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Effect of Clinker Bed Height on Clinker Cooling Process on Clinker Grate Coolers Used in Cement Plant

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Abstract
This research gives a thorough study into the effect of clinker bed height and the thermodynamics process involved clinker cooling process. Performance of a clinker coolers plays a critical role in energy recovery from the discharged clinkers from rotary kiln and also pre-heating of the air used for combustion (Calcination). Improper cooling of clinker inside the clinker cooler is a global challenge in cement plant and this has adverse effect on the entire cement production process and quality of cement. These will lead to cement lumps formation inside cement silos, quick gypsum dehydration inside grinding/crushing chamber and false setting of cement. A three (3-D) model of the clinker bed was developed using SolidWorks Computer Aided Design (CAD) software based on the geometric parameters adopted in the scaled conceptual design. The design model was scaled down to a ratio 25:1, that is, the existing cooler is twenty-five (25) and modelled is one (1), having fixed values of length 1.3 m, width 0.3 m and variable clinker bed height 0.3 m, 0.4m and 0.6m. The simulation involves modelling of high temperature clinker entering the clinker cooler from a heating-up furnace (HUF) at temperature of 1350 ^{o}C. Results from Computational fluid dynamics (CFD) simulation of the modeled clinker revealed that the clinker outlet temperature at bed height of 0.6 m has the optimal energy recovery into the system, secondary air at 817 ^{o}C and low outlet clinker temperature with 68 ^{o}C.
Keywords: Clinker Cooler; Computation Fluid Dynamics; Mass Flow Rate; Bed Height; Clinker Temperature.

I. Introduction

Cement production is one of the most energy intensive industries in the world, in which 30% to 40% of the production cost is on energy. About five percent (5%) of the total global industrial energy is used in cement plants [1-3]. Therefore, one of the possible techniques of reducing energy loss, which has been a major challenge in the cement industry, is the use of clinker coolers. In addition to the reduction in energy loss, the clinker cooler also enables effective reduction in the temperature of hot clinker to a desirable temperature required for final processing of the clinker to obtain good quality cement. There are four major types of clinker coolers: grate, planetary, shaft, and rotary coolers [4]. The most reliable and commonly used clinker cooler in recent years is the grate clinker cooler. The clinker enters from the circular opening on the left side of the cooler as shown in the figure. It then moves with specified velocity on a plate, while ambient air is passed into the cooler through fans position by the side of the cooler, which blow the air vertically upwards, through the pores of the hot clinker. This process leads to the cooling down of the clinker and is depicted by the colour variation of the clinker from light-red to light-blue for hot-clinker to cold-clinker respectively. According to [5] reduction of energy consumption in a cement plant requires optimizing operating parameters in the coolers. [2], further explained that improving the efficiency of heat recovery in the clinker cooler would lead to fuel saving as well as improving the quality of cement production and reduction of the carbon-dioxide emission level.

Despite the popularity gained and the advantage posed by the grate clinker cooler, compared to the other types of clinker coolers, the cement industry is still faced with some problems such as inadequate heat recuperation or improper cooling of the clinker in the cooler. These problems have resulted into a need for large quantities of water to cool the cement product at cement grinding plants, which consequently increases operational cost. This cost is enormous in terms of increase in production cost, high maintenance cost and poor product cost. In order to minimize the operational cost by reducing damage caused by the challenges, several studies were carried out by researchers. [7], investigated the effect of mass of clinker, cooling air, and gate speed, temperature of cooling air on energy and exergy efficiencies of the cooling system. The study covered efficiencies of improved system using secondary and tertiary air as a heat recovery source aspect. In another study by [8], variations of gases, solid temperature, and wall temperature and heat losses through the wall were simulated with respect to grate cooler length in order to evaluate the mass and energy balance in a clinker cooler. An important area which had not been adequately studied to the best of our knowledge is the optimization of geometrical parameters of the clinker cooler. This is because it is not economically viable due to the size of real-life clinker coolers used in cement plants. The best approach to investigating geometrical parameters of a clinker cooler is by scaling down an existing real-life full-size clinker cooler. In view of this, an existing clinker cooler was scaled down, while adopting alternative design to optimize the scaled down clinker cooler parameters, through computation fluid dynamics (CFD) simulation. The paper will study the Effect of Clinker Bed Height and Cooling Air Temperature on Clinker Cooling Process in Cement Plant and energy optimization of the existing clinker cooler. A simplified view of a clinker cooler is presented in Figure 1a shows suction fans arrangement and outer wall and Figure 1b, shows internal arrangement of a clinker cooler undergoing maintenance in Nigeria.

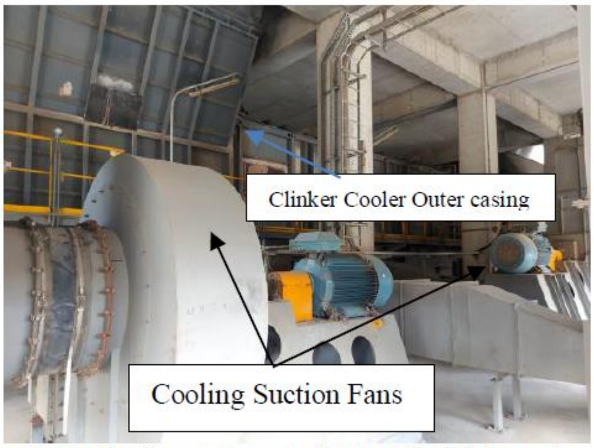


Figure 1a. Suction fan arrangement and outer wall of clinker cooler

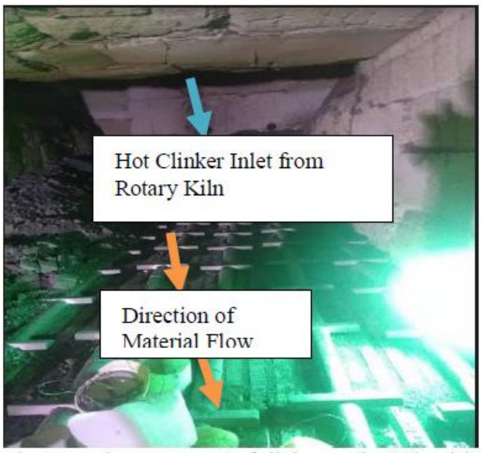
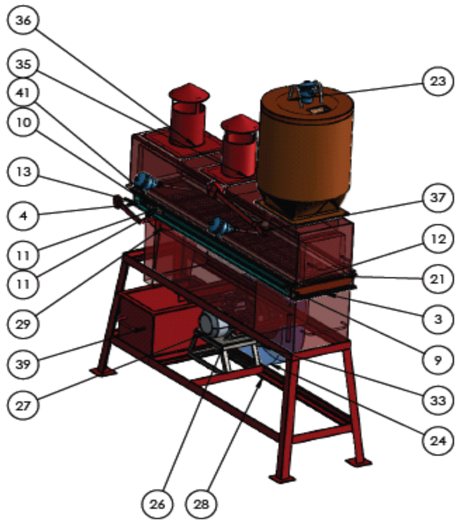


Figure 1b. Internal arrangement of clinker cooler (Nigeria).

II. Methods

2.1 Scaling and Modelling of Clinker Cooler and Heating-Up Furnace (HUF)

Scaling and modelling of the clinker cooler and heating-up clinker furnace was done with relation to an existing and running plant. To analyse the responses of the present clinker cooler, scaling down was done based on similitude and dimensions analysis criteria [5, 9–11]. The scaling down was done to a ratio of 25:1, twenty-five (25) for existing coolers and one (1) for model (test rig). The geometric parameters for the scaled down model is adopted for development of an experimental text rig which would be carry out in future study. In order to reduce to cost of experimental processes in the development of the test rig and to achieving efficient and realistic experimental results, numerical simulation and theoretical data are compared in the current work. The proposed test rig basically comprises of the heating-up furnace, clinker cooling unit (cooler) and the suction fans. Fig. 2, shows an overview of the proposed scaled down clinker cooler. The cooling is achieved by first feeding the hot clinker into cooler by opening the heating-up furnace at a temperature of 1350 ^{o}C into the clinker cooler. Fresh air is being sucked into clinker cooler at ambient temperature of 32 ^{o}C. This hot clinker is being transported in the clinker cooler with pan conveyor from hot clinker inlet (heating up furnace) “Hot Zone” to clinker cooler outlet “Cold Zone”, this results to multiphase flow process.



ITEM NO.	PART NUMBER	QTY.
1	Longitudinal Frame	1
2	Longitudinal Frame_Mirrored	2
3	Cross Member	2
4	B18.3.1M - 10 x 1.5 x 30 Hex SHCS --30CHX	8
5	B18.2.3.9M - Heavy hex flange screw, M8 x 1.25 x 25 --25C	4
6	B18.22M - Plain washer, 8 mm, regular	4
7	B18.2.4.1M - Hex nut, Style 1, M8 x 1.25 --D-N	12
8	SKF - 16005 - 14,DE,AC,14_68	4
9	Tail Sprocket Shaft	1
10	Head Sprocket Shaft	1
11	Head Bearing Cone Take-up Jack	2
12	Tail Bearing Cone	2
13	B18.22M - Plain washer, 10 mm, narrow	8
14	Chain Rail Support Mounting Tab	16
15	Chain Rail Support	8
16	Chain Rail	4
17	40-0.5P1ST14T14S01.418H1.702L1.1250N	4
18	Female Chain Link	103
19	Male Chain Link	103
20	Furnace	1
21	Overflow prevention flat bar	2
22	Hood Cover	1
23	Furnace Cover	1
24	Impeller Housing	1
25	Impeller	1
26	Air Blower Motor Mount Plate	1
27	IEC 80 B3	1
28	Support Frame	1
29	Bottom air box	1
30	Air Blower Motor Support 2	1
31	Blower to manifold flange^Clinker Cooler Assembly	1
32	Cooling Chamber Manifold	1
33	Impeller Housing Cover	1
34	Motor Coupling Adapter	1
35	First Chimney	1
36	Second Chimney	1
37	Dosing Valve Assembly	1
38	Discharge Chute	1
39	Discharge Box	1
40	Discharge Chute Regulator Valve Assembly	1
41	RTD PT 100	3

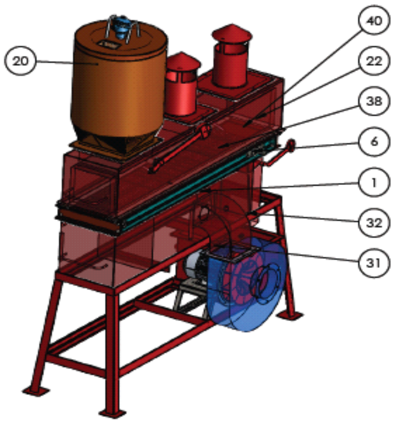


Fig. 2. Modelled clinker cooler overview [2,3]

2.2 *Heat Transfer determination across Clinker Cooler Wall*

Clinker cooler is modelled with such fan unit to handle the inlet air before entering inside the clinker cooler, which features several pan conveyors with a perfectly cross-flow heat exchange [6]. The correlation to macro-hydrodynamic criteria defines the heat transfer and the pressure decrease [8].

Equations (1) and (2) were used to model the clinker cooler (2). The number of heat zones is indicated by the letter "Z_h," while the number of cold zones is shown by the letter "Z_c" [12].:

$$Z_h = \left(\frac{H_h L_h w D_{clk}}{M_{clk} \, t_{res\ time}} \right) \quad (1)$$

$$Z_c = \left(\frac{H_c L_c w D_{clk}}{M_{clk} \, t_{res\ time}} \right) \quad (2)$$

where: H_h is the hot zone height, H_c is the cold zone height, D_{clk} is the clinker density, ,H_{clk} is clinker bed height in hot zone, L_h is the clinker length in the hot zone, L_c is the clinker length in the cold zone, $t_{res\ time}$ is average resident time. Using equation (3), the hot zone height (H_h) of the clinker cooler will be calculated [13].

$$H_h = \left(\frac{M_{clk}}{C_g W_h D_{clk} w} \right) \quad (3)$$

Using equation (6), the cold zone height (H_c) of the clinker cooler will be calculated [12].

$$H_c = \left(\frac{M_{clk}}{C_g W_c D_{clk} w} \right) \quad (4)$$

where C_g is the grate distance covered, w is width, W_h is the grate frequency in hot zone, W_c is the grate frequency in cold zone, M_{clk} is the clinker mass flow rate. Equations (5) to (7) will be used to calculate the heat losses in each segment based on the heat transfer coefficient, thermal resistance, and heat transfer area in each segment [6, 13]:

For losses due to heat dissipation crossing the wall,

$$Q_{pi} = \left(1 / R_{ti}\left(T_{pi} - T_o\right)\right) \tag{5}$$

Using the total heat transfer coefficient h_{fi} for convective heat transfer,

$$Q_{pi} = h_{fi} A_i \left(T_i - T_{pi}\right) \tag{6}$$

Total thermal resistance R_{ti}, is given by;

$$R_{ti} = \left(1 / A_i\left(t_{br} / t_{cbr} + t_s / t_{cs} + 1 / h_c\right)\right) \tag{7}$$

where A_i is segmented area, Q_{pi} is heat loss from each segment, T_{pi} is the wall temperature of each segment, T_i is the temperature of each segment, t_{br} is the thickness of the refractories, t_{cbr} is thermal conductivity, t_s is the shell thickness, t_{cs} is thermal conductivity of refractories, t_s is the thickness of the shell; and h_c is convection heat transfer coefficient. Any segment's thermal resistance depends on its area, refractories, thermal conductivity, thickness, and convection heat transfer coefficient (h_c). The convection heat transfer coefficient is obtained using equation (8) [14]:

$$h_c = \frac{N_u K_{air}}{d_s} \tag{8}$$

Using equation (9), Nusselt number (Nu) is obtained [6]:

$$Nu = \left(0.0295\left(\mathrm{Re}^{\frac{4}{5}}\,\mathrm{Pr}^{\frac{1}{3}}\right)\right) \tag{9}$$

Using equation (10), Reynold number (Re) is also obtained

$$\mathrm{Re} = \frac{d_s \rho_{air} U_{air}}{(1 - por)\mu_{air}} \tag{10}$$

Using equation (11), Prandtl number (Pr) is determined

$$\mathrm{Pr} = \frac{\mu_{air} cp_{air}}{K_{air}} \tag{11}$$

where d_s is the clinker diameter, ρ_{air} density of air, U_{air} velocity of air, P_{or} porosity, K_{air} is the thermal conductivity of air; and μ_{air} is the Dynamic viscosity of air [8]:

2.3 Analysis of Mass Flow Rate and Energy Balance in the Model Clinker Cooler

Clinker mass flow rate from kiln exit and cooler exit remain constant as shown in Fig. (3) and (4). It is expressed in equation (12) [2,3, 15, 16]

$$M_{clk\,in} + M_{air\,in} - M_{clk\,out} - M_{air\,out} = 0 \tag{12}$$

The mass balance equation is expressed in equation (13) [2, 3, 16, 17]

$$\sum\left(M_{clk\,in} + M_{air\,in}\right) = \sum\left(M_{clk\,out} + M_{air\,out}\right) \tag{13}$$

$M_{clk\ in}$ represents mass flow rate of clinker at the inlet and $M_{clk\ out}$ represents mass flow rate of clinker at the outlet.

First law of thermodynamics states that energy cannot be destroyed but can be changed from one form to another during an interaction as shown in Fig.4. The change in the content of energy of a body or a system is equal to the difference between the energy input and the energy output [13-15, 18].

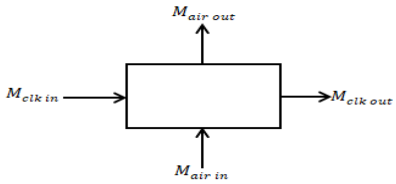


Fig. 3. Mass flow rate in a cross-bar cooler

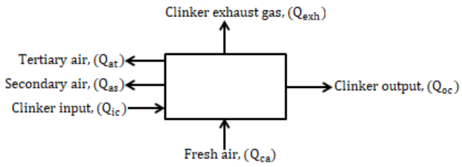


Fig. 4. Grate clinker cooler Energy balance schematic

Therefore, Cooler mass flow rate is constant. For steady-state and steady-flow process, the energy balance equation is as shown in equation (14), [15-17].

$$\sum \dot{E}_{in} = \sum \dot{E}_{out} \tag{14}$$

Total input energy can be defined by equation (15) based on Fig. 4

$$\sum \dot{E}_{in} = Q_{ic} + Q_{ca} = M_{clkin} c_{pclk} (T_{clk} - T_o) + M_{air} c_{pair} (T_{ac} - T_o) \tag{15}$$

Total energy output from the cooler as obtained from [17] can be expressed in equation. (16):

$$\sum \dot{E}_{out} = Q_{as} + Q_{at} + Q_{oc} + Q_{exh} = M_{secair} c_{psecair} (T_{secair} - T_\beta) + M_{terair} c_{pterair} (T_{terair} - T_\beta) + M_{clkout} c_{pclkout} (T_{clkout} - T_\beta) + M_{exhair} c_{pexhair} (T_{exhair} - T_\beta) \tag{16}$$

where Q_{as} is the recoverable heat rate of kiln secondary air, Q_{at} is the cooler tertiary air recoverable heat rate, Q_{oc} is the clinker heat at the cooler output. Q_{exh} is the cooler heat at exhaust air, Q_{ic} is the clinker heat at the cooler input. Q_{ca} is the heat of the cooling air.

Energy efficiency is defined in equation (17) as the ratio of the amount of the energy output to input of the system [13, 15-17]:

$$\eta_E = \frac{\sum \dot{E}_{out}}{\sum \dot{E}_{in}} \tag{17}$$

Equation (18) gives the recoverable energy efficiency of the secondary and tertiary air as [18]:

$$\eta_{recoverable,\ cooler} = \frac{Q_{recoverable}}{Q_{ic} + Q_{ca}} \tag{18}$$

2.4 CFD Simulation

A 3D model of the clinker bed was developed using SolidWorks2014 CAD software based the geometric parameters adopted in the scaled conceptual design, having fixed values of length, width and a variable clinker bed height. The model is then imported into ANSYS 14.0 software platform for CFD simulation. Governing equations of flow are solved in the ANSYS-Fluent 14.0 computational fluid dynamics

(CFD) platform. Tables 1 and 2 present the parameters that formed the basis for evaluation of the clinker cooler performance using clinker cooler specific volume.

The clinker is considered and modelled as a porous medium using the facilities available in the software as regard continuity, momentum and energy equations. The 3-D model was meshed in ANSYS meshing environment where it was discretized into finite element mesh. The number of elements in a mesh can vary, depending on the level refinement or size of the cells in the mesh and hence a very fine mesh size was used, taking into consideration computation time and solution accuracy. Boundary conditions were set, and the following assumptions considered; porous medium is isotropic and homogenous, flow of fluid is steady, flow is turbulent outside the porous medium and laminar in the porous medium section, fluid is incompressible, radiation heat transfer and energy loss across the wall are negligible. The clinker bed is a rectangular moving bed with input parameters and dimensions presented in Table 1. [2, 3, 19].

2.5 *Validation of numerical simulation*

The procedure involved in the simulation was validated by comparing the result obtained from CFD and theoretical results. Theoretical results are obtained using equation (19) and (20) [2, 3, 17, 20].

$$\frac{T_{clkout}-T_o}{T_{clkin}-T_o}=e^{(-Vair/0.77)} \tag{19}$$

$$SN=\frac{M_{air}}{M_{clk}}\times\frac{1}{C_{P\,air}}=\left(\frac{1}{\left(\frac{kg}{Nm^3}\right)}\right) \tag{20}$$

where: SN is specific Volume, $T_{clk\ \mathrm{in}}$ is clinker temperature at cooler inlet (^oC), V_{air} is specific cooling air quantity (m^3/kg) in the clinker with the heat content relative to ambient temperature Cp_{air} is specific heat capacity of air, M_{air} is air flow rate (kg/s), M_{clk} is clinker flow rate (kg/s).
The results of the model are validated by comparing the data records of exiting plant on Table 2.

Table 1. Parameters and dimension for model cooler [2, 3].

S. no.	*Model*	*Value*
1	Dimension (meter)	
	Length of the Cooler	1.3 m
	Width of the Cooler	0.3 m
	Variable clinker bed height of the Cooler	0.3 m, 0.4 m, and 0.6 m
2	Material Inlet Flow rate to the Cooler	0.15 kg/s
3	Specific Volume of clk	2.2041 Nm^3/kg
4	Material Inlet Temperature to the Cooler	1350 ^oC
5	Air Inlet flow rate	0.45 kg/s
6	Ambient air temperature	32 ^oC

Table 2. Other parameters of existing plant [2, 3].

S. no.	*Parameter*	*Value*
1	Clinker bed height (m)	0.45
2	Cooler speed (stroke/min)	16
3	Clinker mass flow (kg/s)	72
4	Clinker inlet Temp (^oC)	1350
5	Clinker Outlet Temp (^oC)	250
6	Cooler Length (m)	30
7	Cooler width (m)	5
8	Secondary air Temp (^oC)	950
9	Specific Volume (Nm^3/kg of clk)	1.78
10	Energy Efficiency (%)	59.2

11	Recoverable Energy Efficient	49.2
12	Exhaust air Temp (^{o}C)	265

III. Results and discussions

Figure 5 shows a 3D model of air and clinker domain showing inlets and outlets, while Figure 6 shows the meshed models with the number of elements and nodes after the model has been discretised. Considering the operation of a clinker cooler with respect to the 3D model used in this study, hot clinker enters from the left side; cold air enters from down part moving upward, in form of cross flow.

Figure 7 shows the temperature contour of the modeled clinker bed, the inlet section of the clinker, and the outlet section of clinker. The Figure shows very hot clinker (1350 ^{o}C) entering the cooler in a longitudinal direction, and cooling air (32 ^{o}C) entering the cooler in the transverse direction. For the temperature values, area weighted average of temperature was computed using the ANSYS solver. The clinker and air inlets were assumed to be continuous hence a dominant color contour was observed for the inlets.

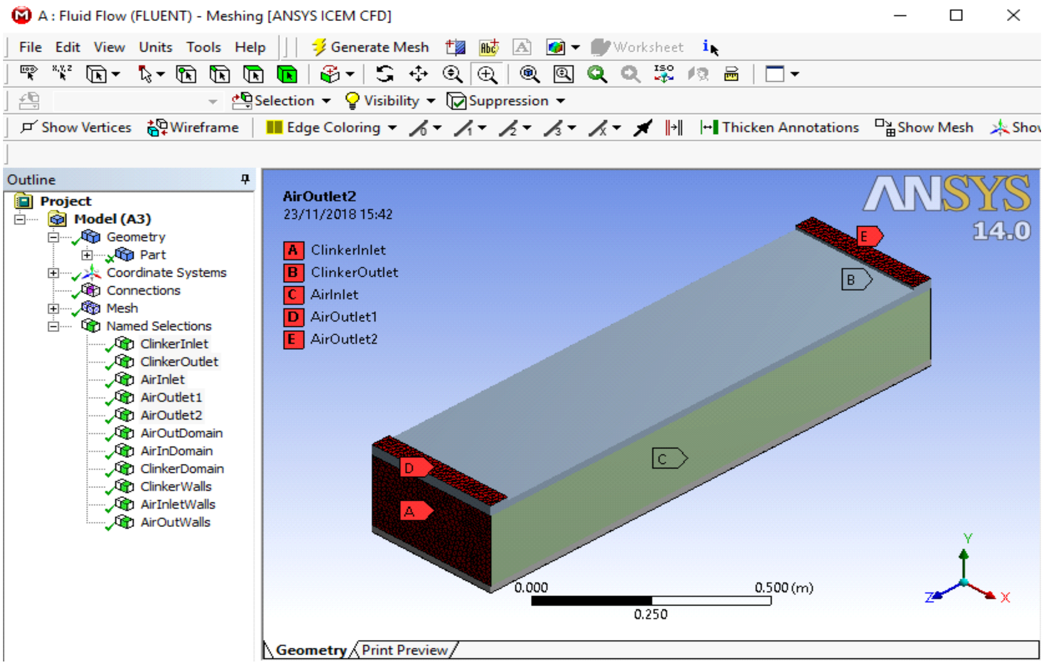


Fig. 5. 3-D Model of air and clinker domain

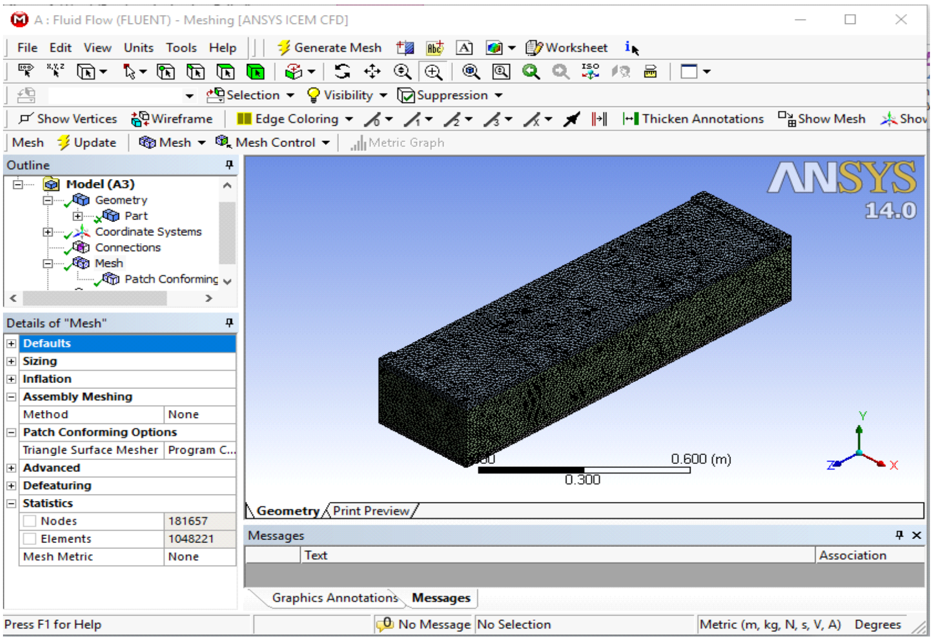


Fig. 6. Meshed model and nodes after model

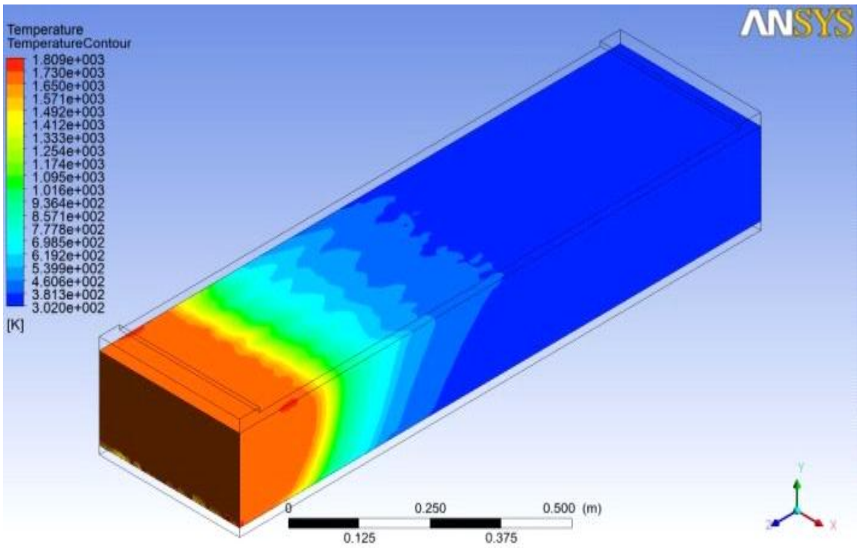


Fig. 7. Sample of Temperature Contour for Clinker Bed

3.1. Result of clinker cooler model

Table 3, shows the CFD results on clinker bed height and clinker outlet temperature and Table 4 presents the CFD results on clinker cooler Energy balance and Energy efficiency. The study carried out comparison between the CFD results for clinker bed height; 0.3m, 0.4m and 0.5m, with computed clinker outlet temperatures; 128 ^{o}C, 122 ^{o}C, and 68 ^{o}C respectively. Figure 8, displays how temperature drops along cooler length of 1.3 m, clinker width of 0.6 m.

Table 3. CFD results on clinker bed height and clinker outlet temperature

Bed Height (m)		0.3	0.4	0.6
Temperature (^{o}C)	Air inlet	32	32	32
	Secondary Air outlet	732	748	817
	Tertiary Air outlet	531	569	601
	Exhaust Air outlet	135	123	92
	Clinker inlet	1350	1350	1350
	Clinker outlet (CFD)	128	122	68
	Theoretical Clinker outlet	107.3	107.3	107.3
Mass Flow rate (kg/s)	Air inlet	0.45	0.45	0.45
	Secondary Air outlet	0.09	0.09	0.09
	Tertiary air outlet	0.11	0.11	0.11
	Exhaust Air outlet	0.25	0.25	0.25
	Clinker inlet	0.15	0.15	0.15
	Clinker outlet	0.15	0.15	0.15
Specific Volume (Nm^3/kg)		2.204	2.2041	2.2041

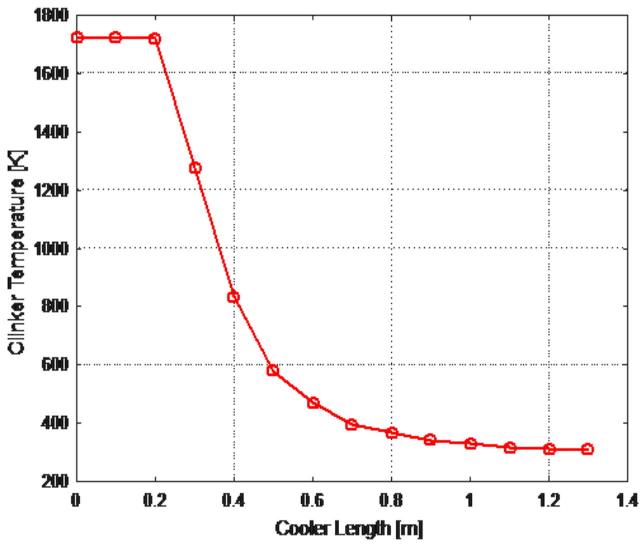


Fig. 8. Graph of temperature drop along cooler length (with bed height, 0.6 m)

The increase in clinker bed height leads to corresponding decrease in clinker outlet temperature: for 0.3 m clinker bed height, clinker outlet temperature was 128 ^{o}C; for 0.4 m clinker bed height, clinker outlet temperature was 122.62 ^{o}C and for 0.6 m clinker bed height, clinker outlet temperature was 68.4 ^{o}C. It is obvious that when the clinker bed height increases it means that the rate of heat transfer and heat recuperation into the system via secondary and tertiary air temperature will increase as in the case of 0.6 m with secondary air temperature of 817 ^{o}C and tertiary air temperature of 601 ^{o}C. The low clinker bed heights are largely responsible for the poor heat transfer into the system, with excessive energy loss to the environment via exhaust air and clinker outlet temperature. CFD clinker outlet temperature at bed height of 0.6 m has the optimal energy recovery into the system. This is because it resulted in the highest secondary air temperature of 817 ^{o}C and also the lowest outlet clinker temperature of 68 ^{o}C. Since high secondary high is desirable for heat recovery and reuse, and low outlet clinker temperature is highly recommended for effective and efficient clinker processing, it is logical to say that bed height plays a significant role in clinker cooler performance.

Table 4. CFD results on clinker cooler energy balance and energy efficiency

Energy Balance (kJ/kg clk)	Qic	211.81	211.81	211.81
	Qca	3.18	3.175	3.175
	Qexh	28.20	27.36	17.04
	Qas	71.26	73.04	80.79
	Qat	60.54	65.45	69.63
	Qoc	14.29	13.47	5.95
	Total Energy *(in)*	214.99	214.99	214.99
	Total Energy *(out)*	174.29	179.32	173.41
	Losses	40.70	35.67	41.57
	EnergyEff (%)	81.07	83.41	80.66
	RecEnergyEff (%)	61.30	64.42	70.00

When considering other bed heights studied in this work, clinker bed height of 0.3 m has the lowest recovered heat efficiency 61.30% clinker cooler model with temperature from secondary air (732 ^{o}C) and tertiary air (531 ^{o}C) and the maximum heat loss to the environmental are via exhaust (128 ^{o}C) and clinker outlet (122 ^{o}C). Using Table 2, the existing cement plant has a clinker outlet temperature of 250 ^{o}C and by comparing with Table 3, the CFD result, bed height of 0.6 mm has a clinker outlet temperature of 68.4 ^{o}C. Existing plant clinker cooler recoverable energy is 49.2% and energy efficiency 59.2% and the modeled clinker cooler recoverable energy and energy efficiency are 70.00% and 80.66% respectively. This is largely responsible for the high outlet clinker temperature (250 ^{o}C) leaving the existing clinker cooler. However, with proper clinker bed height optimization of the existing cooler the current results obtained from the running can improved upon because poor energy recovery will lead to poor cement qualities, high maintenance cost and low revenue generation.

IV. Conclusions

The need to improve the quality of cement, while ensuring conservation of energy has led to series of research. Due to the cost of experimental trials, the studies by researchers have been limited. In view of these, this study investigated the effect of bed height on performance of clinker coolers used in cement plants. This was achieved by scaling down an existing cooler and adopting computational fluid dynamics tool to investigate the performance of the cooler. Findings from this study reveal that;

- optimizing clinker via bed height in cement plant has a great potential of improving entire cement production process, quality of cement, increase in revenue and improve the rate of heat transfer between fresh clinker (1350 ^oC) entering inside the clinker cooler and the counter-current of air (32 ^oC) entering inside the clinker cooler.
- the optimum energy transfer in this study was observed with clinker bed of 0.6m and the clinker outlet temperature was 68.4 ^oC.
- the results from the study also suggest that the existing clinker cooler with clinker outlet temperature above 200 ^oC can be optimize by increasing the clinker bed height from the initial conventional value of 0.45 m to 0.6 m.
- the modelled clinker cooler performance using clinker bed of 0.6 m when compared with the existing clinker cooler is 20.80% in terms of energy efficiency.
- by introducing proper clinker cooler bed, optimization with clinker bed height above 0.45 m in the existing clinker cooler can possibly limit the current challenges being faced with the existing clinker cooler performance which are poor energy recovery, poor cement qualities, high maintenance cost and low revenue generation.
- finally, the scaling down method and computational fluid dynamics approach would provide insight for designers and researchers to develop quick and effective design procedure for development of more efficient and effective clinker coolers both for field application and academic purposes.

List of Abbreviations

Symbol	Meaning	Unit
CAD	Computer Aided Design	
CFD	Computational Fluid Dynamics	
3-D	Three Dimension Model	
Q_{pi}	Heat losses	J
R_{ti}	Total internal resistance	Ω
T_{pi}	Wall temperature	°C
A_i	Segmented area	m^2
T_i	Temperature of each segment	°C
t_{br}	Thickness of the refractories	m
t_{cs}	Thermal Conductivity	W/mK
t_{cbr}	Thermal conductivity	W/mK

t_s	Shell thickness	°C
H_c	Cold Zone Height	m
Z_h	Number of hot zone	
L_c	Length of cold zone	m
H_h	Hot zone height	m
D_{clk}	Clinker density	kg/m^3
H_{clk}	Height of the clinker bed in hot zone	m
L_h	Length of the clinker in the hot zone	m
L_c	Length of the clinker in the hot zone	m
$t_{res\ time}$	Average resident time	s
C_g	Distance covered grate	m
W_h	Frequency of grate in hot zone	Hz
W_c	Frequency of grate in cold zone	Hz
$M_{clk\ in}$	Mass flow rate of Clinker Inlet	kg/s
$M_{clk\ out}$	Mass flow rate of Clinker Outlet	kg/s
$M_{air\ in}$	Mass flow rate of Air Inlet	kg/s
$M_{air\ out}$	Mass flow rate of Air Outlet	kg/s
$\dot{E}_{in}$	Energy Input	J
$\dot{E}_{out}$	Energy Output	J
h_{fi}	Heat transfer coefficient	W/m^2K
D_s	Clinker diameter	m
ρ_{air}	Density of air	kg/m^3
U_{air}	Velocity of air	m/s
K_{air}	Thermal conductivity of air	W/m^2K
μ_{air}	Dynamic viscosity of air	kg/m/s
η_{ε}	Energy Efficiency	%

$\eta_{recoverable,cooler}$	Recoverable Energy Efficiency	%
T_{clkout}	Clinker Outlet Temperature	°C
T_{clkin}	Clinker Inlet Temperature	°C
cp_{air}	Specific heat capacity	kJ/kg °C
Q_{as}	Recoverable heat of kiln secondary air	J
Q_{at}	Recoverable heat of tertiary air	J
Q_{oc}	Heat of clinker at the cooler output	J
Q_{exh}	Heat of cooler at exhaust air	J
Q_{ic}	Heat of clinker at the cooler input	J

Competing Interests
The authors declare that they have no competing interests" in this section.

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Authors' Contribution

SO carried-out the industrial research, laboratory research, simulation on Computational Fluid Dynamics (CFD) and Computer Aided Design (CAD). He is the major author contributor, research coordinator and research/data analyst on "effect of clinker bed height on clinker cooling process on clinker grate coolers used in cement plant". He has more than 20 years of experience in Industrial Engineering, Operational and Project Management, project execution at all stages of process plants. He has a B.Eng, M.Eng, and Ph.D. in Mechanical Engineering. His areas of specialization are Operations Management/ Project Management/ Mechanical Engineering/Process Engineering, Energy Management. He is currently a staff of BUA Cement Plc as an Assistant general Manager and also a researcher at Auchi Polytechnics Edo state. **All authors read and approved the final manuscript.**

ET performed the designing of the Computational Fluid Dynamics (CFD), Computer Aided Design (CAD) and analysing simulation data. He has B.Eng and M.Eng Mechanical Engineering. He has about six years of experience in the application of computer aided software in solving engineering problems related to heat transfer and computational fluid dynamics. He is currently a Ph.D student at Federal University of Technology, Akure. **All authors read and approved the final manuscript.**

MA performed the interpretation of data and analysing the data gotten from the industries, laboratory, and simulation results. He is the major supervisor for the research work and research/data analyst. He is a Professor of Mechanical Engineering with expertise in Build Services and Thermo fluid at Federal University of Technology Akure, Nigeria and with a lot of scholar awards. Currently, he is a visiting Professor to University Mines and Technology Ghana. **All authors read and approved the final manuscript.**

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SS performed interpretation of data and also analysed the data gotten from the industries, laboratory, and simulation results. He is a co-supervisor for the research work and research/data analyst. He is an Associate Professor of Mechanical Engineering with expertise in Thermo fluid at Federal University of Technology Akure, Nigeria and with a lot of scholar awards. He is currently the rector of Kwara State Polytechnic Kwara state Nigeria. **All authors read and approved the final manuscript.**

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