Parameters for Design and Construction of a Pilot Scale Pyrolysis Gas-Furnace

Ishola Felix A, Aworinde Abraham Kehinde, Ajayi Oluseyi O, Oyawale F. A and Inegbenebor A. O
Mechanical Engineering Department
Covenant University
Ota, Ogun State, Nigeria
felix.ishola@covenantuniversity.edu.ng, aworinde@covenantuniversity.edu.ng,
oluseyi.ajayi@covenantuniversity.edu.ng, festus.oyawale@covenantuniversity.edu.ng,
anthonyinegbenebor@covenantuniversity.edu.ng

Abstract

The objective of this study is to analyse the design parameters for a pyrolysis furnace designed and built for experimental purposes using the principle of heat transfer. The furnace was made of a casing of low carbon steel sheets inside which the refractory bricks were moulded, forming the furnace cavity to prevent heat loss. The pyrolysis capsule was made of high carbon steel tube with flanges which can be opened for batch loading of the precursors and evacuation of products. The furnace was designed to be gas-fired due to high efficiency and cleaner nature of gas energy. The pyrolysis capsule is installed along the centre of the furnace cavity where combustion takes place. The heat energy accumulated around the capsule is being absorbed into the pyrolysis chamber where precursors are being loaded, the regulation of the temperature of the combustion chamber via the installed feedback mechanism to monitor and control the system. The capsule has a Nitrogen gas inlet for the inert environment needed for effective pyrolysis process and an outlet duct for pyrolysis oil collection and gas recovery. The experimental initial conditions were inputted in Solidworks Flow Simulation to determine the heat distribution at different regions of the furnace and thus made it easy to determine the furnace combustion chamber temperature at which the pyrolysis temperature will be attained inside the pyrolysis chamber.

Keywords

Pyrolysis, Furnace, Design and Simulation, Heat transfer, CFD

1. Introduction

Pyrolysis is the thermal degradation of materials at elevated temperatures in the absence of air. The process is irreversible and it has been considered the most promising process for the waste treatment. The solid products of pyrolysis: Carbon black and at further pyrolysis; Graphite had been found to have different kinds of Engineering applications in refractory applications, Aerospace applications, as coatings and lubricants, in paint and ink production; Crystalline graphite is used in production of batteries, Carbon brushes and grinding wheels as well as in Powder metallurgy and Nuclear Power plants (Pierson, 1993) (Chhabra, Shastri, & Bhattacharya, 2016). A furnace is a confinement for heat exchange between a material and the surrounding medium with a regulated temperature (Jawad, 2010). A furnace is primarily to provide and retain heat to a precursor load. The quality of the production depends on how well evenly distributed and controllable the temperature inside a furnace is. At time rapid heating of the load to the desired temperature is a prerequisite to have to achieve an intended product (Abioye, Atanda, Kolawole, & Olorunniwo, 2015). In a nutshell, high heat transfer rates and uniformity of temperature distribution are important factors in determining furnace characteristics (Cadena-Ramírez, Favela-Contreras, & Dieck-Assad, 2017). The pyrolysis furnace analysed in this article is a pilot scaled model purposely for experiments to optimise pyrolysis conditions on some certain precursors. Some agricultural wastes such as coconut shell and palm kernel shell and some inorganic waste materials such as plastics, waste tyres and other rubber-based materials had been found to have a significant level of Carbon contents that can be recovered by pyrolysis process (Athanassiades, 2013), (Sunphorka, Chalermsinsuwan, & Piumsomboon, 2015).

In this paper, Section 2 describes the details of the furnace model. Section 3 highlighted the basic principles guiding the furnace operations. Section 4 presents the design specifications showing the detailed drawings of the different components of the furnace model while section 5 discussed the design parameters showing the mathematical background of the principle used and then went ahead to describe the simulation model using Solidworks software inputting the initial parameters as obtained from the experimental data. Section 6 displays the results of the analysis as a result of computing the parameters earlier stated in section 5. The result was discussed in correlation with the real experimental data and it was discovered to have verified the process.

2. Model Description

There are different classifications of furnace based on the type fuel they use (natural gas, electricity, oil), taking into consideration the fact that the Furnace is expected to reach a high temperature needed for the pyrolysis process special attention to fuel requirements of the furnace is important. Making use of some foundation data for thermal efficiency calculation for different types of furnaces. Summers (1999) shown that Gas source is the most efficient provided there is adequate air supply for complete combustion. Gas energy is relatively cleaner, more affordable, more available, safer and efficient energy choice. The furnace was designed to be powered by the combustion of the flammable methane gas due to the availability and low cost of the methane gas. The combustion at the gas inlet points serves as the origin of the heat flux and then the heat transfer process occurs in the cavity of the furnace making use of a designed swirl burner (Adewole, Abidakun, & Asere, 2013). The thick layers of the refractory bricks mould round the heat flux cavity is to prevent heat loss into the Environment thus makes the heat to be retained and built up inside the main cavity of the furnace.

For simplicity sake, the design was aimed at being a single stage, as well as the furnace structural dimensions being cubic. The furnace is a rectangular hollow cubic refractory built with a hollow cylindrical anaerobic chamber which is closed at both ends. Two burners were placed at two points along the length L of the cylinder. In order to minimize the amount of heat loss at both ends of the horizontal chamber, thereby ensuring optimum efficiency, a thermal resistive cork of 12.5cm formed Kaolin was attached to the flanges at the two ends of the cylindrical chamber. The pyrolysis capsule as shown in Fig 3.1 was designed such that by-products of the pyrolysis process can easily be recovered with an opportunity of reusing the hydrocarbon gas and the tired oil for an energy source (Chu & Majumdar, 2012)(Kern et al., 2012).

3. Principles of Operation in the Furnace

The principles of operation for the pyrolysis furnace are basically three modes of heat transfer; Conduction, Convection and Radiation relating together at a level of complex interactions.

3.1 Conduction

Conduction is the mode of heat transfer in which energy exchange takes place from the region of high temperature to that of low temperature. This mode of heat transfer is prominent vertically along the length of the pyrolysis chamber (Cylindrical pipe), there is an energy transfer from the high-temperature region (the points of direct heating) to the low-temperature region along the pipe length. (Serth, 2007).

3.2 Convection

Convection occurs when fluid flows over a solid body or inside a channel while temperatures of the fluid and the solid surface are different, heat transfer between the fluid and the solid surface takes place as a consequence of the motion of fluid relative to the surface (D. Q. Kern, 1983).

3.3 Radiation

Radiation heat transfer involves the transfer of heat by electromagnetic radiation that arises due to the temperature of the body. Radiation does not need matter. All bodies continuously emit energy because of their temperature, and the energy thus emitted is called thermal radiation. After the gas nozzles are turned on, the flame produced is emitted by radiation to the cargo chamber where the material which would be processed stays and conduction helps to transmit the heat all through the chamber (Vondál & Hájek, 2015).

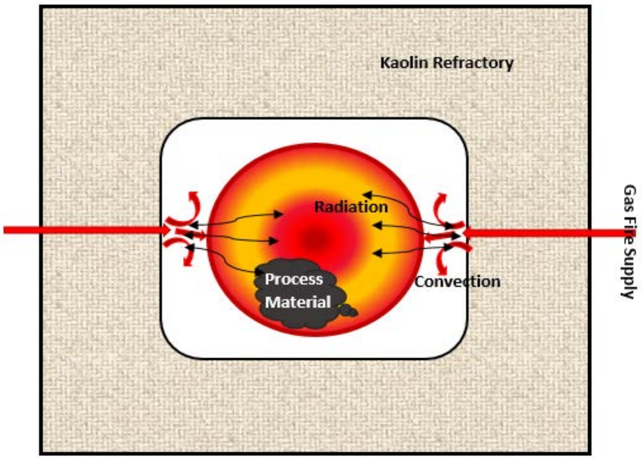


Figure 1: Sectional View to show Basic Features of the Pyrolysis Furnace

4 Design Specifications

The furnace is 0.8m by 0.8m square at the outside with a combustion chamber of 0.3m by 0.3m square opening cutting through the length of the furnace (i.e 0.8m). Refractory bricks occupying the spaces around the combustion chamber amounting to a 0.5m thickness of refractories for an effective heat conservation. The combustion chamber houses a pyrolysis chamber which is a 1.2m long and 0.17m wide 3mm thick pipe made of high carbon steel inside where the material to be pyrolysed is concealed (Ishola, Oyawale, Inegbenebor, & Boyo, 2018).

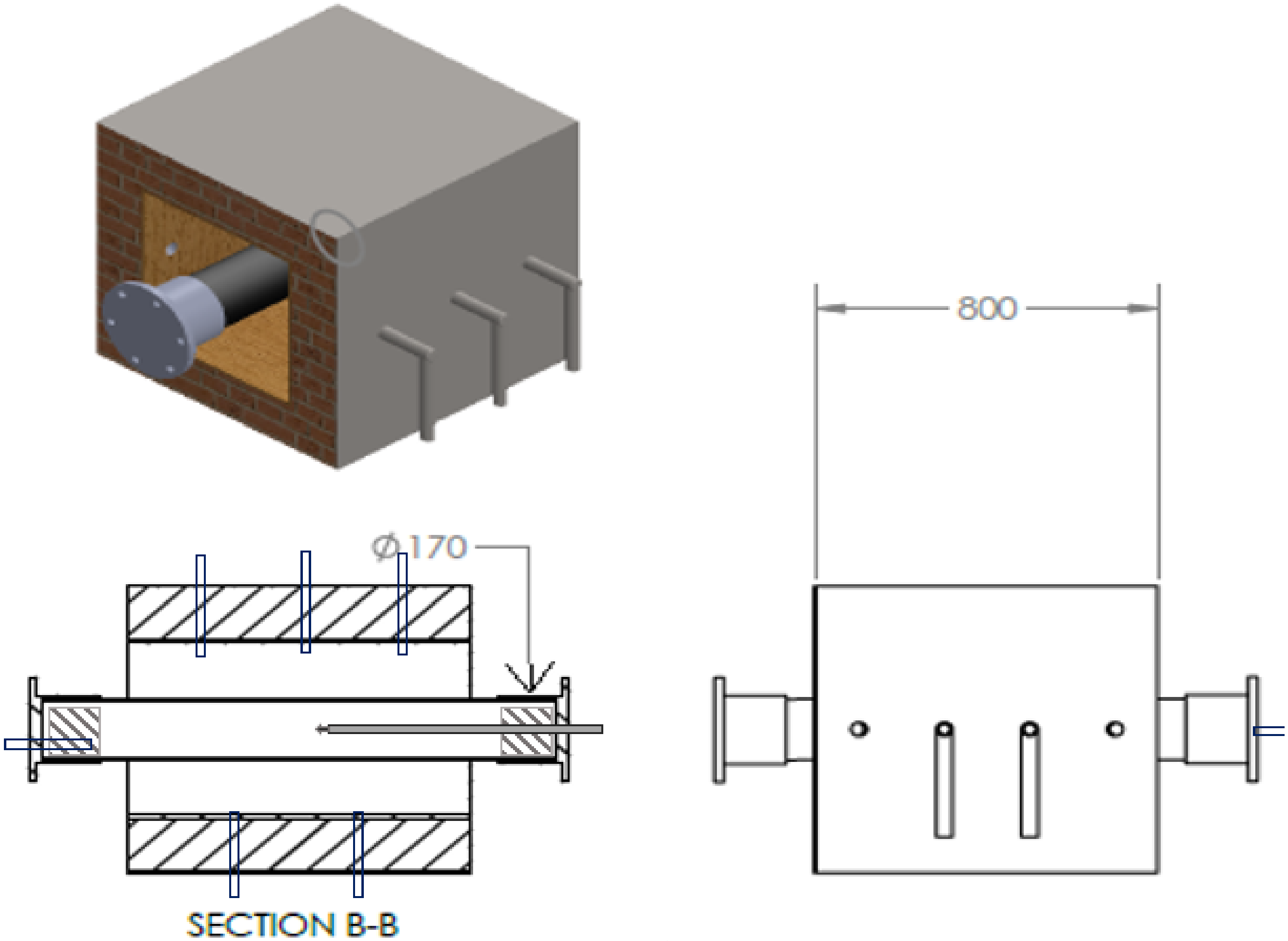


Figure 2: Engineering drawing of the Pyrolysis Furnace

5 Design Parameters

5. 1 Mathematical Model

The design parameters for the furnaces involve considerations of the mode of operation, their heating mechanism, heat transfer within the furnaces, materials of furnaces, waste utilization, energy utilization, their capacity and efficiency (Jawad, 2010). The efficiency of furnaces is directly related to the ability to minimize heat loss; heat loss being the heat from the surface of the pyrolysis furnace to its surroundings by natural convection and radiation (Kodera & Kaiho, 2016). All the assumptions, foundations, and implications of design were defined per time. The temperature distribution of the thermal system was calculated from the energy balance method i. e "***The rate of heat conduction at all sides + rate of heat generation inside = rate of change of the energy content.***" Given the general heat flow equation using the one-dimensional steady heat conduction. $\frac{\partial^2 T}{\partial x^2} + \frac{\dot{g}}{K} = 0$ (i)

5.1.1 Thermal Resistance

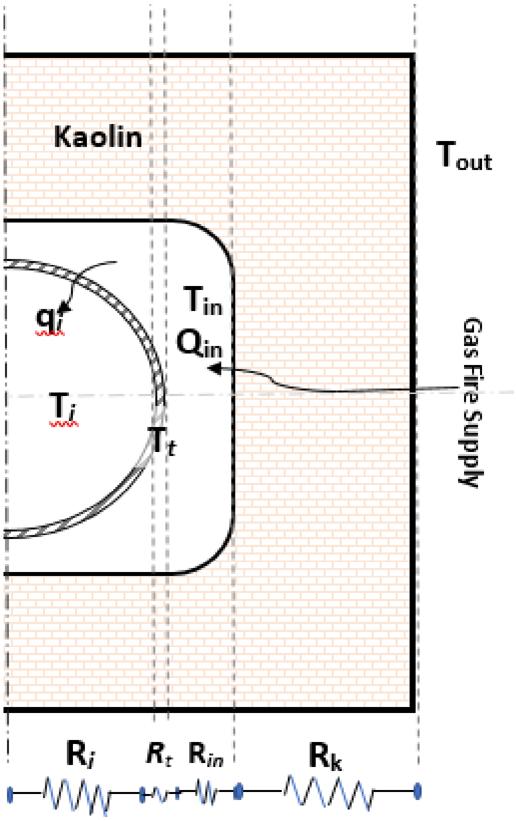


Figure 3: Schematic representation of the Pyrolysis Furnace

Given Heat Origin, Q_{in} from the combustion gas, n the radial direction, the thermal resistance from the innermost part of the furnace to the outermost part which is the kaolin layer is represented by:

$$\boldsymbol{R_{total} = R_i + R_t + R_{in} + R_k} \qquad \text{(ii)}$$

Where R_{total} is the total thermal resistance of the whole system in series, $\boldsymbol{R_i}$ is the thermal resistance to radiation inside the cylinder, $\boldsymbol{R_t}$ is thermal resistance to conduction through the shell of the cylinder, $\boldsymbol{R_{in}}$ is the thermal resistance to radiation and convection just outside the shell of the cylinder and $\boldsymbol{R_k}$ is the thermal resistance to conduction in the kaolin refractory. The setup involves three different media on the radial direction which is the innermost part of the furnace (pyrolysis chamber), the region for heat transfer by radiation into the cylinder shell where the heat transfer is mainly by conduction along its length from the area of high heat concentration towards terminal ends having flanges. The outside surroundings of the cylinder are where the exposure to the main heat course i.e the combustion arena. Heat transfer in this region is by radiation as well as. Therefore, the equation becomes;

$$\boldsymbol{R_{total}} = R_{rad} + R_{cyl,cond} + R_{rad,conv} + R_{rect,cond} \qquad \text{(iii)}$$

$$= \frac{1}{\varepsilon_1 \sigma A_1} + \frac{\ln(r_2/r_1)}{2\pi L K_1} + \left(\frac{1}{\varepsilon_2 \sigma A_2} + \frac{1}{h_1 A_2}\right) + \frac{1}{K_2 A_3} \qquad \text{(iv)}$$

ε_1 is the emissivity of the gas used in the furnace, σ is the Stefan-Boltzmann constant, A_1 is the area of the part of the cylinder, r_2 is the outer radius of the cylinder, r_1 is the inner radius of the cylinder, L is the length of the cylinder, ε_2 is the emissivity of air just outside the cylinder, A_2 is the area of free air just outside of the cylinder, h_1 is the convection constant of air, K_2 is the thermal conductivity of the kaolin thermal insulator, A_3 is the area occupied by the kaolin thermal insulator (Li & Hui Zhou, 2016).

5.1.2 Temperature Distribution within the pyrolysis Chamber

Given the general heat flow equation

$$K\frac{\partial^2 f(x,t)}{\partial x^2} = \frac{\partial f(x,t)}{\partial t} \quad (1)$$

for $0 \leq x \leq 1$ and $t \geq 0$ where
$f(0,t) = 1$

$f(x,0) = 1 + x$ and
$\frac{\partial f(x,t)}{\partial x} = 0$, at $x = 1$

Where x is chosen to be 0.2 and $t = 0.02$. These values have been chosen to be the mesh size. If the diffusion constant is included, the numerical form of the equation can be written as:

$$[k\rho C_p]\frac{t}{x^2}(f_{i-1,j} + f_{i+1,j}) - [k\rho C_p]2f_{i,j} + f_{i,j} = f_{i,j+1} \quad (2)$$

Where $\frac{K}{\rho C_p}$ is the thermal diffusivity k, and $k\rho C_p$ is the thermal conductivity K?

$$[K]\frac{t}{x^2}(f_{i-1,j} + f_{i+1,j}) - [K]2f_{i,j} + f_{i,j} = f_{i,j+1} \quad (3)$$

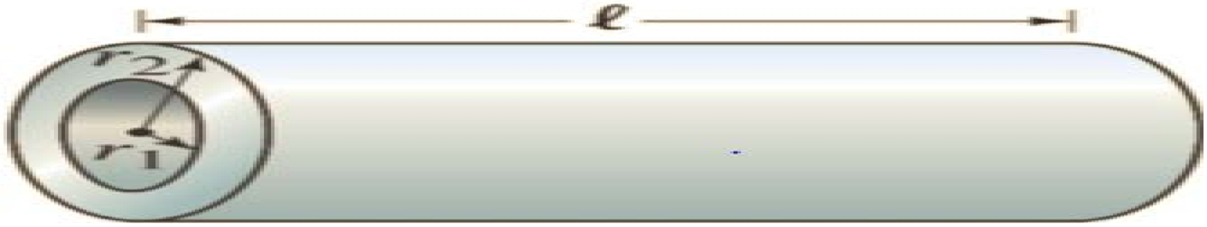


Figure 4: A hollow cylinder with length L, the internal and external radius of r_1 and r_2 respectively.

For a hollow cylinder as shown in figure 4.1, the equation for temperature distribution within its shell by conduction for the radial direction is:

$$[K_{cyl,\ cond}]\frac{t}{(r_2-r_1)^2}(f_{i-1,j} + f_{i+1,j}) - [K_{cyl,\ cond}]2f_{i,j} + f_{i,j} = f_{i,j+1} \quad (4)$$

And that for the L direction is:

$$[K_{cyl,\ cond}]\frac{t}{L^2}(f_{i,j-1} + f_{i,j+1}) - [K_{cyl,\ cond}]2f_{i,j} + f_{i,j} = f_{i,j+1} \quad (5)$$

Where $K_{cyl,\ cond} = \frac{\ln(r_2/r_1)}{2\pi LR}$, R is the thermal resistance, r is the radius of the cylinder, r_1 and r_2 are the internal and outer radius of the cylinder assuming the cylinder is hollow and L the length of the cylinder.

For the cylinder, the equation for temperature distribution by radiation inside it for the radial direction is:

$$[\varepsilon\sigma]\frac{t}{{r_1}^2}(f_{i-1,j} + f_{i+1,j}) - [\varepsilon\sigma]2f_{i,j} + f_{i,j} = f_{i,j+1} \quad (6)$$

And that for the L direction is:

$$[\varepsilon\sigma]\frac{t}{L^2}(f_{i,j-1} + f_{i,j+1}) - [\varepsilon\sigma]2f_{i,j} + f_{i,j} = f_{i,j+1} \quad (7)$$

Where ε is the emissivity and σ is Stephan's constant (Li & Hui Zhou, 2016).

5.2 Simulation Parameters

The followings are the Input Parameters for the SolidWorks Flow Simulation.

5.2.1 Mesh Settings

Table 1: Table showing the Mesh Dimensions per unit meter

Cell number in X	8
Cell number in Y	10
Cell number in Z	30

5.2.2 Additional Physical Calculation Options

Analysis for Heat Transfer: Conduction in solids: On
Type of Flow: Laminar and turbulent
Analysis for Time-Dependent: On
Gravity: Off
Radiation: On
Default Wall Roughness: 0 micrometre

5.2.3 Material Settings

Fluids

Nitrogen – For the pyrolysis chamber to create an inert environment
Air – For the adequate complete combustion chamber

Solids

Steel (Mild)
Ceramic Porcelain

5.2 Initial Conditions

Table 2: Table showing the initial Conditions

Thermodynamic - parameters	Static Pressure: 101325.00 Pa Temperature: 293.20 K
Velocity - parameters	Velocity vector: X direction; Y direction; Z direction = 0 m/s
Solid - parameters	Default material: Ceramic Porcelain Initial solid temperature: 293.20 K Radiation Transparency: Opaque
Concentrations	Substance fraction by mass; Nitrogen -1.0000 Air – 0
Turbulence - parameters	

5.3 Boundary Conditions

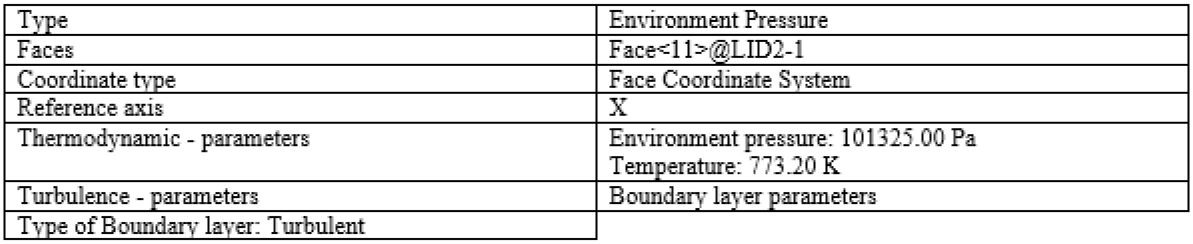
Table 3: Inlet Mass Flow 1

Type	Inlet Mass Flow
Faces	Face<3>@LID5-1 Face<2>@LID9-1 Face<4>@LID6-1
Coordinate type	Global coordinate system
Reference axis	X
Flow - parameters	Flow vectors direction: Normal to face Mass flow rate: 0.0100 kg/s Fully developed flow: No Inlet profile: 0
Thermodynamic - parameters	Approximate pressure: 101325.00 Pa Temperature: 1473.20 K
Turbulence - parameters	Boundary layer parameters

Table 4: Inlet Mass Flow 2

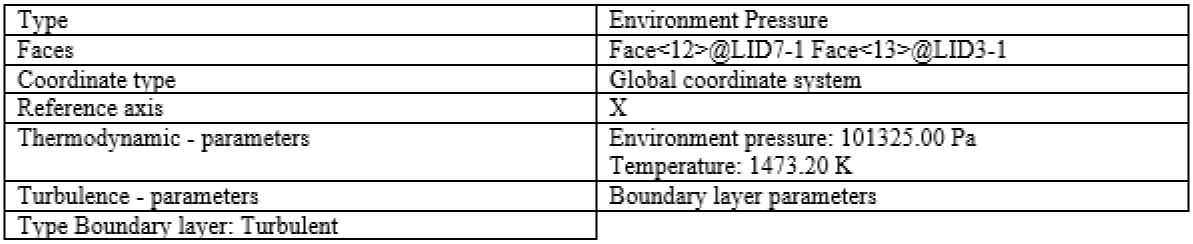
Type	Inlet Mass Flow
Faces	Face<1>@LID1-1
Coordinate type	Face Coordinate System
Reference axis	X
Flow - parameters	Flow vectors direction: Normal to face Mass flow rate: 1.0000e-005 kg/s Fully developed flow: No Inlet profile: 0
Thermodynamic - parameters	Approximate pressure: 101325.00 Pa Temperature: 773.20 K
Turbulence - parameters	Boundary layer parameters
Type of Boundary layer: Turbulent	

Table 5: Environment Pressure 1



Type	Environment Pressure
Faces	Face<11>@LID2-1
Coordinate type	Face Coordinate System
Reference axis	X
Thermodynamic - parameters	Environment pressure: 101325.00 Pa Temperature: 773.20 K
Turbulence - parameters	Boundary layer parameters
Type of Boundary layer: Turbulent	

Table 6: Environment Pressure 2



Type	Environment Pressure
Faces	Face<12>@LID7-1 Face<13>@LID3-1
Coordinate type	Global coordinate system
Reference axis	X
Thermodynamic - parameters	Environment pressure: 101325.00 Pa Temperature: 1473.20 K
Turbulence - parameters	Boundary layer parameters
Type Boundary layer: Turbulent	

6 Analysis of Results

The result of the experimental test running of the pyrolysis furnace as well as the performance analysis using SolidWorks$^{@}$ solid-state flow Simulation to validate the parameters of the real-life experiments are here presented.

6.1 Experimental Analysis of the accumulated Temperature over Time

The furnace was heated up and the time taken for the furnace to reach 1200˚C was considered. The readings were taken digitally via a thermocouple control mechanism over six runs and Figure 6.1 is a graph showing the thermal holding behaviour of the pyrolysis furnace. The furnace combustion chamber temperature reached 1200˚C at an average time of 60 minutes using 12.5g methane gas. The function of the Pyrolysis Furnace temperature with time is Y= 19.14x -51.52 with a Regression of 0.99. Depending on the type of precursors it has been established that a typical pyrolysis process of wood begins at a temperature of about 320˚C (Di Blasi, 2008). From figure 4 it can be conveniently deduced that the pyrolysis had started taking place from the 45th minute of the heating process when the temperature inside the pyrolysis chamber had hit 400 ˚C.

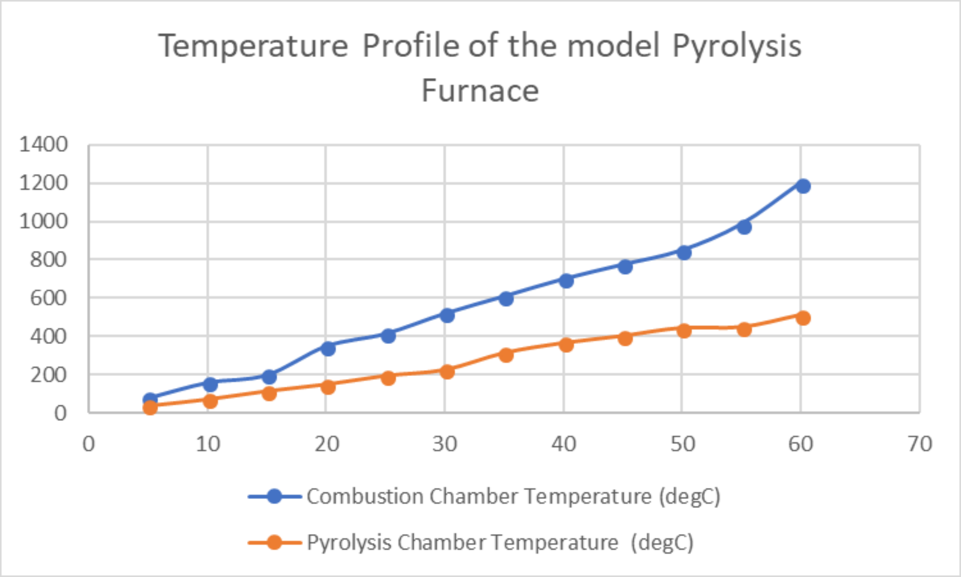


Figure 5: The model furnace temperature against time

Figure 6: Test- Running the model Pyrolysis furnace

6.2 Simulation Analysis of the Temperature over Iterations

The furnace was simulated using SolidWorks$^{@}$ Flow Simulation software. The results show that the model is an appropriate method for checking possible means of performance enhancement by varying the initial conditions, the boundary conditions and the operating conditions like inlet mass flow of burners and so on. Figure 7 below shows the temperature distribution by convection in the combustion chamber as a result of hot gas inflow. It is a turbulent kind of flow around the pipe serving as a pyrolysis chamber. It can be deduced that the temperature flow inside laminar as it can be explained as to the fact that the convection did not get into the (pipe) pyrolysis chamber, but rather the convection energy was absorbed as radiation that transfers from around the outside environment of the pyrolysis chamber: this corroborate the theoretical principle of heat transfer in the furnace as established in section 5 and demonstrated with figures 1 and 3. Figure 8 shows the body temperature variation at an instance of a working temperature using the temperature colour indicator scale. It can be clearly seen that the temperature of the furnace body is very low which validates the theory of thermal resistance of the system given in section 5 as the Kaolin refractory contains the temperature inside the furnace so as to have a concentration of high temperature inside the combustion chamber and then being transferred into the pyrolysis chamber.(Inegbenebor, 2002)

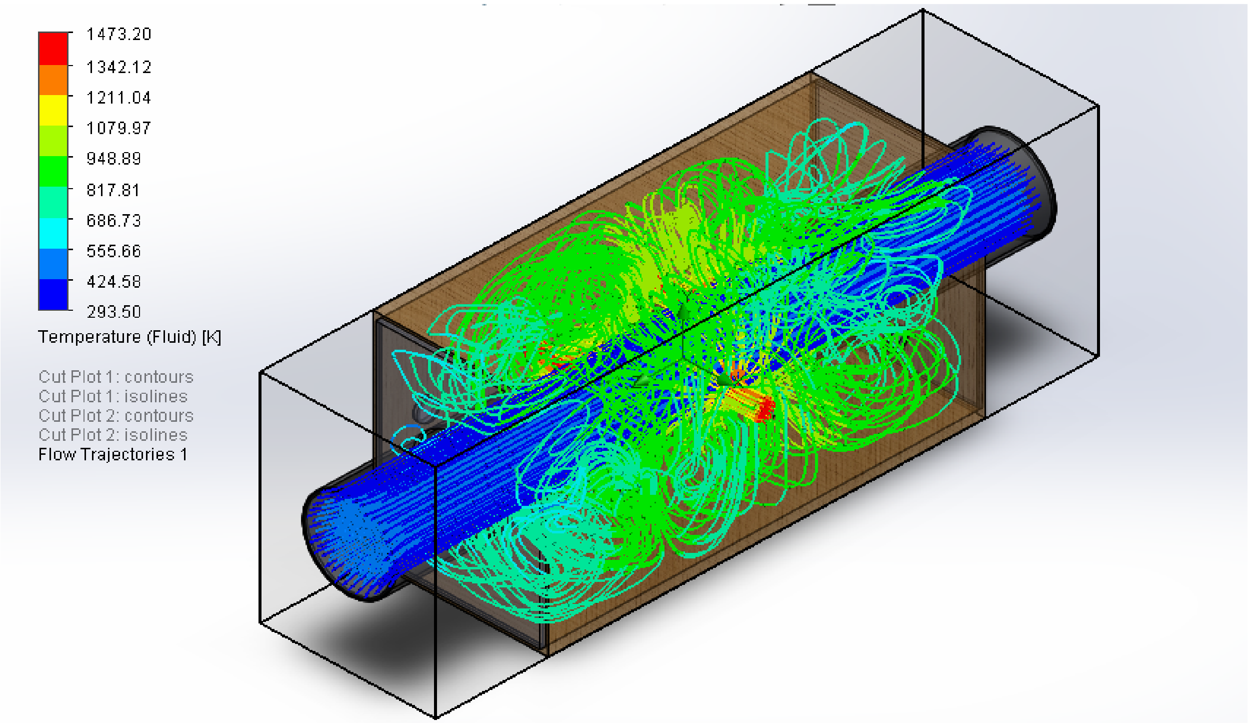


Figure. 7: Results of the running of the model on 3-D Simulation

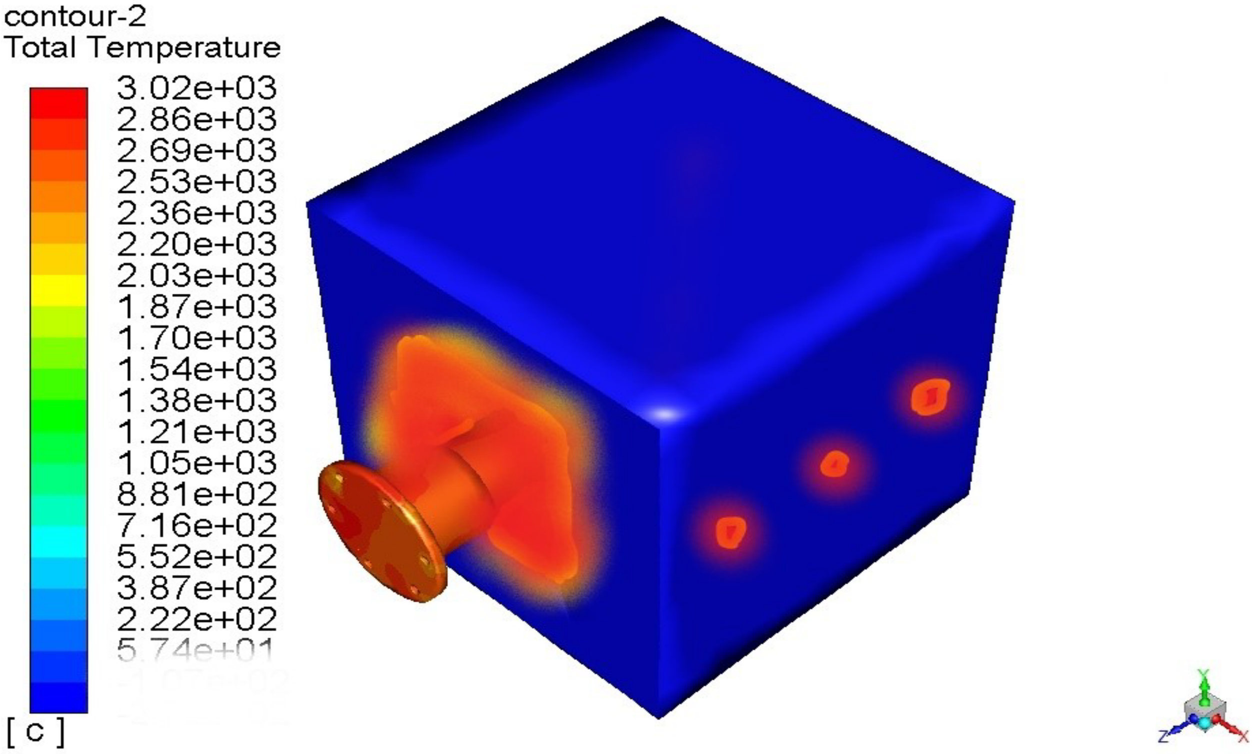


Figure 8: A Result representation showing temperature profile in 3D for running the Pyrolysis Furnace model on a Simulation package at an equilibrium state

7 Conclusion

The experimental analysis has been observed to have followed the same pattern as the simulated analysis of the Pyrolysis Furnace. It was noticed that the temperature difference between the combustion chamber and pyrolysis chamber is a bit not favourable as the high temperature is much needed in the Pyrolysis chamber. The heat loss is minimal via the kaolin bricks lining the furnace and thus this makes the furnace efficient in the sense that in little time and little fuel consumption a high temperature was attained. The Computer simulation shows that in transient mode, the furnace does not produce the desired conditions but with a continuous heating over time the furnace will acquire a forced convection energy capable of saturating the pyrolysis chamber with enough heat energy that will overcome the thermal resistance to radiation inside the pyrolysis Chamber, $\mathbf{R_i}$ and thermal resistance to conduction through the thickness of the pyrolysis chamber, $\boldsymbol{R_t}$. A rapid rate of radiation from the combustion chamber will give rise to the temperature inside of the pyrolysis chamber where a higher concentration of heat energy is needed for pyrolysis. One of the major advantages of using a simulation tool for evaluation is that all data for temperature, heat flux and energy are available for every part of the furnace as against the real system whereby the measurement was being done at disjointed and asymmetric points.

Acknowledgements

Covenant University, Ota, Nigeria contributed to this research financially.

References

Abioye AA, Atanda PO, Kolawole OF, Olorunniwo OE, Adetunji AR, Abioye OP and Akinluwade KJ. The Thermal Analysis of Fuel Fired Crucible Furnace Using Autodesk Inventor Simulation Software. Advances in Research. 2015;5(3):1-7.

Adewole, B. Z., Abidakun, O. A., and Asere, A. A. Artificial neural network prediction of exhaust emissions and flame temperature in LPG (liquefied petroleum gas) fueled low swirl burner. Energy. 2013 *61*, 606–611. https://doi.org/10.1016/j.energy.2013.08.027

Athanassiades, Eliana. “Waste Tyre Pyrolysis: Sustainable Recovery and Reuse of a Valuable Resource.” PQDT - UK & Ireland, 2013.

Cadena-Ramírez, Alejandro, et al. “Modeling and Simulation of Furnace Pulse Firing Improvements Using Fuzzy Control.” Simulation, vol. 93, no. 6, 2017, pp. 477–87, doi:10.1177/0037549717692418.

Chhabra, V., et al. “Kinetics of Pyrolysis of Mixed Municipal Solid Waste-A Review.” Procedia Environmental Sciences, vol. 35, 2016, pp. 513–27, doi:10.1016/j.proenv.2016.07.036.

Chu, Steven, and Arun Majumdar. “Opportunities and Challenges for a Sustainable Energy Future.” Nature, vol. 488, no. 7411, 2012, pp. 294–303, doi:10.1038/nature11475.

D. Q. Kern. Process Heat Transfer. Internatio, McGraw-Hill International Book Company, 1983.

Jawad, Salah K. “Investigation of the Dimensions Design Components for the Rectangular Indirect Resistance Electrical Furnaces.” American Journal of Engineering and Applied Science, vol. 3, no. 2, 2010, pp. 350–54.

Colomba Di Blasi “Modeling chemical and physical processes of wood and biomass pyrolysis” Progress in Energy and Combustion Science, vol. 34, Issue 1, 2008, pp. 47-90.

Inegbenebor A.O. A Study of Physical Properties of Selected Nigerian Clays for Furnace Brick Lining Production. Global Journal of Mechanical Engineering. 2002;3(1):69-77.

Ishola, F. A., Oyawale, F. A., Inegbenebor, A. O., and Boyo, H. Design of a high Temperature ‘Anaerobic Gas-Furnace’ suitable for Pyrolysis. IOP Conference Series: Materials Science and Engineering, vol. 413, 2018. p. 012079. https://doi.org/10.1088/1757-899X/413/1/012079

Kern, Stefan, et al. “Rotary Kiln Pyrolysis of Straw and Fermentation Residues in a 3 MW Pilot Plant - Influence of Pyrolysis Temperature on Pyrolysis Product Performance.” Journal of Analytical and Applied Pyrolysis, vol. 97, Elsevier B.V., 2012, pp. 1–10, doi:10.1016/j.jaap.2012.05.006.

Kodera, Yoichi, and Mamoru Kaiho. “Model Calculation of Heat Balance of Wood Pyrolysis.” Nihon Enerugi Gakkaishi/Journal of the Japan Institute of Energy, vol. 95, no. 10, 2016, pp. 881–89, doi:10.3775/jie.95.881.

Li, Qifeng (Chinese Academy of Sciences DOE), and Hui Zhou. Heat Transfer Calculation in Furnaces. no. October 2017, 2016, pp. 131–72, doi:10.1016/B978-0-12-800966-6/00005-3.

Pierson, Hugh O. Handbook of Carbon, Graphite, Diamond and Fullerenes By. Noyes Publications, 1993.

Serth, R. W. Process Heat Transfer Principles and Applications. Elsevier Ltd, 2007.

Summers, Claude M. “The Conversion of Energy.” Scientific American, vol. 225, no. 3, 1999, pp. 148–60, doi:10.1038/scientificamerican0971-148.

Sunphorka, Sasithorn, et al. "Application of Artificial Neural Network for Kinetic Parameters Prediction of Biomass Oxidation from Biomass Properties." Journal of the Energy Institute, Elsevier Ltd, 2015, doi:10.1016/j.joei.2015.10.007.

Vondál, J., and J. Hájek. "Wall Heat Transfer in Gas-Fired Furnaces: Effect of Radiation Modelling." Applied and Computational Mechanics, vol. 9, 2015, pp. 67–78.

Biographies

Felix Ishola is a Lecturer at Department of Mechanical Engineering, Covenant University, Nigeria. He earned a B.Tech in Mechanical Engineering from the Ladoke Akintola University of Technology, Ogbomoso, Nigeria; a Post Graduate Certificate in Water and Waste Engineering from WEDC, Loughborough University, Leicstershire, U.K and an M.Sc in Industrial and Production Engineering from University of Ibadan, Nigeria. Felix is a Registered Engineer with Council for the Regulation of Engineering in Nigeria (COREN) who practised as a Graduate Engineer in a Private Building Services outfit. His research interests are Risk Analysis, Waste Management, Materials development, Design and Modelling. He is a member of Nigerian Society of Engineers (NSE) and Chartered Institute of Water and Environmental Management (CIWEM).

Festus Oyawale is a Professor of Production and Manufacturing Engineering presently lecturing at Department of Mechanical Engineering, Covenant University. He earned BSIE (Industrial) and B.Sc. (Statistics) Western Michigan University, Kalamazoo; M.Sc (Operations Research) and PhD (Industrial Engineering) from University of Benin, Nigeria. He has published several journal and conference papers. Prof. Oyawale has completed research projects with special interests in Design and manufacturing, Welding and Casting techniques, Statistics, Operations research and Addictive manufacturing. He is a Registered Engineer with Council for the Regulation of Engineering in Nigeria (COREN) and also a member of Nigerian Society of Engineers (NSE) and Nigerian Institute of Industrial Engineers (NIIE).

Anthony Inegbenebor is a Professor of Metallurgy and Materials Engineering presently working at Department of Mechanical Engineering, Covenant University. He bagged M.Sc (Metallurgy and Materials Engineering) from the Donetsk Polytechnic Institute Former U.S.S.R.and PhD (Metallurgy and Materials Engineering) from University of Wales, Cardiff, UK. He has been a University lecturer for 36years and has published several journal and conference papers. Prof. Inegbenebo has research interests in Metallurgy and Materials Engineering, Engineering Management, Selection of Materials for Engineering Applications, Activated Carbon from local materials, Engineering Design and Applications. He is a Registered Engineer with Council for the Regulation of Engineering in Nigeria (COREN) and a member of Institute of Materials (AMIM) UK, Nigeria Society of Engineers (MNSE) and Nigeria Institute of Production Engineers.

Oluseyi O Ajayi is a Professor at the Department of Mechanical Engineering at the Covenant University, Ota in Ogun State, Nigeria. Oluseyi Ajayi holds a Bachelor of Engineering degree from Obafemi Awolowo University, Ile-Ife (1998), a Master of Engineering in Mechanical Engineering from University of Nigeria Nsukka (2004) and PhD in Mechanical Engineering from Covenant University, Ota Nigeria (2011). He has published about 100 journal and conference papers. His research interest includes Renewable energy and Low Carbon Development; Machine Design; Stress and Failure analyses; Vibration and Acoustics as a condition monitoring; Materials and Corrosion studies, industrial material scheduling and Transportation. Dr. Ajayi has successfully supervised 8 Masters and 3 Ph. D students. He is a member of The Nigerian Society of Engineers. He is a registered engineer with Council for the Regulation of Engineering in Nigeria (COREN).

Aworinde K. Abraham is a full-time lecturer and Ph.D student in the Department of Mechanical Engineering, Covenant University, Ota, Ogun State, Nigeria. His research interest is in the area of fracture Mechanics.