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Original Research Paper

# CFD Simulation of Biogas Fired Clay Brick Kiln

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**Abstract:** More strong and quality clay bricks are obtained if and only if bricks are fired with uniform optimum temperature during clay brick firing process in the clay brick kiln. To insure this transient temperature of fluegas and brick are analyzed using CFD simulation during clay brick firing in the clay brick kiln. In the simulation, 3-D geometrical model of fluegas and clay brick with inlet boundary of velocity and wall condition used respectively. Contour and vector of total temperature of brick and fluegas at different flow time is presented. In addition, temperature variation of selected brick and fluegas at different flow time is analyzed.

**Keywords:** Brick Kiln, CFD Simulation, Fluegas, Clay Brick

## Introduction

Clay brick firing has several advantages. The first importance of light firing clay brick is to bring color for the brick which is resulted by color inducing oxide like $Fe_2O_3$ and $TiO_2$ are neglected. The other effect resulted from the action of heating of brick is the weight loss of the brick, as analyzed by Kabesh (2008) weight loss 26% in between room temperature and 1000°C and 22% in between 110°C and 1000°C. The research that was done by Kabesh (2008) shows an impact of brick firing on increment of brick strength. The researcher did brick firing test with heating rate of 40°C/h from room temperature to 300°C in the muffle furnace. By increasing the rate of heating to 80°C/h and to the final temperature of 900°C or 1000°C, the strength of clay brick increased.

Clay brick firing is one of the energy intensive activity. Different clay brick manufacturer uses different energy source to fire clay brick. Most of clay brick manufacturer were used firewood, caw dung and coal in clay brick firing process which has problem of greenhouse gas emission, land degradation, different air born disease and global warming.

Quality bricks can be obtained in the market if the bricks are fired in uniform and standard optimum temperature. Because of this, controlling and ensuring the temperature distribution of brick firing process is very import in the brick arrangement in the clay brick kiln.

In this CFD simulation, bricks are fired by combustion of methane in the biogas combustion box using biogas burner designed in the section by Beyene *et al*. (2018). Tehzeeb *et al*. (2012) used CFD simulation in order to analysis the flow in the Hoffman kiln brick firing furnace. This paper did a CFD simulation of clay bricks firing which are fired using biogas in clay brick kiln.

## Simulation Procedure

To predict the transient temperature distributions of brick and fluegas, we have used ANSYS FLUENT version 14.5 CFD software Dhayal *et al*. (2013), Marshall (2007). The geometrical model was created in 3-D model. We have used turbulent k-$\epsilon$ model. Because of the inlets are both fluegas with initial temperature and solid (clay) with wall initial temperature, we were used coupled solution method. The mesh size used in the simulation is 0.001. Generally we have 13,502 fluid elements, 51,336 solid elements and 64,838 all domain elements.

The properties of clay brick feed in the simulation is seen in the Table 1 Dadam (2009).

**Table 1:** Properties of green clay brick and fired (common) clay brick (Source: Dadam (2009))

| Component | K(W/mK) | $c_p(J/kgK)$ | $\rho_b$ |
|---|---|---|---|
| Green clay brick | 1.00 | 1,000 | 2,000 |
| Common brick | 0.72 | 835 | 2,083 |

Science Publications

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## Boundary Conditions

In this simulation, because of memory and computational time we have used 28 bricks. The arrangement is given in the Fig. 1.

The front, bottom and top views of the brick arrangement in the simulation process are seen in the Fig. 2.

In this CFD simulation, the inlet boundary conditions are fluegas and clay brick wall. In the fluegas inlet, fluegas of velocity 0.05 m/s to the surface was assigned which is calculated in biogas design section Tehzeeb *et al*. (2012). For the solid inlet part wall and thermal condition was selected. For brick part, wall inlet was selected and in the thermal button initial temperature was assigned. Adiabatic flame temperature of biogas was taken as inlet temperature in both fluegas and wall in the combustion box by considering combustion efficiency of boigas. The adiabatic flame temperature is calculated in the section of Combustion of Biogas Beyene *et al*. (2018) which is equals to 2145.8K. By taking combustion efficiency of biogas as 98%, the inlet temperature for fluegas would be 2103K and the adiabatic flame temperature at 35mm from burner plate is taken as inlet wall temperature which is approximated to 1800K. For all well boundary conditions thermal condition of room temperature was assigned (298K). All the shadow well boundary conditions were set to be coupled.

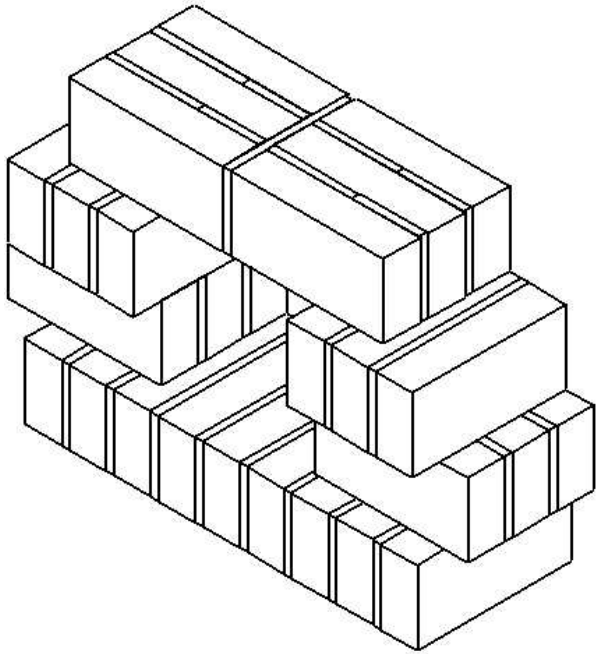


**Fig. 1:** Clay brick arrangement in a single combustion box

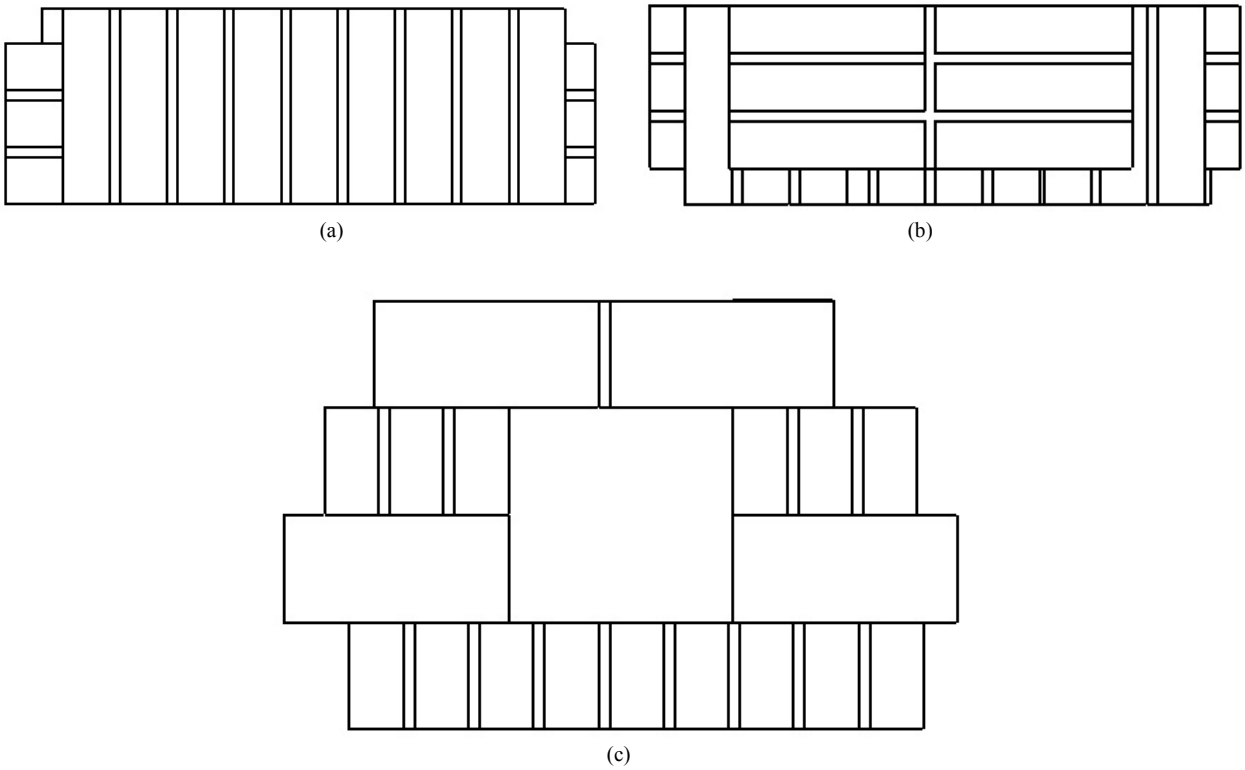



**Fig. 2:** Different views of clay brick arrangement of the simulation (a) Bottom view (b) Top view (c) Front view

Solution methods that are power-full in handling transient simulation is coupled which is reported by? Since we have two inlet boundary conditions, hybrid solution initialization was used.

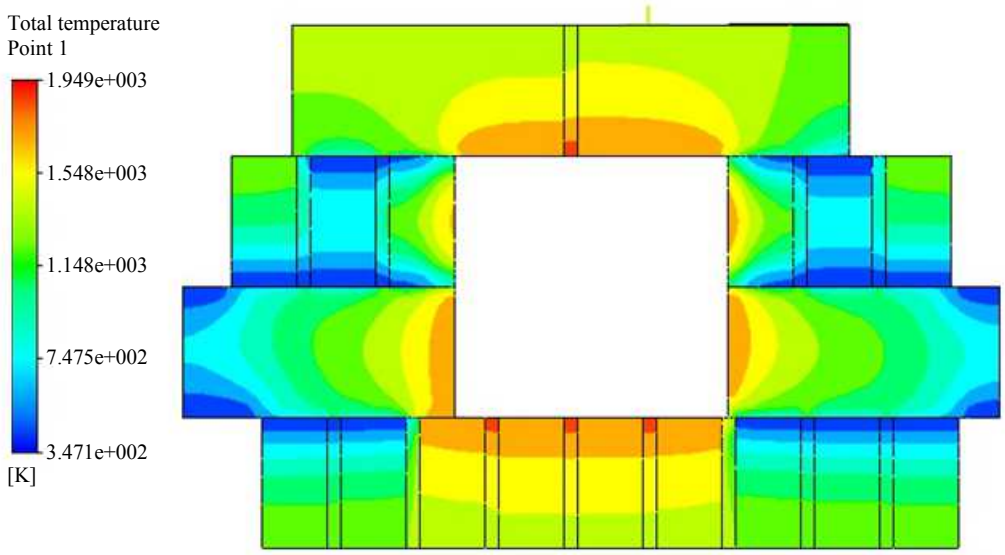
## CFD Results

In this study the time steps size (hr) selected are 0.25, 0.125, 0.1875, 0.1, 0.05 and 0.075. For those of time steps, we have seen total temperature contour of both fluegas and bricks, temperature variation of fluegas and bricks with respect to time and temperature comparison of fluegas and bricks at the same y and z point by varying x.

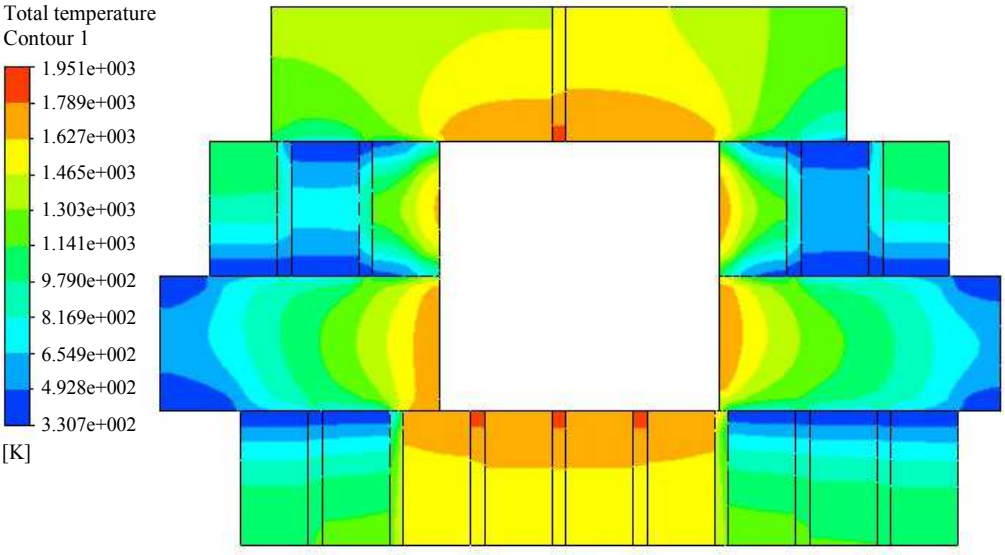
Total temperature of bricks at different flow times are given in the Fig. 3. As it is seen in the Fig. 3a and compared to the temperature distribution in the Fig. 3d, the temperature distribution of bricks at flow time of 5,400s is not cover larger area of the bricks.

Temperature distribution of brick firing process and total temperature of bricks and fluegas during brick firing in the clay brick kiln was considered. The result of total temperature contour distribution of brick firing at flow times of 13,500s is seen in the Fig. 4.

Total temperature contour of both fluegas and brick in the brick firing process were separately analyzed. The change in total temperature of fluegas from inlet side to the outlet was observed. The CFD post result of brick and fluegas of total temperature contour of front and isometric views at 5,400s are presented in the Fig. 5.




(a)

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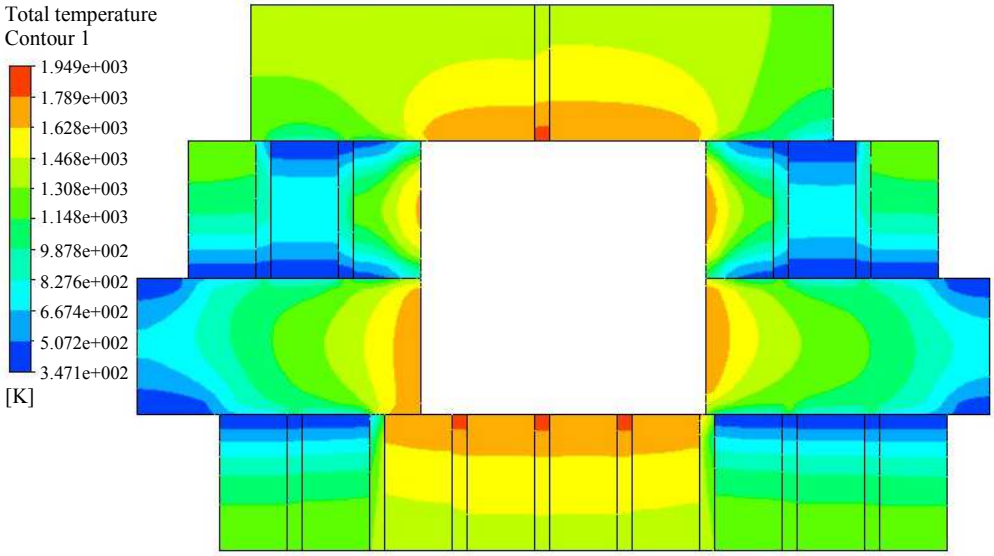


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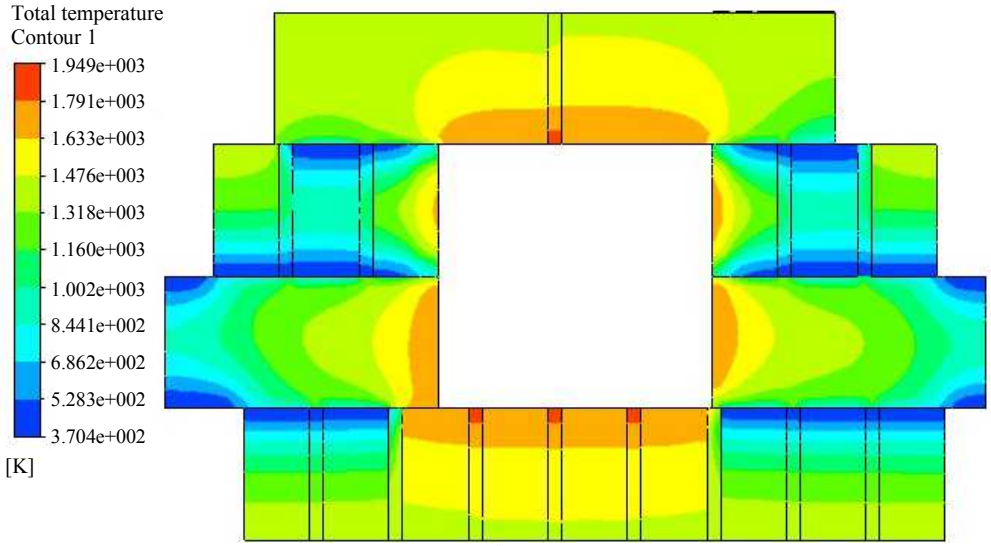
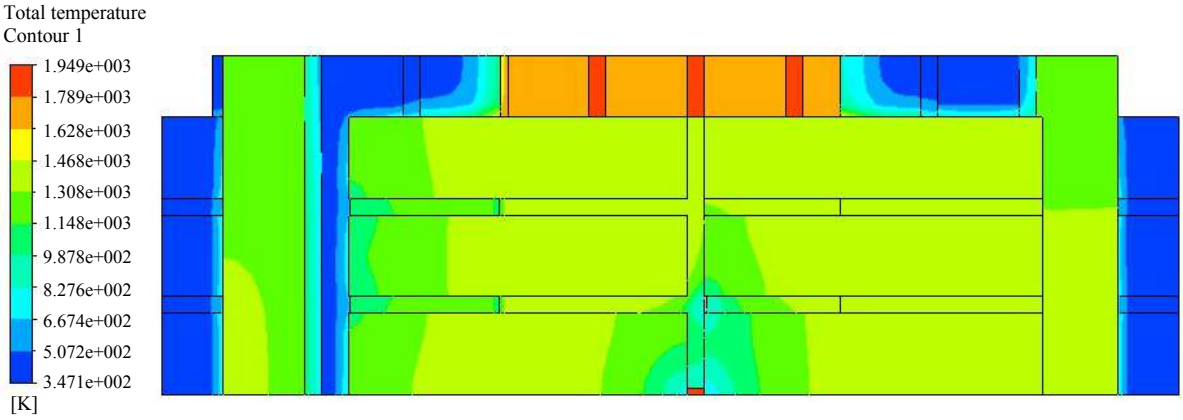



(d)

**Fig. 3:** Contours of total temperature of brick firing (a) At 5,400s (b) At 13,500s (c) At 9,000s (d) At 18,000s




(a)

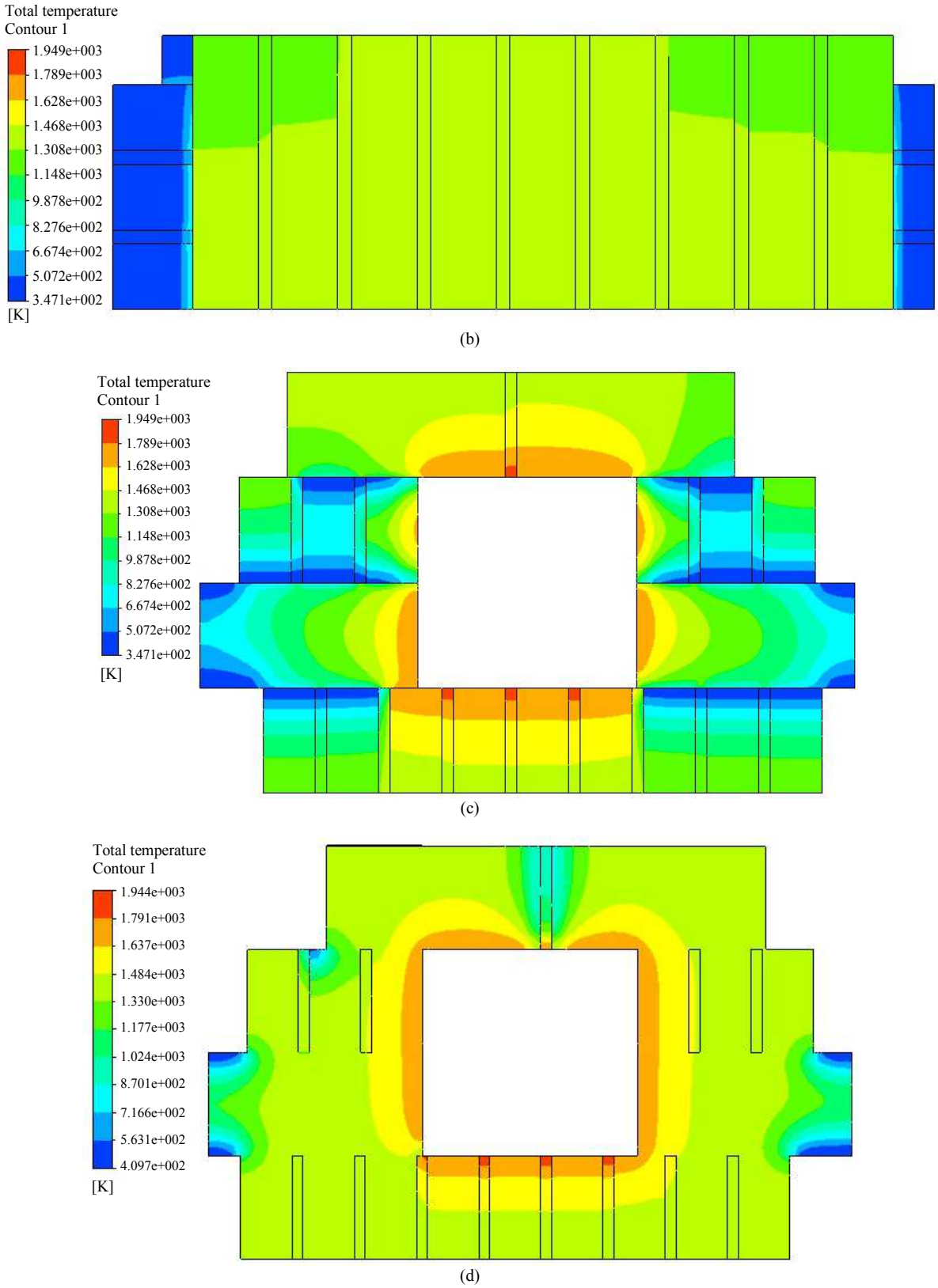



**Fig. 4:** Different views of contour of total temperature of brick firing at flow times of 5,400s (a) Top side view (b) Bottom side view (c) Front side view (d) Back side view

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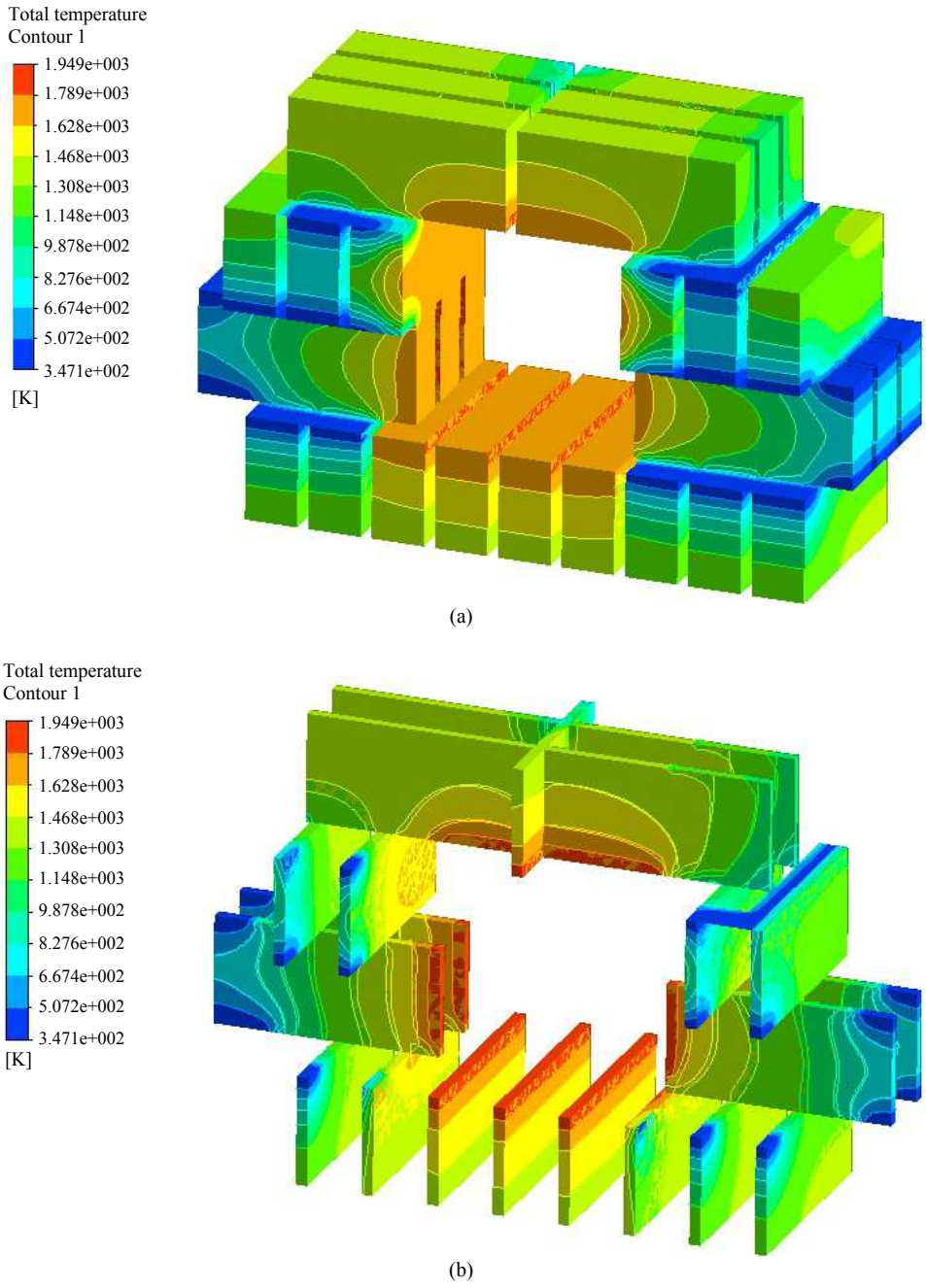


**Fig. 5:** Contours of total temperature of brick and fluegas at 5,400s (a) Isomeric brics at 5,400s (b) Flue gas at 5,400s

As it is seen in the Fig. 5, the temperature of fluegas getting decreased and decreased as we move away from inlet side to the outlet side which reflect existence of transfer of heat between bricks and fluegas. But the temperature of bricks getting increased as firing time is increased. The heat lost from fluegas as the fluegas flow through the arranged bricks is gained by the bricks and consequently temperature increment of the bricks is resulted.

Streamline is the path of zero mass particle pass through fluid domain. The vector streamline of clay brick firing process which is colored by total temperature at 13,500s is presented in the Fig. 6.

The vector total temperature of fluegas of fluid domain is observed in the simulation. It shows how the fluegas is flow in the clay bricks arranged in the clay brick kiln during the firing process. The vector total temperature of simulation at flow time of 13,500s is presented in the Fig. 7.

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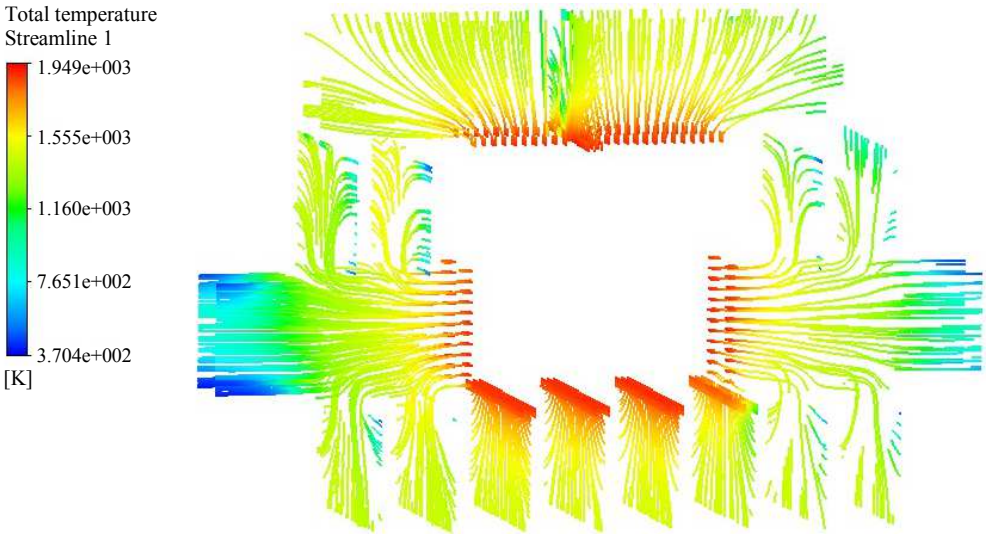


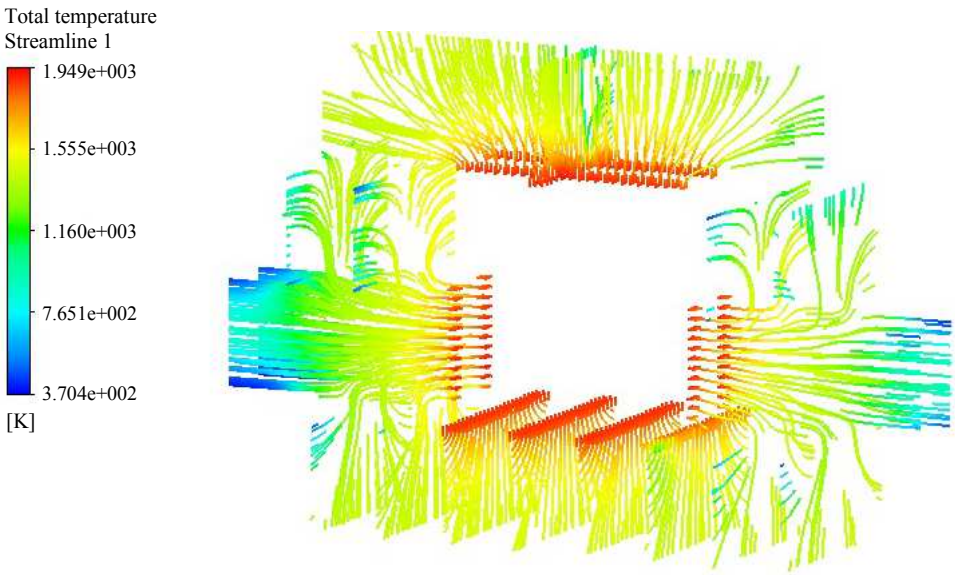


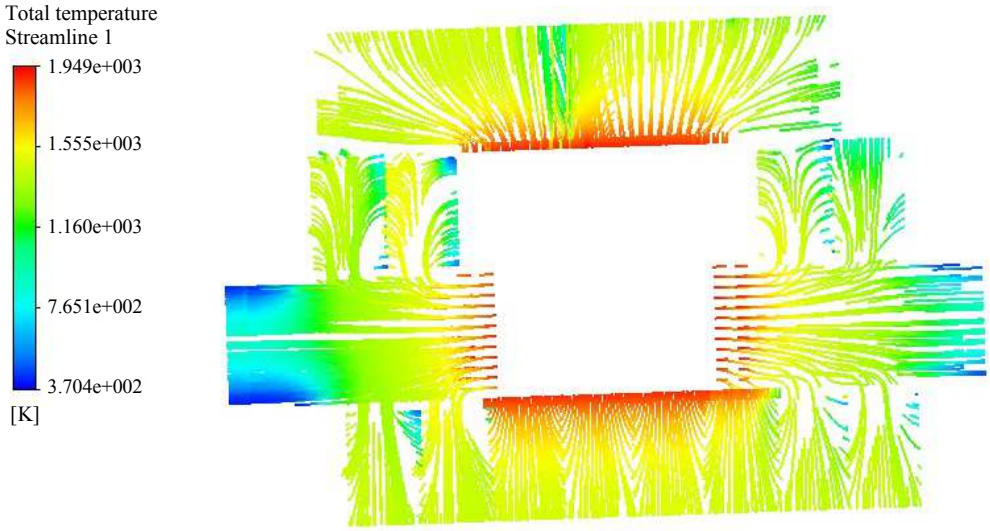

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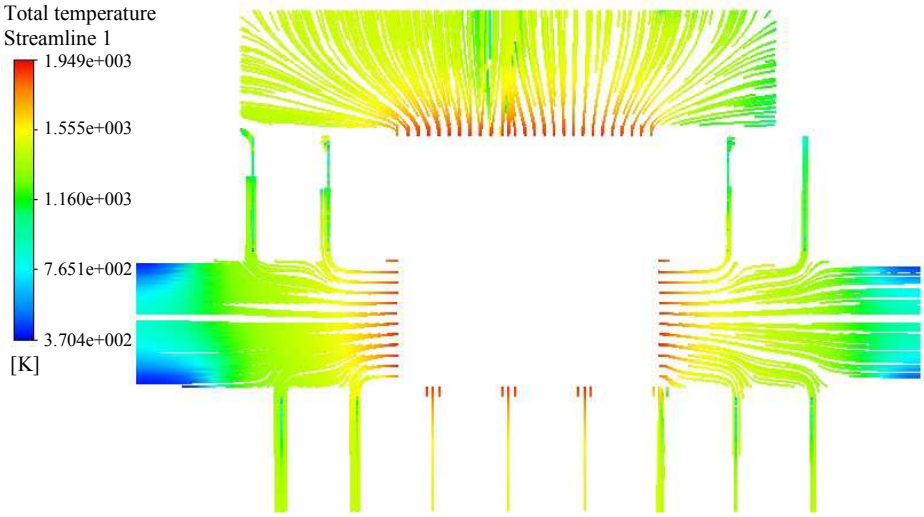


**Fig. 6:** Different views of streamline at 13,500s

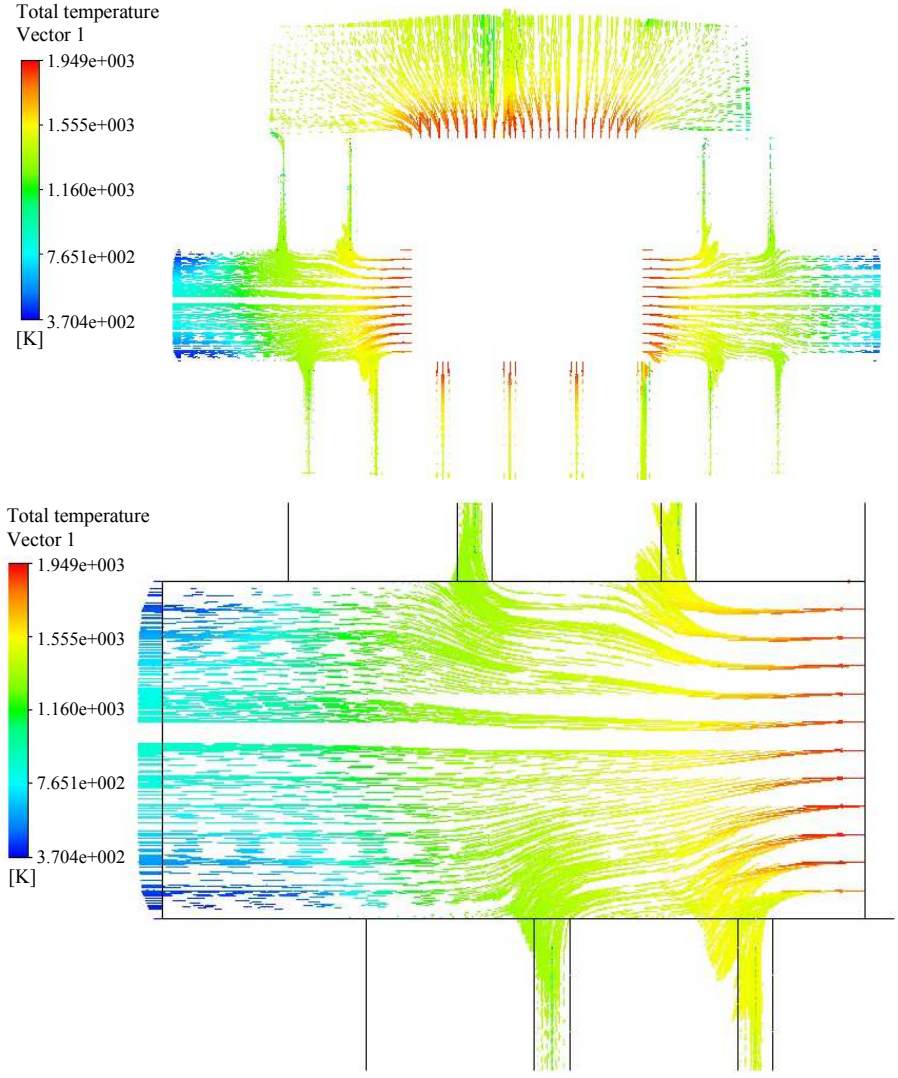


**Fig. 7:** Vectors of total temperature at 13,500s

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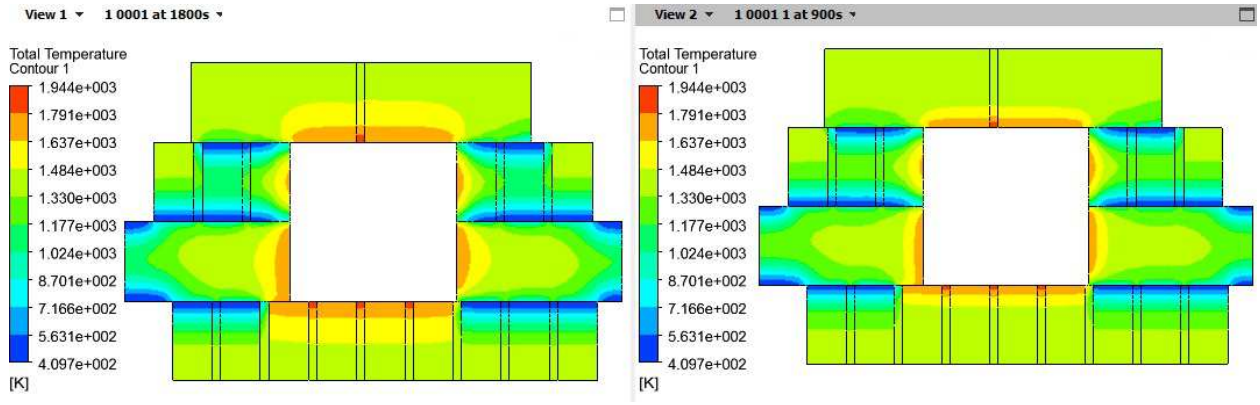



**Fig. 8:** Contours of total temperature of brick at 1,800s and 900s

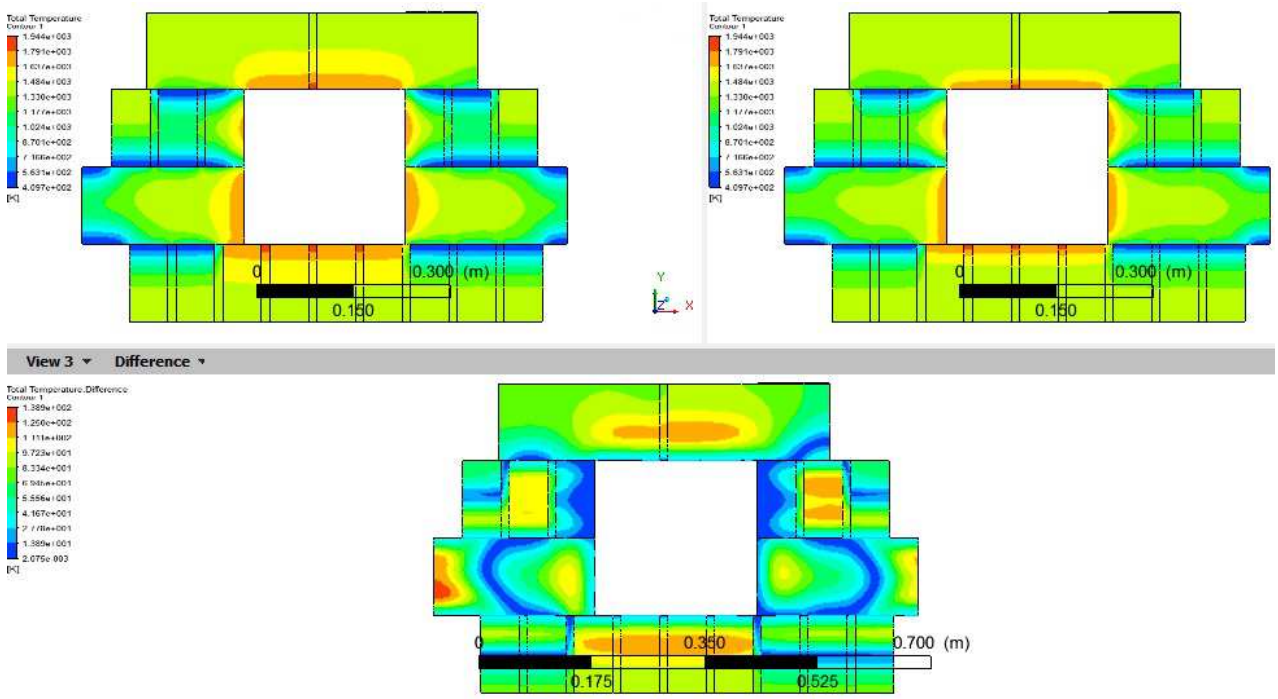



**Fig. 9:** Contours of total temperature of brick comparison at 1,800s and 900s

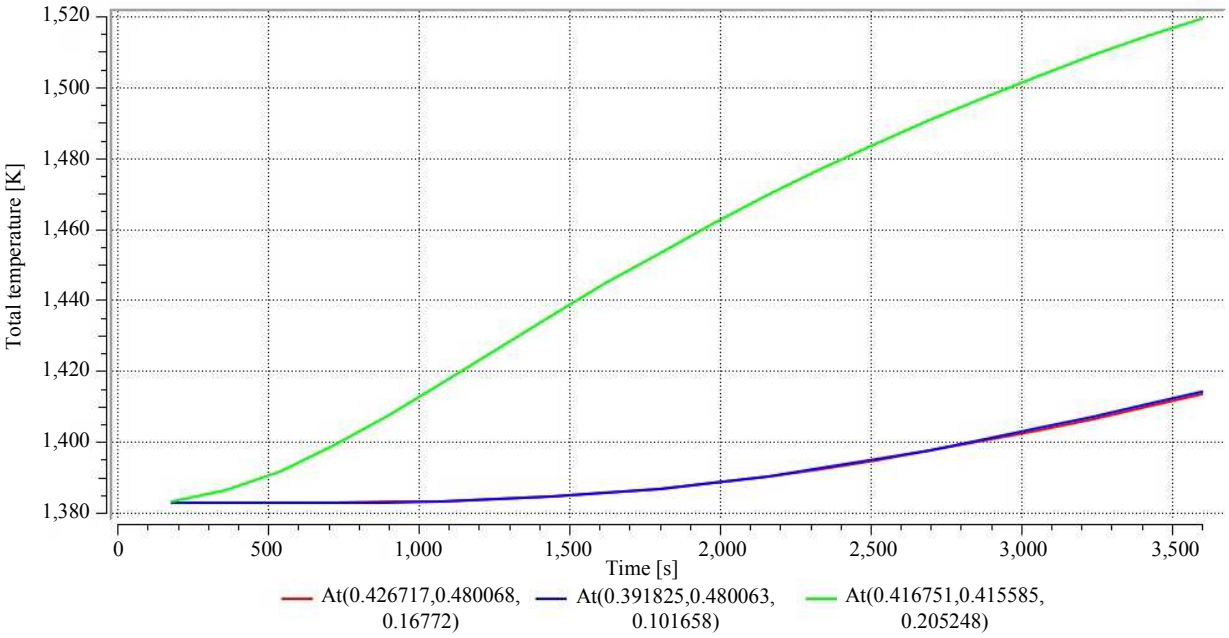
The variation of total temperature on the surface of bricks with different flow times were also observed. The total temperature contour of bricks and fluegas at flow times of 1,800s and 900s are seen in the Fig. 8. The comparison of total temperature contour of bricks firing in these flow times and total temperature contour are presented in the Fig. 9.

The figures seen in the Fig. 10 are the graph of total temperature of clay bricks versus flow times.

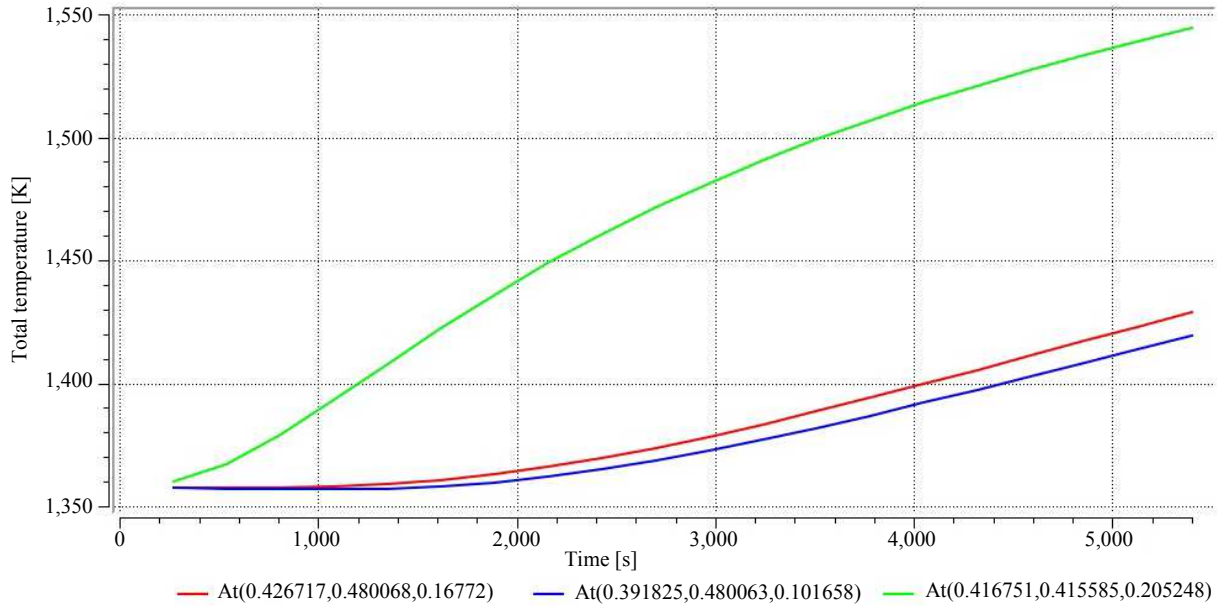
In the analysis of total temperature variation of bricks with respect to the firing time, we have taken three different point on the brick (0.426717,0.480068,0.16772), (0.391825, 0.480063, 0.101658) and (0.416751, 0.415585,0.205248). The total temperature of bricks at those points at different time are different. The temperature of brick is almost the same at 3600s at point 0.426717,0.480068,0.16772) and (0.391825, 0.480063, 0.101658) where as the temperature of bricks at point (0.416751, 0.415585,0.205248) is increased sooner than that of the other two points. The temperature of bricks at those two points did not show

any temperature change until the time of 1250s. Even though the temperature increment is seen at those two points after 1250s, the increment is not as fast as bricks at (0.416751,0.415585, 0.205248). The graph of total temperature of brick at different flow times are seen in the Fig. 10a.

As it is seen in the Fig. 10a to 10f, the temperature of bricks are increased with time. But the temperature of bricks at three points are not increased in the same rate. By taking the temperature of bricks at flow time of 3600s as baseline, we have compared the factor by which the temperature of bricks increased as the firing time increased by the factor of (2n+3)/2 for the first three flow times and the other two flow times are increased by the factor of (4n+15)/4. In these two cases, n = 0,0.5,1 for the first three points and n = 0,1.25 for the other two points.




(a)




(b)

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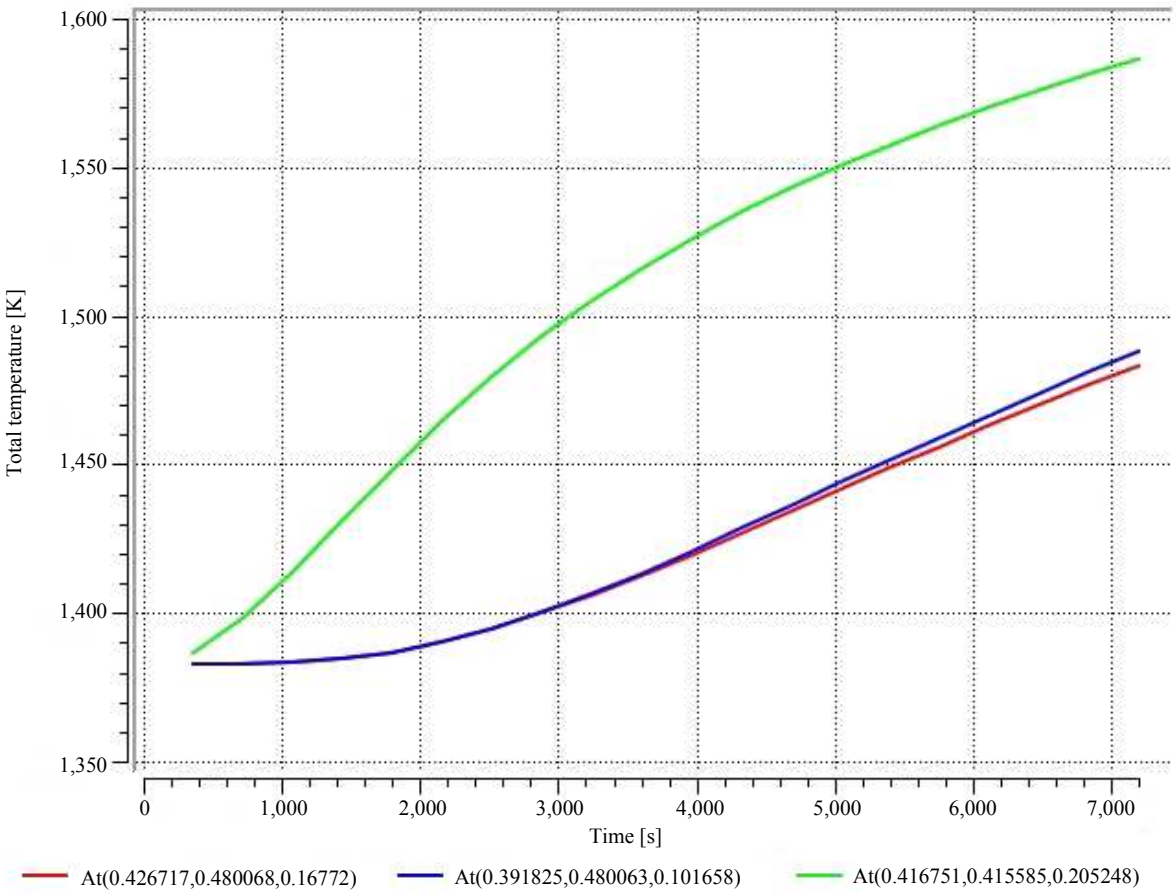


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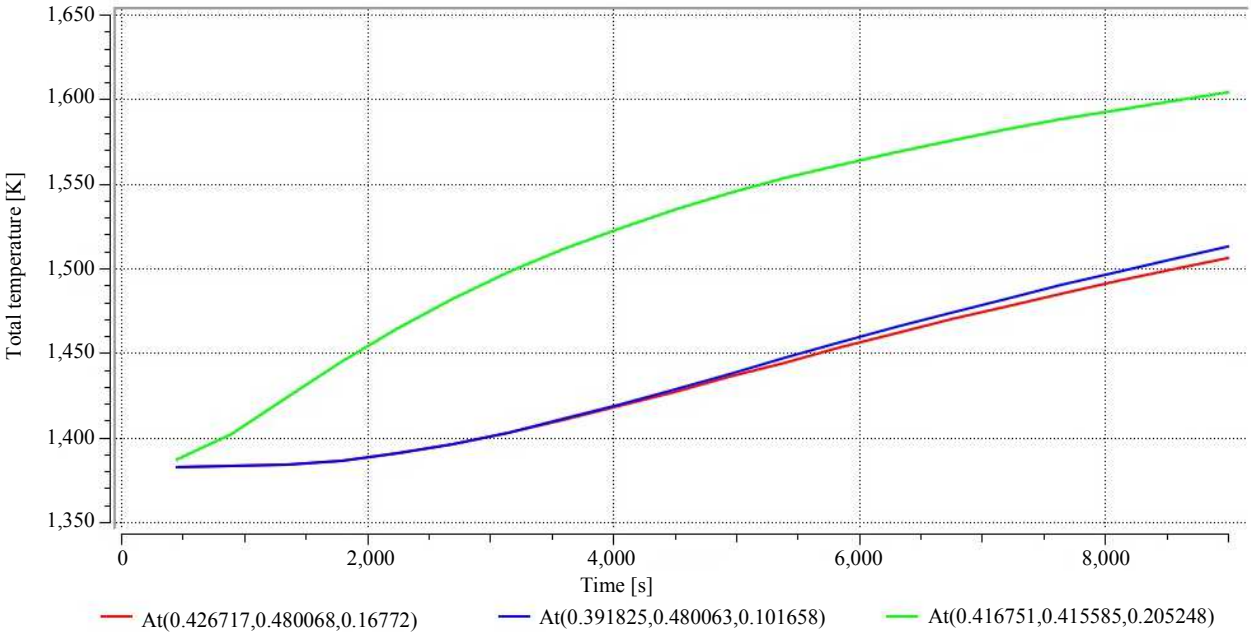
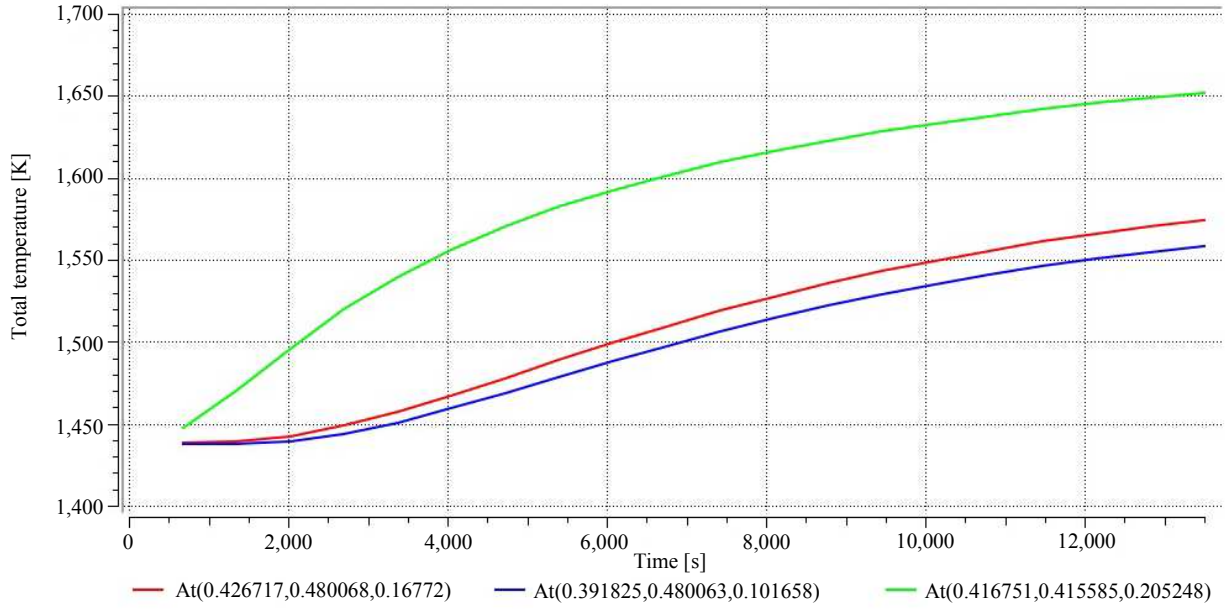
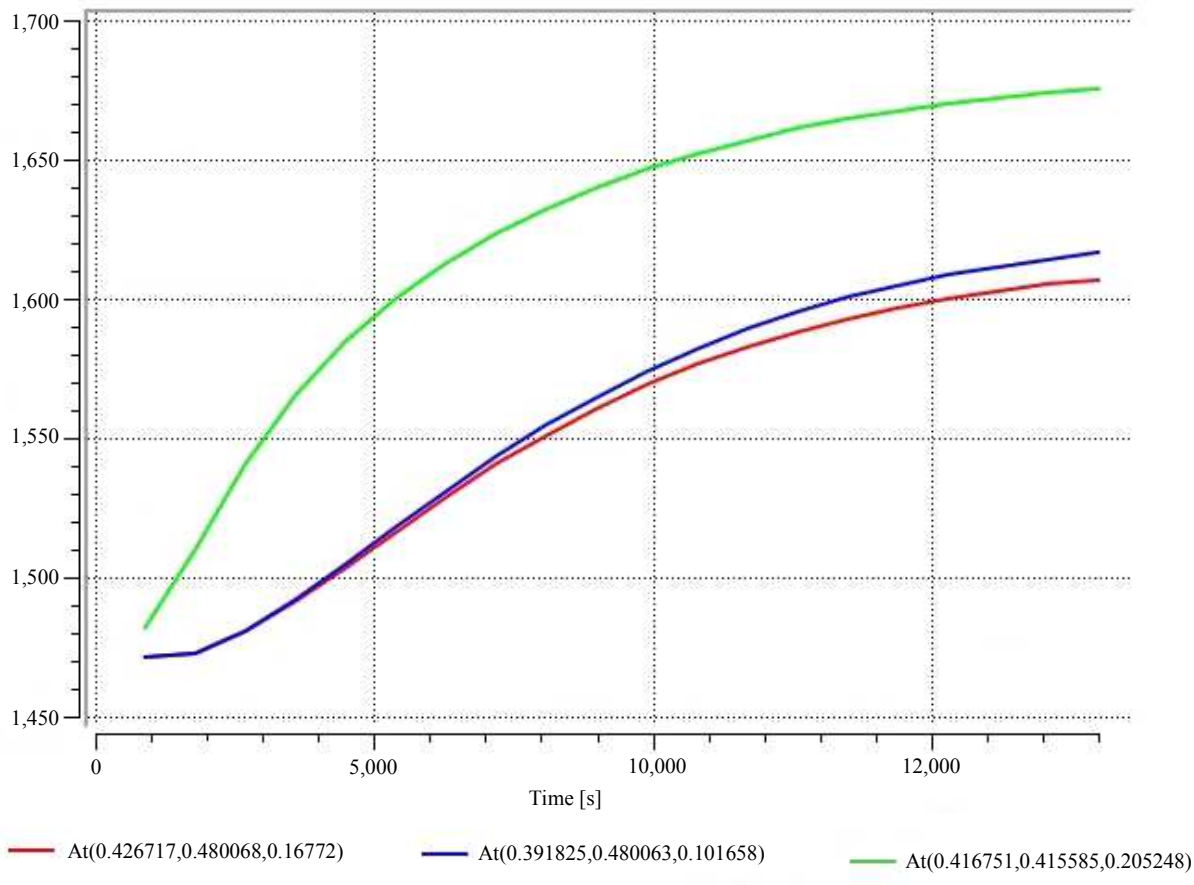



(d)




(e)




(f)

**Fig. 10:** Total temperature vs. time graphs of clay brick firing at three different points (a) At 3,600s (b) At 5,400s (c) At 7,200s (d) At 9,000s (e) At 13,500s (f) At 18,000s

By considering point (0.426717, 0.480068, 0.16772) and from Fig. 10, we have generated data that is seen in the Table 2.

If the temperature change seen in the Table 2 at 5,400s is written as:

$$\delta_{t_1} = 14 + 5^0$$

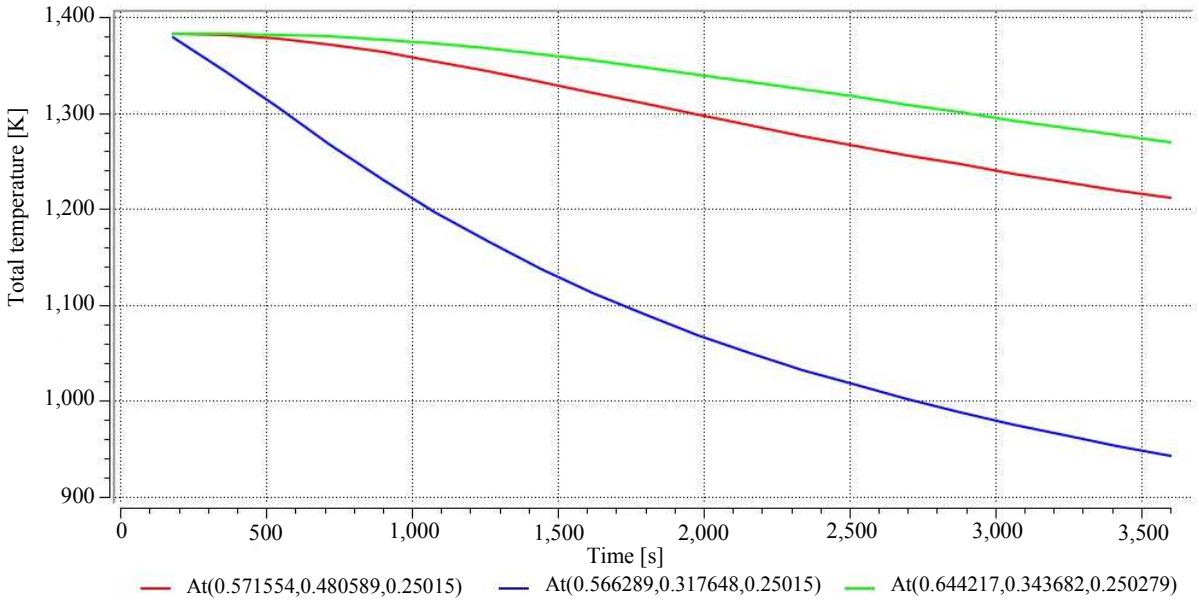
It is possible to write the temperature change happened at 7,200s as:

$$\delta_{t_2} = 3\delta_{t_1} + 5^1$$

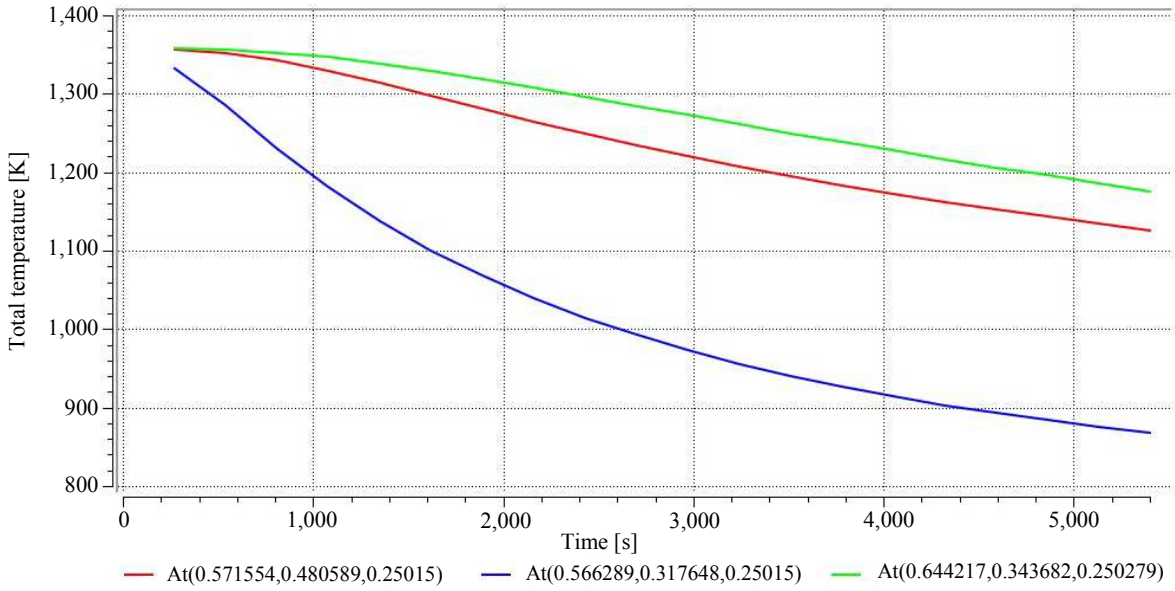
In the same way it is possible to write the temperature change seen at 9,000s as:

$$\delta_{t_3} = 2\delta_{t_2} + 5^2$$

As firing time of clay brick firing increased by the factor of (4n+15)/4 at n = 0, the temperature of clay brick would be increased by the factor of 1.05 and as the brick firing time increased by the factor at n = 1.25 in the firing factor of (4n+15)/4, the temperature of bricks are increased by the factor of 1.02.




(a)

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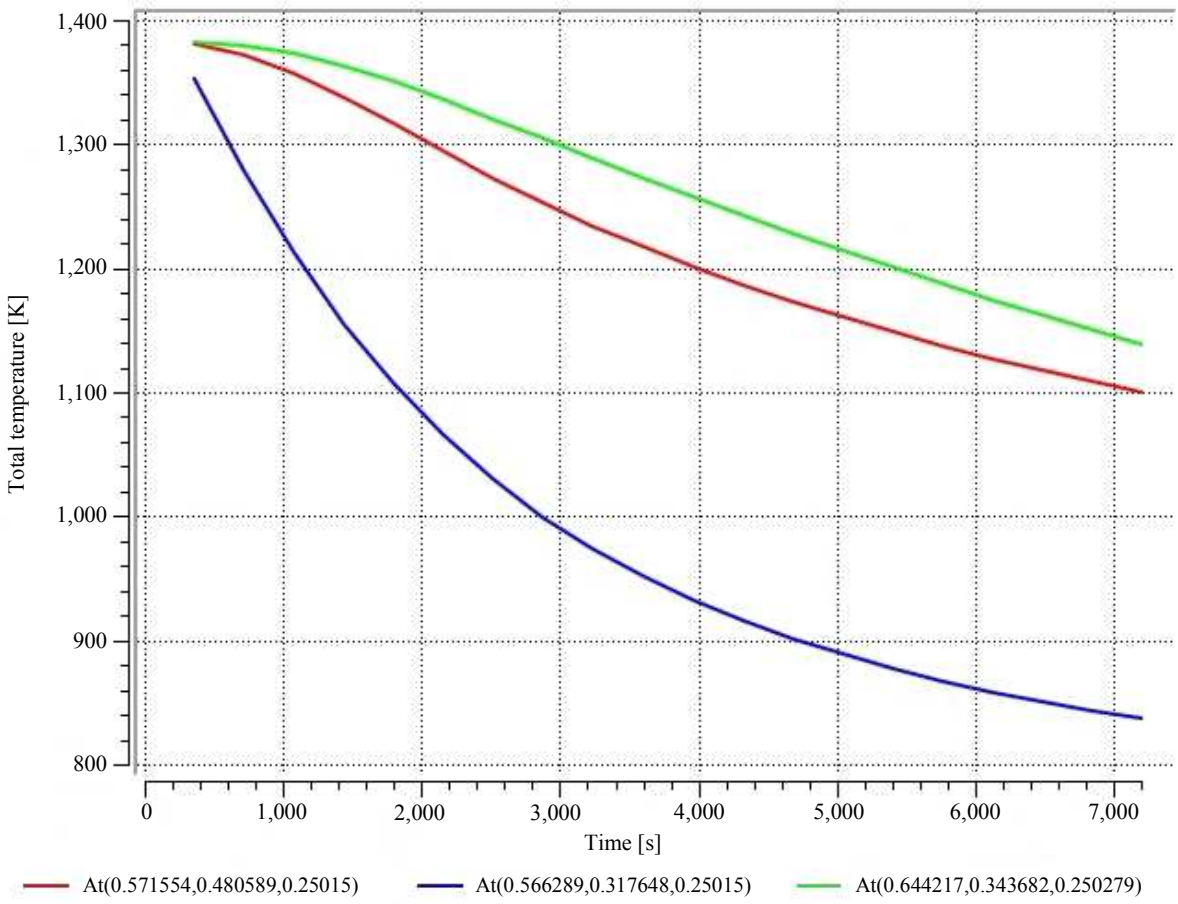
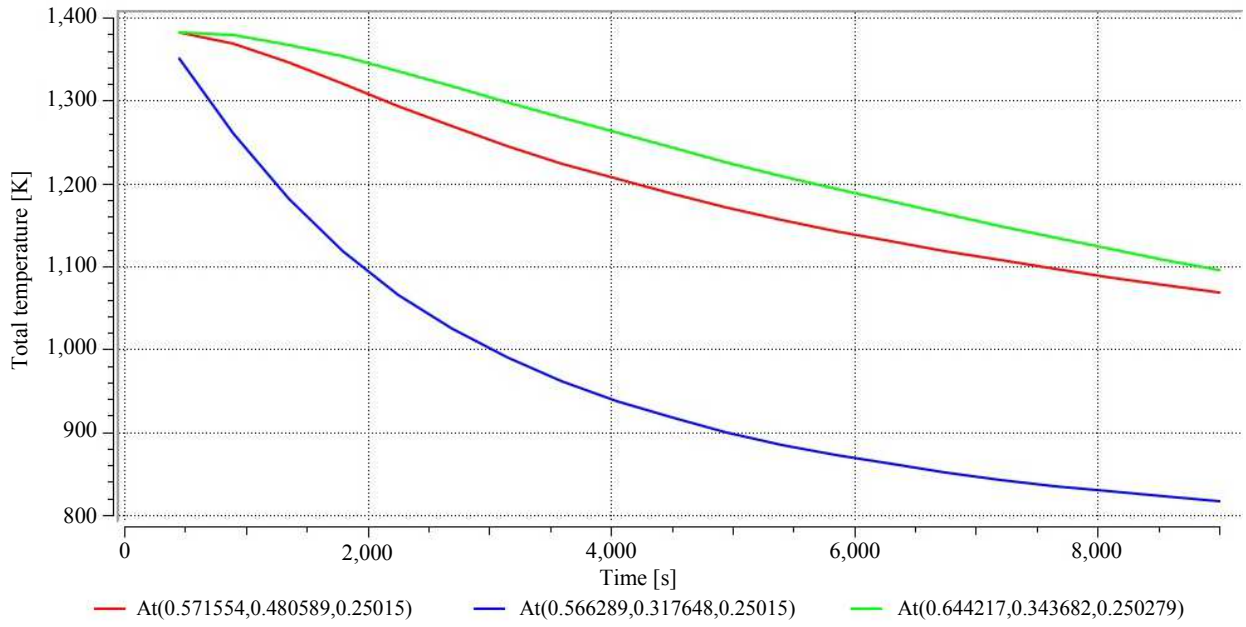
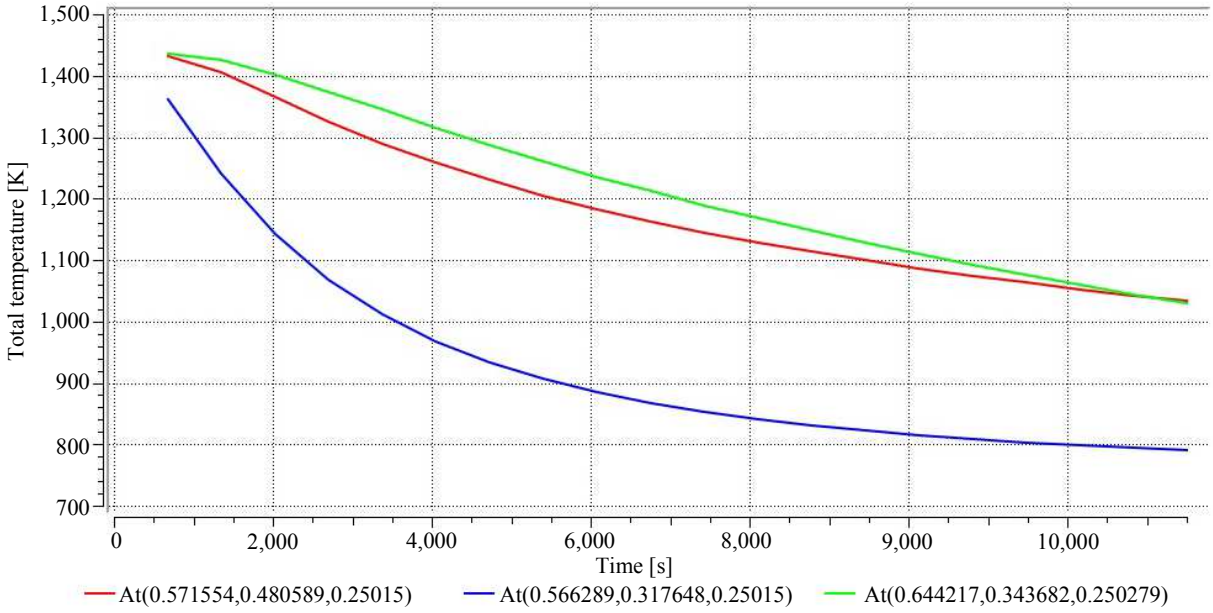

1,400
1,300
1,200
1,100
1,000
900
800
Total temperature [K]
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
Time [s]
At(0.571554,0.480589,0.25015)
At(0.566289,0.317648,0.25015)
At(0.644217,0.343682,0.250279)

(c)


1,400
1,300
1,200
1,100
1,000
900
800
Total temperature [K]
0
2,000
4,000
6,000
8,000
Time [s]
At(0.571554,0.480589,0.25015)
At(0.566289,0.317648,0.25015)
At(0.644217,0.343682,0.250279)

(d)

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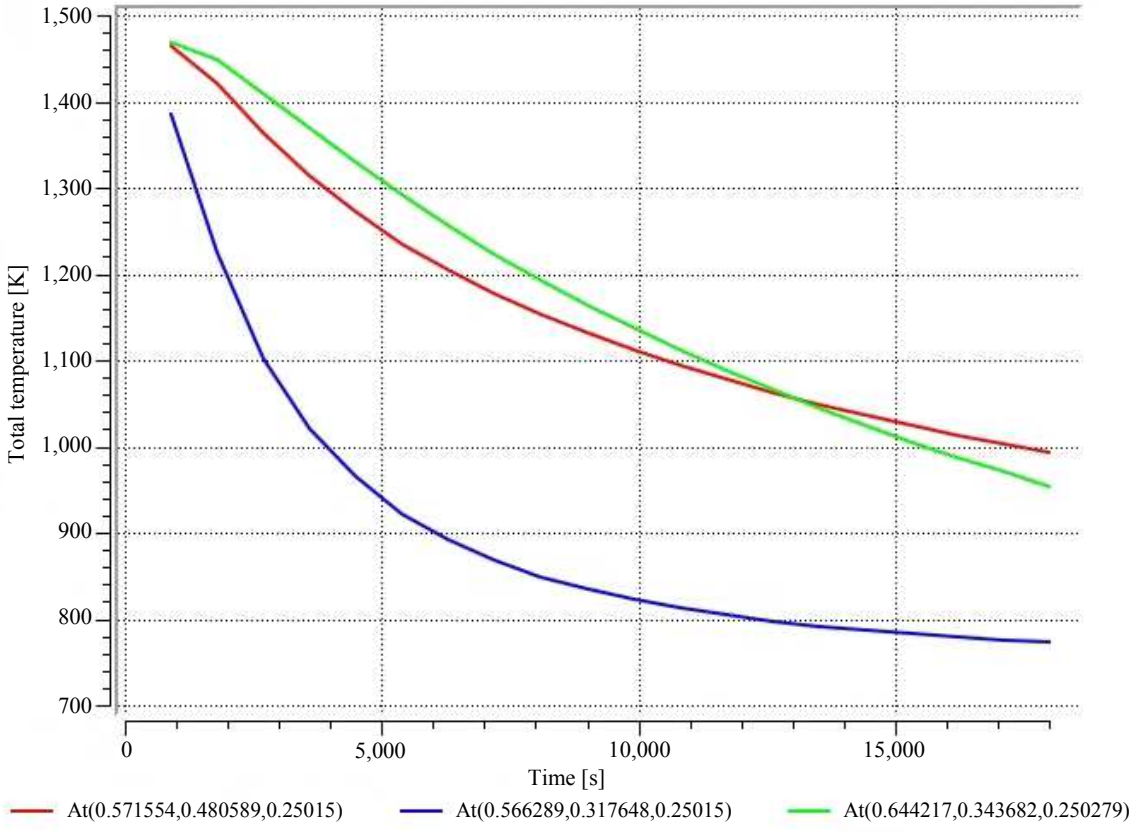
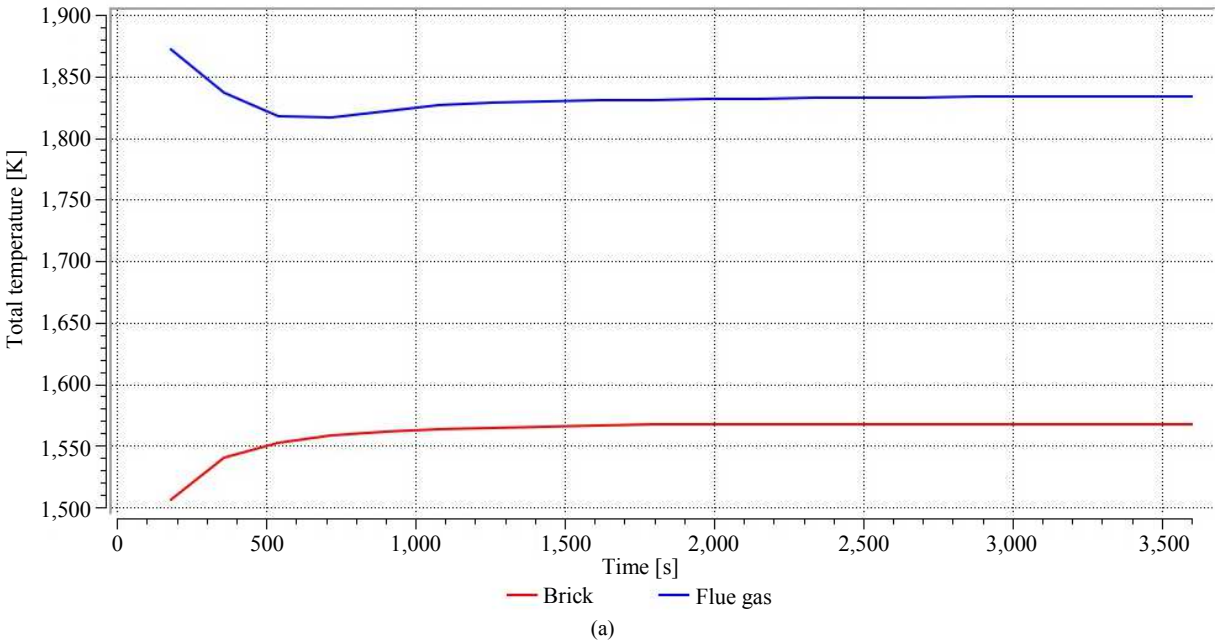
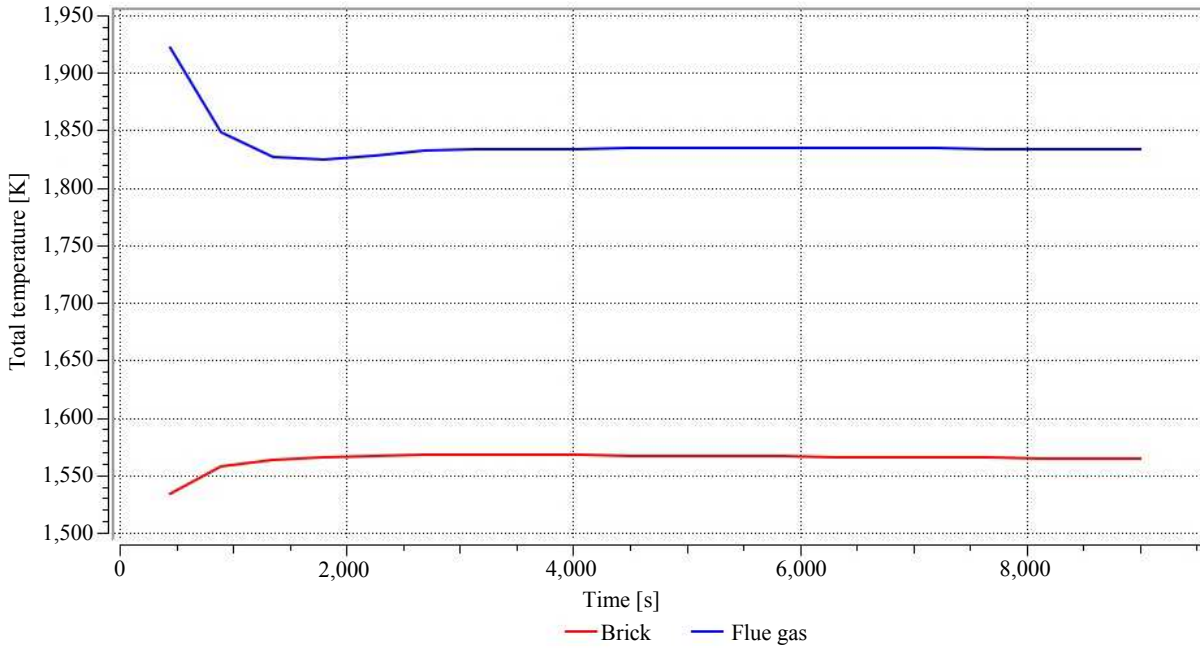



(f)

**Fig. 11:** Total temperature vs. time graphs of fluegas at three different points (a) At 3,600s (b) At 5,400s (c) At 7,200s (d) At 9,000s (e) At 13,500s (f) At 18,000s




(a)




(b)

**Fig. 12:** Total temperature vs. time graphs of fluegas and brick (a) At 5,400s (b) At 9,000s

**Table 2:** Temperature of bricks at different time (source: CFD simulation graph)

| No. | Time(s) | Temperature (K) | Temperature change (K) |
|---|---|---|---|
| $t_0$ | 3,600 | 1,415 | 0 |
| $t_1$ | 5,400 | 1,430 | 15 |
| $t_2$ | 7,200 | 1,480 | 50 |
| $t_3$ | 9,000 | 1,505 | 25 |
| $t_4$ | 13,500 | 1,580 | 75 |
| $t_5$ | 18,000 | 1,610 | 30 |

The total temperature variation of fluegas in the brick firing simulation was analyzed. As fluegas flow between bricks in the clay brick kiln, the total temperature of fluegas is decreased. The decreased in temperature of fluegas as it flows in between bricks show how much heat is transferred from fluegas to bricks in the clay brick firing process. Graphically it is seen in the Fig. 11.

Unless the temperature of fluegas at same x, or y, or z coordinate is greater than the temperature of brick, transfer of heat from fluegas to clay brick is not expected. To see this reality of science, we have used one point in the fluegas and other point on the brick. In the simulation and post CFD result, we have selected (0.501538,0.0338917,0.250159) point for fluegas and (0.521747,0.0338917,0.250159) point for clay brick. As it is seen in the points, we did not find fluegas and clay brick on the same point. Therefore transforming the coordinate of fluegas to positive off set of x direction is required. So that we have transformed the fluegas plane by +0.020209 off set to the x direction and we find the coordinate of brick (0.521747,0.0338917,0.250159). The total temperature variation of fluegas with respect to temperature of brick are seen in the Fig. 12.

## Conclusion

Quality of clay brick is assured if we control the temperature distribution of clay brick firing in the clay brick kiln. Analysis of transient temperature distribution in the clay brick kiln is possible using CFD simulation. As expected, the temperature of clay bricks that are far away from combustion box of the biogas is at lower temperature as compared to temperature of clay bricks near to the combustion box. Therefore to fire the bricks far from combustion box with nearly the optimum standard temperature to that of the brick near to combustion box, bricks should be fired for longer time. This leads to use more energy and the clay near combustion box fired with over temperature. The appropriate placement of the combustion box play great role in obtaining uniform temperature of clay brick in the clay brick kiln. Right placement of combustion box in the clay brick kiln have advantage in terms of reducing the firing time of clay brick and consequently the energy required for the clay brick firing decreased. Clay brick firing is possible using biogas considering the right placement of combustion box in the clay brick kiln. The analysis of transient temperature of clay brick and fluegas flow in the clay brick arrangement in the clay brick kiln is possible using fluent CFD simulation.

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## Author's Contributions

**Alemayehu Beyene:** Contributed a lot such as doing the research, simulating, data analysis and create this structure of the paper and making ready the paper for publication.

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**Getachew Shunki:** Did and invest an effort in simulation part and contribute in obtaining the CFD data from ANSYS Fluent software.

## Ethics

This material is original and contains new unpublished design. We assure you that not ethical issues and no conflict of interest that may comes after the publication of this paper.

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