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Design of a high Temperature 'Anaerobic Gas-Furnace' suitable for Pyrolysis

Ishola Felix A[1]**, Oyawale F. A**[1]**, Inegbenebor A. O**[1] **and Boyo Henry**[1]

[1]Covenant University, Ota, Ogun State, Nigeria
Correspondence to: felix.ishola@covenantuniversity.edu.ng

Abstract. The need for a high temperature anaerobic furnace for pyrolysis is fast becoming indispensable for technological growth in Nigeria. In this project, a high temperature furnace was designed and built using the principle of heat transfer. The furnace was made of casing of low carbon steel sheets in four rectangular shapes. The refractories made of bricks filling the cavities of the furnace. This help to preserve heat loss. The pyrolysis capsule (chamber) was made of high carbon steel tube with flanges which can be opened for loading the products and evacuate. The mechanism to regulate the temperature and the gas input were installed. The furnace was gas-fired due to its high combustibility and providing a solution to the limited supply of electricity in the country. The prototype furnace produced is easy to use and multi-versatile with the innovation of the detachable pyrolysis capsule which can be modified by intent of pyrolysis products and by-products. The pyrolysis capsule is surrounded by the flame jacket (of the furnace main chamber) created to heat up the capsule at a regulated rate to any desired temperature up to 1,200 ºC with the automated control system for the gas supply unit. The designed high temperature anaerobic gas furnace is deployable for a wide range of pyrolysis processes and can be used for different precursors to produce an achievable end-product within the temperature limit.
Keywords: Pyrolysis, Furnace, design

1. Introduction

Nigeria, at this point in time, is focusing on technological development which is her only chance at catching up with the back logs in her race towards Industrialization and economic advancement. Undisputedly, a lot of efforts will have to go into researches in the field of Metallurgy and Material development using local contents. This reality brought about this project; design and development of an efficient high temperature furnace using basic principles of Furnace development using locally available materials. In as much as the pilot scale furnace can be used for numerous conventional furnace purposes it can be modified for anaerobic heating of materials, a process known as pyrolysis. Practically, the efficiency of a furnace is directly related to the ability to minimize heat loss. Heat loss is the heat from the surface of a pyrolysis furnace to its surroundings by natural convection and radiation [6]

This project focused on building an anaerobic furnace which could be used for pyrolysis purposes. When a solid material heats up, it eventually reaches a temperature threshold where it begins to chemically break down. This process is called pyrolysis; the more the absence of air the more the process flourishes. Pyrolysis is the simultaneous change of chemical composition of a material (eg, long hydrocarbon chains to shorter chains) the process is irreversible and it has been found to be the most promising thermochemical process for the waste treatment [3].

The particular interest for this project is in the production of activated carbon and graphite from different locally available precursors such as bamboo, coconut husk, palm kennel shell and some inorganic waste materials. Nigeria had heavily relied on importation of these essential Engineering materials (activated

carbon and graphite) thereby neglecting the exploration of the abundant opportunities available in our local resources. Adopting this model of furnace can help in preservation of foreign reserve by producing such furnaces for the local industries, without importing them. Also, this project, aimed at providing furnace suitable for experimental purposes on a primary objective and on a secondary objective for Small and medium Scale foundry industries in the country.

On a preliminary basis; the authors identified several types and categories of furnaces according to the fuel they use (natural gas, electricity, oil), and their technology (single-stage, dual stage or multi-stage) [2].
Gas furnaces: Gas furnace utilizes fossil fuel to transfer heat and are commonly considered the most efficient and economical method of heating. Typical efficiencies of coal, oil and gas furnaces have been investigated and the system with natural gas had been found to be most efficient [8]. Essentially, the furnace converts gas into heat by either using burners with natural air mixture, when necessary the air supply may be aided with blowers or using burners with oxygen-gas mixture.

Oil furnaces: An oil furnace is a heating device which burns heating oils, diesel fuel or other similar fuels to produce heat sufficient to carry out industrial activities. New oil furnaces can be fairly efficient and relatively clean and safe. There are now oil furnaces mimicking close-sealed combustion high efficient gas furnaces, able to provide high levels of efficiency.

Electrical Furnaces: a heating chamber with electricity as the heat source for achieving very high temperatures to melt metal alloy. The electricity has no electrochemical effect on the metal but simply heats it. The cleanliness of electric furnaces and the precise control that they afford is of distinct advantages - Even when the cost of electricity exceeds the cost of other forms of heating [1].

2. Design Philosophy

Design philosophy is simply defined as an individual's vision on a particular concept i.e. what an individual is trying to accomplish with the design, and, more importantly the principal aim and objectives of such venture. As it's well recognized during the course of many design activities, the use of past experiences, and previously acquired knowledge, either from the designer's own experiences or from available resources is an important part of the design process [4]. In Design philosophy, we try to relate with the assumptions, foundations, and implications of design. For simplicity sake the design is aimed at being a single stage, as well as the furnace structural dimensions being cubic.

Design Initial Specifications

A   =   Area, m^2 L   =   Length, m   B   =   Breath, m
V   =   Volume, m^3 H   =   Height, m

<u>Area of Sheet metal</u>
Length of Sheet metal for Casing   =   0.8m

Breath of Sheet metal for Casing   =   0.8m

Area of sheet Metal =   L x B   =   0.8 x 0.8   =   0.64 m^2

<u>Casing Volume</u>
This involve joining 4 sheet metals of the given area to form a box like structure.

Height of Casing   = 0.8m

V   =   L x   B x H = 0.8 x 0.8 x 0.8 = 0.512 m^3

<u>Internal Frame</u>
Length of wood for framing = 0. 8m

Breath of Wood f or framing =   0.5m

Area of framing = 0.8 x 0.5 = 0.40m^2

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 [8] investigated the thermodynamic efficiencies for types of fuel used in an energy conversion device. The schematic representation of the summary of results gotten is as depicted below.
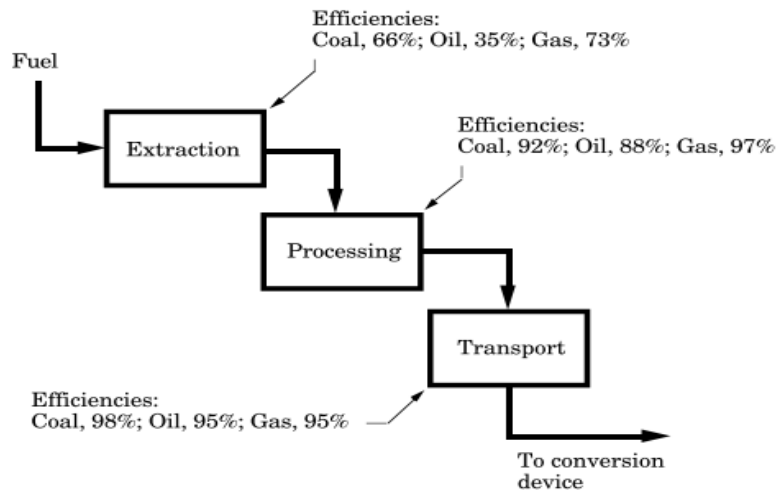
Fig. 2.1: A typical thermodynamic efficiencies of Fossil Fuels (Summers, 1999)

The design takes a turn towards a gas fired furnace because gas is a cleaner, affordable, safer and efficient energy choice. Apart from the fact that gas costs less than electricity, electrical power is poorly supplied in the country.

Working Drawing

The working drawing of the design of the built furnace are shown below as assembly drawing, exploded drawing and detail drawing as shown in the figures below using SolidWorks$^@$ Software:
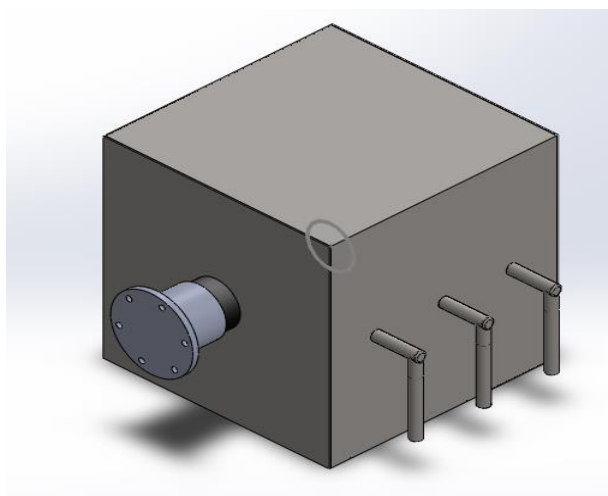
Figure 2.2: Assembly drawing of furnace
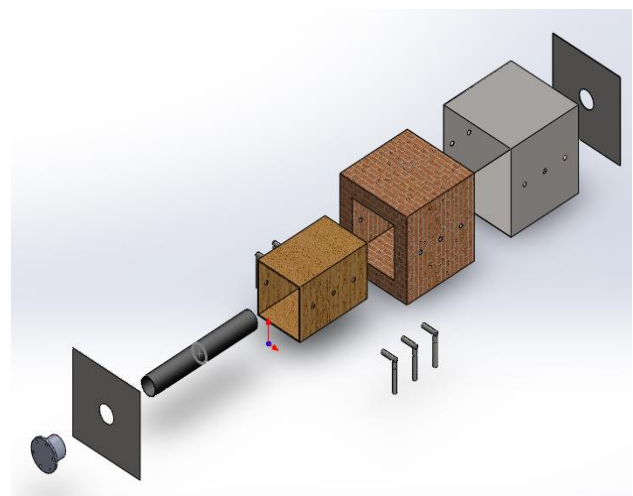
Figure 2.3: Exploded view of furnace

Design Procedures

This stage involved the design of the anaerobic furnace from scratch to completion. The materials used in the design was carefully selected with utmost consideration of various design factors such as wear, cost, reliability, weight, life, recycling, lubrication, friction, size, maintenance, safety, liability and availability;

➢ The sheet metal of 2mm which would be used for the furnace framing was cut into the desire shaping and size in the workshop.

➢ The sheet metal was then joined to give a box like shape. Welding technique was used. Steel sheets was used for the fabrication of the furnace casing,

➢ Next, the mould was constructed which would aid the casting of the refractories into lay-able bricks. The inner part of any furnace is generally expected to be a dense-phase zone with refractory materials to conserve and thus concentrate the heat generated on the enclosure.

➢ Next the internal framing which would serve as a support for the refractories was constructed. This was done with a wood of 3.5 inches. The wooden part is expected to be removed or burnt off at the first fire introduction into the furnace.

➢ After that, the area of the spacing in which the refractory bricks would come in was calculated to determine the structural dimensions of the inner chamber where combustion is expected to be taking place.

➢ The refractories bricks are made of Kaolin made to cure naturally. Kaolin is a locally available ceramic known to have a very good refractory property.

➢ The cargo chamber, cylindrical in shape in which the raw material would be placed was gotten and a flange and blind as well.

➢ The flange was welded to both ends of the cargo chamber.

3. Principle of Operation

The principle of operation for this furnace is simple. The furnace is gas powered and thus produces heat by burning gas and heat transfer occurs.

Given the three modes of heat transfer; Conduction, Convection and Radiation.

➢ 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. [7]

➢ 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 [5].

➢ 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 [9].

4. Results and Discussion

The result of the test running the anaerobic furnace, the performance involved in running the furnace, are here presented.

Time VS. Temperature

When the design and fabrication of the project was done, the testing of the furnace was carried out. The furnace was heated up and the time taken for the furnace to reach 1200˚C was considered. The readings were read from the digitally programmed control mechanism.

Furnace incumbent Temperature

After running the furnace, it was noticed that the furnace's temperature is a function of time. Below is a representation of the furnace temperature as it varies with time.

Table 4.1: Time against Temperature

TIME (min)	TEMPERATURE (^{0}C)
5	80
10	160
15	200
20	350
25	415
30	520
35	610
40	700
45	775
50	850
55	985
60	1200

TEMPERATURE (0C)

$y = 19.136x - 51.515$
$R^2 = 0.9858$
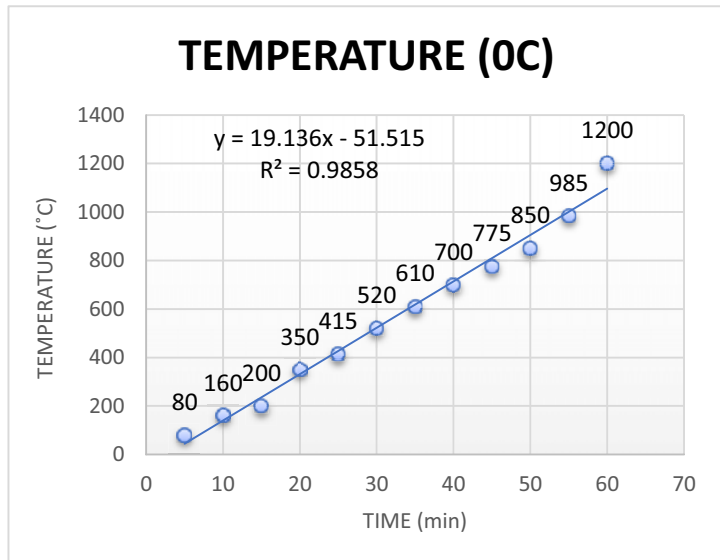
Figure 4.1: Showing the furnace temperature against time

After starting the furnace, we waited 5 minutes before taking the initial temperature reading of the furnace. And we recorded 80°c after just 5 minutes. We kept on taking the readings after every 5 minutes for the next 1 hour. From the graph we are the temperature increases drastically as time goes on. From the data given above we see that in an hour the temperature gets to 1200°c.

The furnace was able to reach 1200˚C in an hour using 12.5g methane gas. The furnace consumed 12.5g of methane gas from the gas cylinder in an hour.
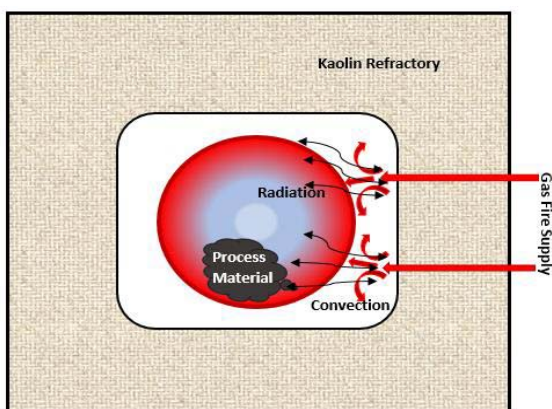

Fig 4.2: Sectional View to show Basic Features of the Furnace with the Pyrolysis

Fig. 4.3: Test- Running the model Anaerobic furnace

5. Conclusion and Recommendation

The project produced a prototype anaerobic furnace, which can "pyroduce" 6 – 10 kg of activated carbon from locally accessible precursors. The furnace built can adopt changeable anaerobic chamber and can

deliver high thermal energy. Hence, higher temperature within limited time. It is useful when rapidly high temperatures are required moreover it is an anaerobic chamber furnace which is not common for its size. The heat loss is minimal in the furnace and thus this makes it efficient in the sense that in little time and in less consumption of fuel it can attain a very high temperature.

For further works, a chimney exit would be manufactured and incorporated with the furnace. This would discharge the exhaust gas to the desired location.

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