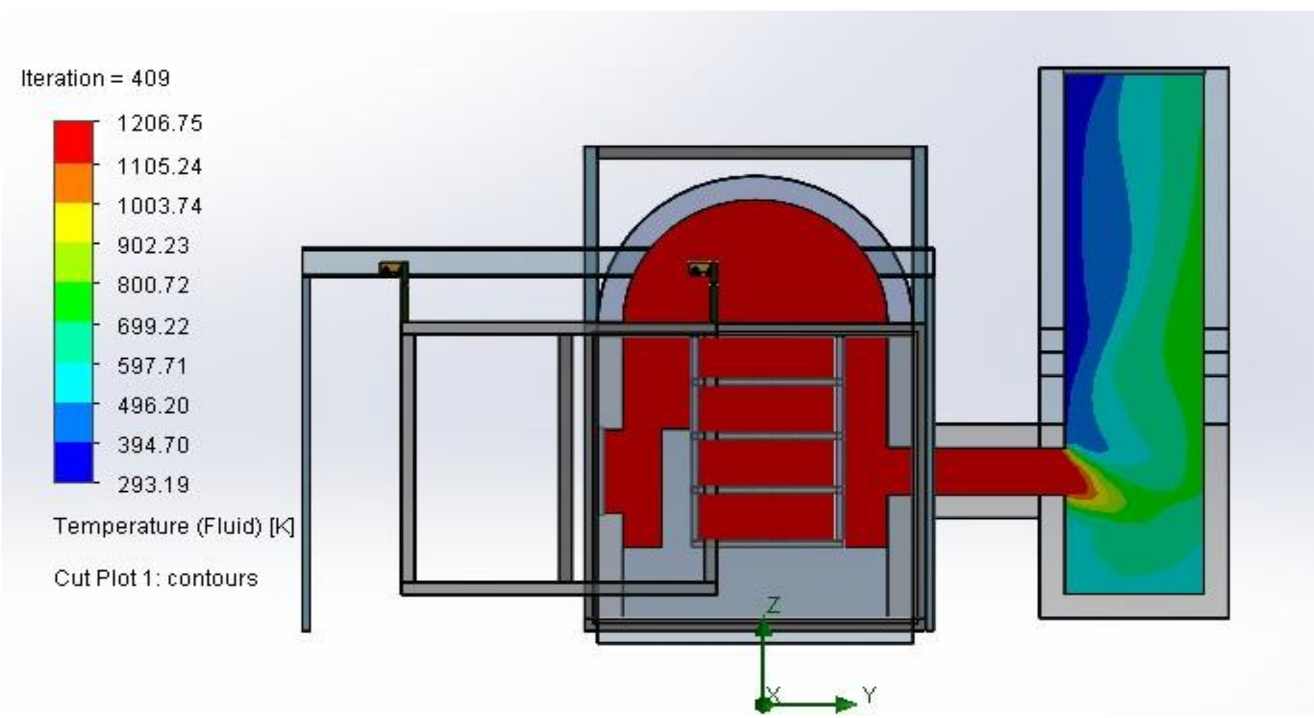

Figure 6: Temperature distribution inside the kiln at 1000mm firewall height

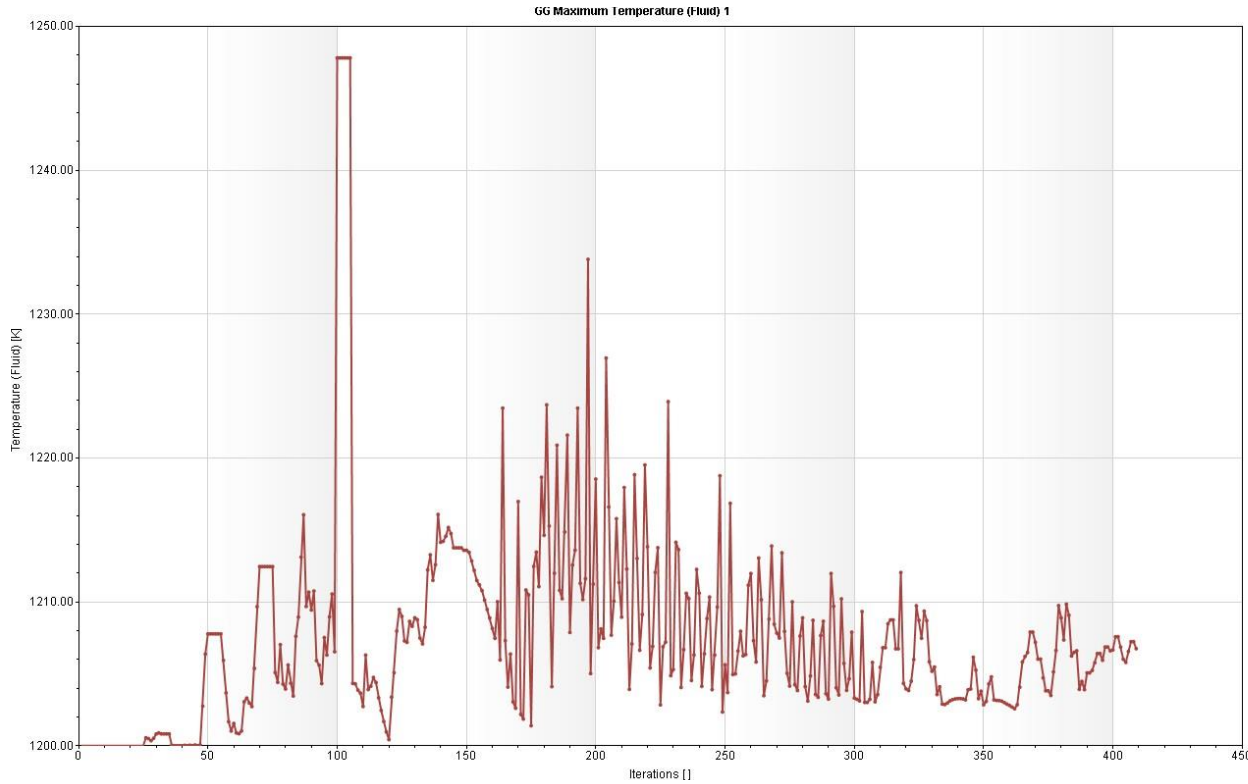

Figure 7: Temperature profile of kiln at 1000mm firewall height

3.2 Effect of changing dome height on the temperature distribution

After simulation, a chart and diagram were obtained of the temperature distribution.

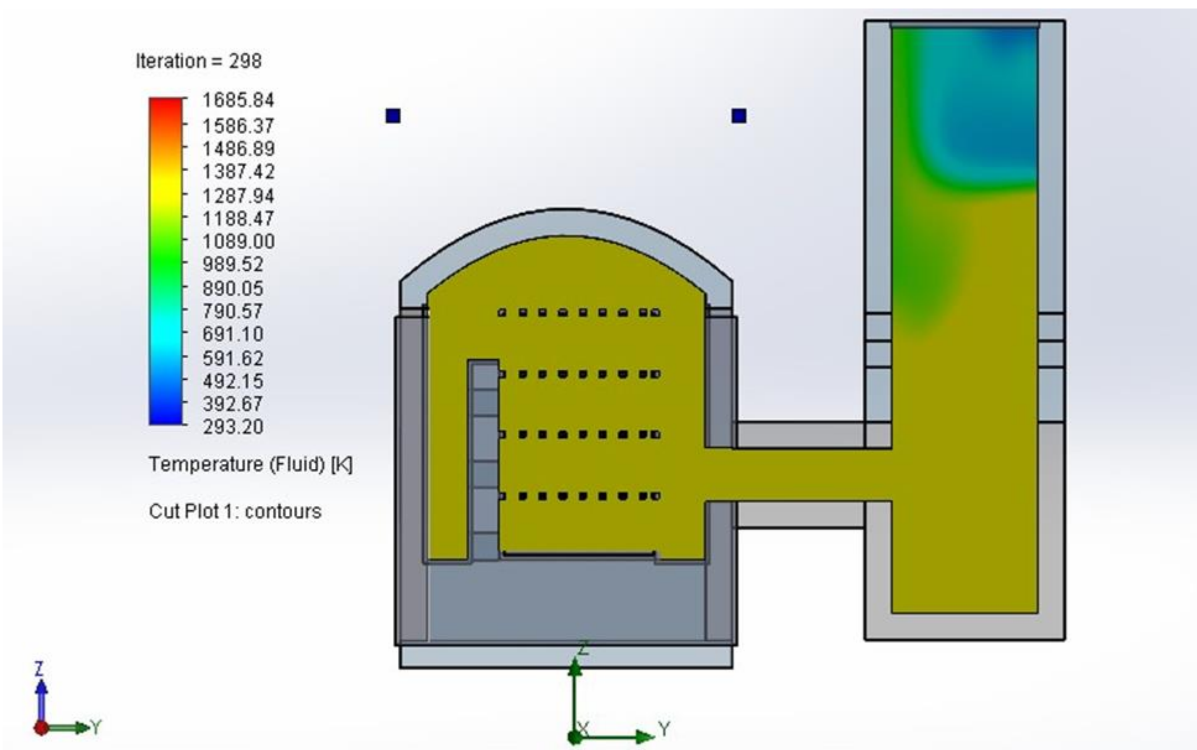

Figure 8: Temperature distribution of kiln at dome radius of 2000mm and firewall height of 1500mm

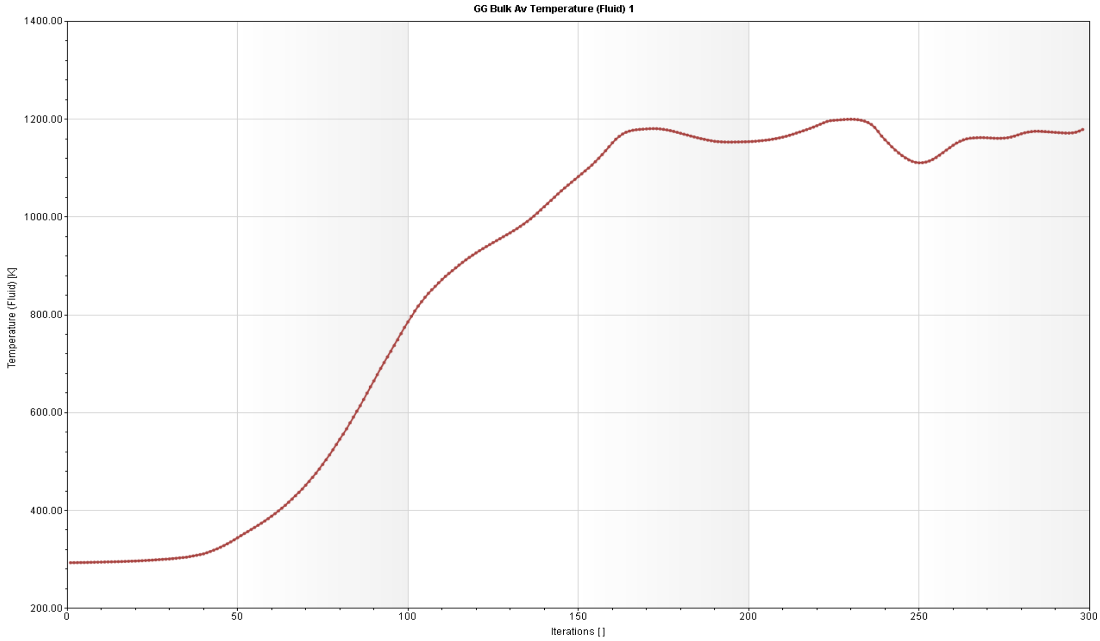

Figure 9: Temperature profile of kiln at dome radius of 2000mm and firewall height of 150mm

The whole kiln and the lower part of the chimney had a constant temperature distribution of 1188.47K while the top half of the chimney had a temperature distribution ranging between293.20K and 989.52K.

3.3 Effect of changing both firewall height and dome radius

After the simulation, the following temperature distribution was obtained.

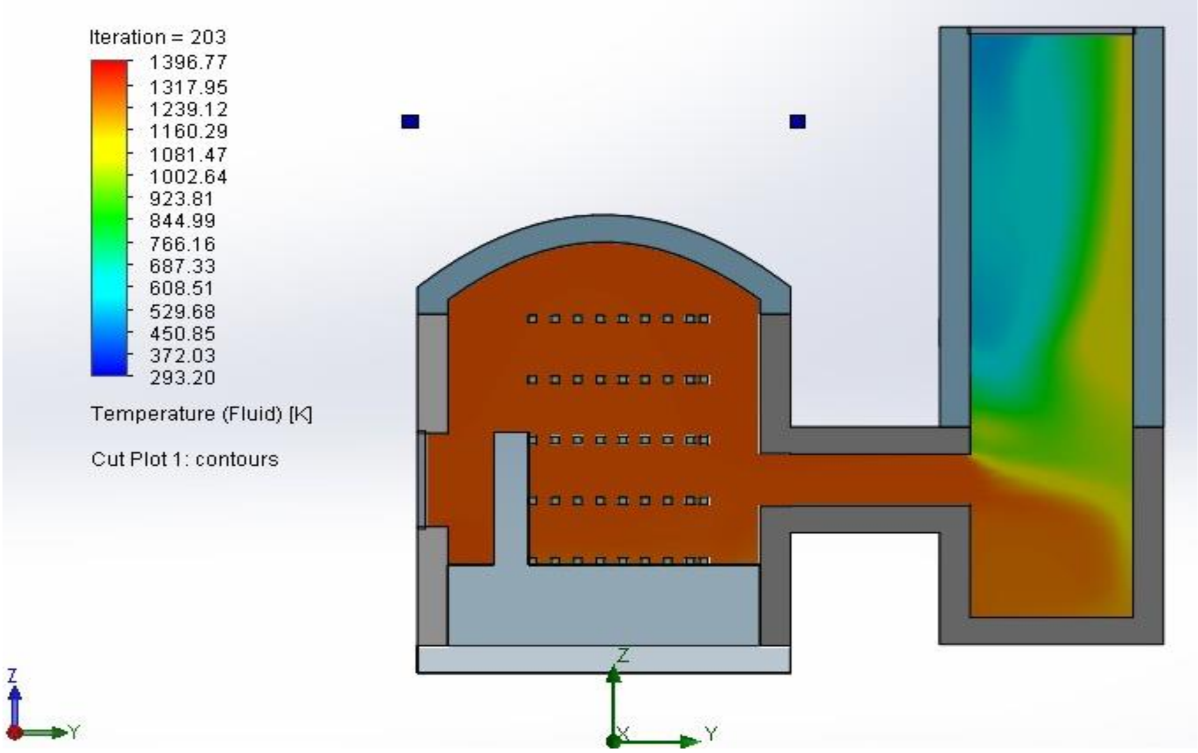

Figure 10: Temperature distribution of kiln at firewall height of 1000mm and dome radius of 2000mm

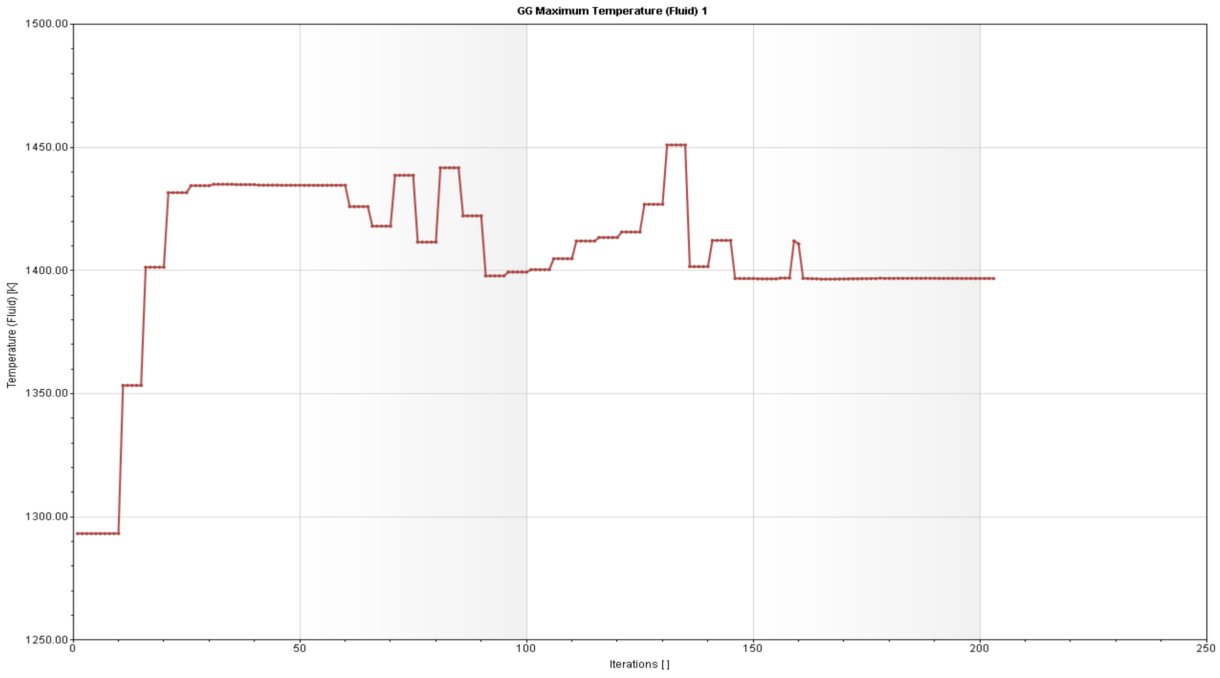

Figure 11: Temperature profile of kiln at firewall height of 1000mm and dome radius of 2000m

The kiln part showed a constant temperature distribution of 1317.95K with the chimneys ranging from 1160.29K to 450.85K from the bottom to the top of the chimney respectively.

3.4 Effect of changing chimney's height and cross-sectional area and flue vent connector's length

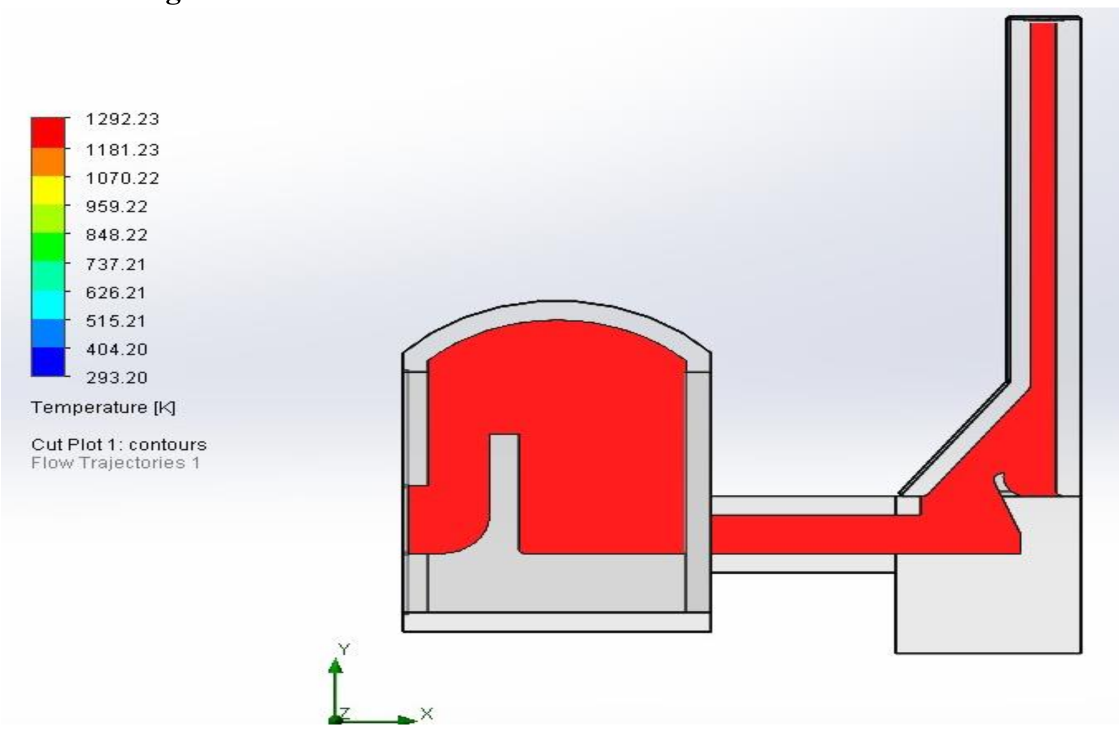

Figure 12: Temperature distribution at 5000mm chimney height:

After the simulation of kiln conditions under different height levels, the following heat distribution was obtained. The whole kiln maintained a constant temperature of 1292.23K.

4. CONCLUSION AND RECOMMENDATIONS

A modern kiln was designed and simulated for use under the improved cook stove production line. The kiln would help in the preparation of clay liners with the purpose of efficiency and durability through the production and utilization stages. The following deductions were made after modelling and simulating different iterations of the kiln:

1. The temperature at the entrance is considerably higher than at the exit of the kiln due to the source of heat being closer.
2. With a decrease in firewall height with a constant dome radius, it was noted that the temperature inside the kiln increased.
3. A decrease in the firewall height and an increase in the dome radius raised the temperatures inside the kiln.
4. With a rise in chimney height, the temperature was gradually dropping by almost half its original value at the end of the chimney
5. At a chimney height of 5 metres, it was noted that the temperature distribution in the kiln was constant.

ACKNOWLEDGEMENT

The authors acknowledge the Dedan Kimathi University of Technology and the GIZ Kenya.

REFERENCES

[1] K. P. U. K. R. K. R. Kiran Govind, "DESIGN AND SIMULATION OF POTTERY KILN," Research Square, Durham, 2021.

[2] J. Muriithi, "World Environmental Library," Ministry of Energy/GTZ-Special Energy Programme, August 1993. [Online]. Available: http://www.nzdl.org/cgi-bin/library.cgi?e=d-00000-00---off-0envl--00-0----0-10-0---0---0direct-10---4-------0-0l--11-en-50---20-about---00-0-1-00-0-0-11-1-0utfZz-8-00&cl=CL1.9.2&d=HASH8e575900afef0b37166183.12&gt=1. [Accessed 28 October 2022].

[3] C. a. S. Kothandaraman, Heat and Mass Transfer Data Book, New Delhi: New Age International Publishers, 2007.