

Thermal Analysis and Cost Evaluation of Boilers Considering Different Insulation Materials and Fuel Oil

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Abstract: The energy cost of heat transferred across the walls of a gas-fired and water tube boiler adopting the fibreglass and calcium silicate as insulating materials is analyzed adopting finite volume numerical scheme. A two-dimensional view of the heat transfer process is analyzed considering varied insulation thickness across the walls where results show from the point of critical thickness that the fibreglass material is a better energy saver compared with the calcium silicate material for varying insulation across the boiler walls. Result reveals the annual energy cost accrued per litre of fuel consumed at critical insulation point are ₦6.630 and ₦8.250 respectively for the gas-fired boiler utilizing LPFO for Fibreglass (FG) and Calcium silicate (CS) respectively. While the annual energy cost accrued per litre of fuel consumed at critical insulation points are ₦17.004 and ₦21.511 respectively utilizing Diesel Oil for FG and CS materials of insulation respectively for a gas-fired boiler. This paper reveals the cost of energy required using the LPFO with fibreglass insulation for gas-fired boiler is more economically viable compared with water tube boilers. However, the pollutants emission produced from LPFO is higher compared to diesel oil leaving a higher footprint in the environment.

Keywords: CO₂ heat transfer; finite volume method; critical insulation analysis; energy analysis; pollutants emission.

I. Introduction

Boilers are enclosed pressurized vessels designed to heat water or produce steam for the various process, having a wide range of applications in domestic, manufacturing and industrial sectors. A considerable amount of energy has been devoted to the study of this equipment [1-30]. However, not much has been presented from the viewpoint of energy savings and pollutants effect due to boiler operations. The good performance of the boiler is influenced by the maximum heat absorbed and minimum heat loss. The design of the boiler may be influenced by factors,

including process requirements, economics, ecosystem and safety.

In the effort to analyse such process in the past, [1] utilized the six flux radiation model to investigate the swirling diffusive natural gas flame in axisymmetric confinement while [2] studied radiative heat transfer in a furnace considering grey gases effect.[3] simulated combustion aerodynamics by interfacing Star-CD computational fluid dynamics package with combustion research library validating with measurements taken at various outlets which shows good agreement. [4] evaluated circulating fluid bed (CFB) boiler heat transfer adopting heat transfer coefficient data from industrial CFB boilers. [5] enhanced boiler performance and heat transfer in the boiler using different geometry of the boiler tube. Also,[6] used heat treating process to improve material properties of

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furnace walls in the bid to enhance thermal conditions of the boiler making it more efficient, less emissive and less prone to tube rupture. Border and [7] used the Zone method analysis to analyse the field velocity of a turbulent jet from combusted fuel from the burner.

In recent past, computational fluid dynamics (CFD) models have been developed to simulate the behaviour of thermal and flow performance of the boiler. To improve working efficiency, [8] developed a computational fluid dynamics simulation of thermal flow in an industrial boiler which was used to determine the thermal condition inside the boiler tube to resolve the operational problem and search for an optimal solution. [9] used a CFD code incorporating a deposit formation model on two tangential fired boilers; results validation was performed by comparing it with boiler power variation. In the quest to enhancing the working conditions of a boiler, the CFD model of a 375MW tangential furnace was developed by [10] where coal feed rates, airflow rates, coal particle size distribution are used as input conditions for the model. [11] considered phenomena such as turbulence, radiation, convective heat transfer, particle transport and chemical reaction in simulating the combustion process of a commercially operated power plant. A numerical solution was presented by [12] examining furnace flow and combustion of 350MW utility boiler having 24 swirl burners at the furnace front wall. Also, [13] modelled radiative heat transfer in a combustion system. [14] adopted CFD to optimize the finned tube for diesel heat exchanger performance. The CFD as a tool has advanced the development of the boilers and heat exchange equipment by providing optimal designs with heat recovery, minimum pressure drop, optimized operation and performance, also minimum construction

materials for efficient performance [14-18]. [15] evaluated internal temperature of a pressurized tank filled with hydrogen. Shell and tube heat exchanger reliability analysis was performed by [16] computing the analysis with data obtained from carbon black manufacturing plant. Heat transfer and fluid flow inside a pressure cooker was examined by [17]. [18] presented the heat balance characteristics of pressure vessels while theoretical and experimental heat transfer study was performed by [19] during gas venting from a pressure vessel. Power obtained through heat transfer of compressed air energy storage was presented by [20] with the aim of reducing the cost of the power plant. Heat transfer numerical investigation was performed by [21] for four pass fire tube boiler. [22] reviewed the heat transfer analysis on thermal energy systems and phase change materials. Simulations for double spiral water wall were studied by [23] to determine the heat transfer in the reheat boiler. [24] determined forces of reaction for boiler support utilizing equivalent membrane stiffness method. A steam pipeline was modelled numerically by [25] using the finite volume method to model the transient pipeline operations. [26] developed a novel analytical and numerical method for enhancing heat transfer and thermal management in a square two-dimensional enclosure at the various angle of inclination utilizing the finite volume procedure. Finite volume method was adopted by [27] to predict emission, anisotropic scattering and absorption in a media. Analysis of two cavities for thermal control was presented by [28] using insulator thickness optimization. [29] investigated numerically thermal radiation uniformity of a billet for reheating furnace. [30] numerically modelled heat exchange in a vacuum resistance furnace utilized in the study of radiative processes of heat transfer.