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Analysis of Heating System in FBC of Sand Reclaimer

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ABSTRACT

In recent years, the foundry sector has been showing an increased interest in reclamation of used sands. Grain shape, sieve analysis, chemical and thermal characteristics must be uniform while molding the sand for better casting characteristics. The problem that tackled by every foundry industry is that of processing an adequate supply of sand which has the properties to meet many requirements imposed upon while molding and core making. Recently, fluidized bed combustors are becoming core of 'clean wastes technology' due to their efficient and clean burning of sand. For proven energy efficient sand reclamation processing, analysis of heating system in fluidized bed combustor (FBC) is required. The objective of current study is to design heating element and analysis of heating system by calculation of heat losses and thermal analysis offluidized bed combustorfor improving efficiency.

***Keywords*:** Sand Reclamation; Fluidized Bed Combustor; Analysis; Heat loss; Heating Efficiency

1. Introduction

Metal casting process generates several kinds of waste, in which foundry sand is the main waste and which is intensively used as primary direct material in foundry industry. A number of small foundries do not reuse sand, due to lack of infrastructure facilities. In view of this, it is essential to focus on the regeneration and reuse of this sand as main factor in environmental performance to achieve sustainable development in foundry industries (Danko *et al.*, 2007). Reclamation is becoming a necessity in foundry operations. For foundries cannot afford to continue paying money to buy and for freight to the foundry and thereafter pay for freight and disposal costs. Casting production using sand molds is considered as 80% of the world casting production. The reclamation process involves treatment of sand and then reusing it for mold/core production.The sand reclamation processing can be done by using either cold or hot reclamation process. In thermal sand reclamation heating of sand is done in fluidized bed combustor and cooling in sand cooler. The fluidized bed combustor (FBC) is the prime component of the system. To make reclamation processing energy efficient, the analysis of sand reclamation system is required. Selection of sand reclamation system depends on fuel availability, required applications in the market, innovation spill over and competing technologies. 'Getting rid of waste' is the ultimate goal when the FBC technology is introduced. This goal evolved over time to 'clean energy for the future'. The bubbling fluidized bed is the first version of FBC technology which is developed for effective utilization of energy (Koornneef *et al.*, 2007). The heat in bubbling fluidized bed combustor is mainly transferred in the lower part of the combustor so it is necessary to control the temperature to prevent failure of system by blockage of nozzles. Energy utilization for heating in sand reclamation system plays a vital role.

2. Sand Reclamation Processing

The sand reclamation processing should beenvironmental sustainable, technically strong andeconomically viable. The foundries want to reduce the total sand cost, which includes purchase cost, freight cost and disposal costs. Environmentally, it is becoming more difficult to dispose large quantity of sand onto the ground. Technically, during sand reclamation binders and catalyst may be reduced in reclaimed sand. Minor efforts for sieve analysis to remove the fine sand particlesoffer better casting quality. The reclamation of sand can be done by different techniques by considering various factors such as, bonding mechanism, sand mixture, time for reclamation, cycle of reclamation etc. Most of the foundriesuse mechanical reclamation. Dry reclamation system is a desirable for brittle binder coatings on sand. Wet reclamation involves removal of binder coating on sand by scrubbing with intensive turbulence and whirling in sand-water slurry. No bake sand casting is the most precise casting method of the modern days. Complicated castings and excellent surface finish can be achieved as compared to other sand casting techniques. No bake sand can be reclaimed by thermal reclamation system preferably.Not much change in grain size and shape is observed in wet reclamation and thermal reclamation system. In case of organic binder system, thermal reclamation is superior to dry reclamation system. Thermal reclamation will be adopted by the foundries, due to its economicalbenefits and energy efficient process (Ghosh, 2013).

Fluidized bed combustors are becoming core of 'clean wastes technology' due to their efficient and clean burning of sand. The heat transfer process is affected by many operating conditions such that, velocity of fluid, shape and size of nozzlein FBC's(Hamada *et al.*, (2015)). Thermal reclamation with electric heating system offers some special advantages than gas fired units.Oil fired FBC creates pollution and gas fired FBC is hazardous so;for higher safety, higher efficiency, uniform heating of sand and for small volume (i.e. 20kg sand) thermal reclamation with electric heating system is preferable. According to environment friendly mode i.e.% reductionof pollutants and energy efficient process, it is important to analyse the heating system of FBC. Process flow of thermal sand reclamation is shown in **Figure 1.**

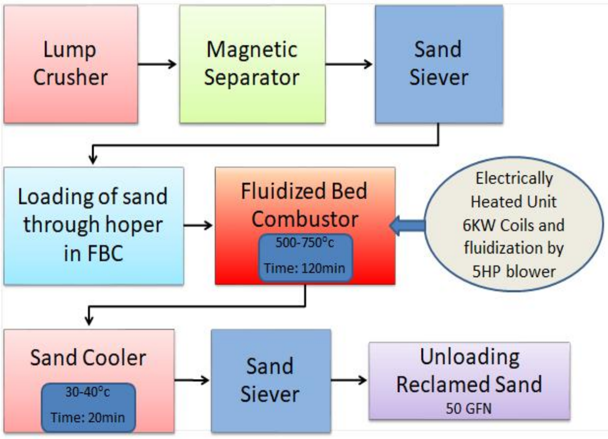

Figure 1; Process flow of Thermal sand reclamation**.**

3. Design of Heating System

3.1 Power calculation for heating coil:

Power required for thermal sand reclamation system is calculated as below;

A] For FBC Heat Requirement

As, H(FBC) = m × c × ΔT(1)

For, FBC Mass (m) 19.38kg, Specific heat of SS 310 (c) = 500 J/kg K at temperature (T1) 800˚C and Final temperature (T2) is 30˚C therefor, H(FBC) = 1783.2935kcal

B] For Sand Heat Requirement as Sand Mass (m) = 20 kg and Specific heat of sand (c) = 830 J/kg K

So, from equation (1); H(Sand)= 3054.9713 kcal

Total heat required for heating of 20kg sand at 800˚C in FBC is 4838.2648 kcal

Therefore; 6 kW heating coil is required to heat 20kg sand in combustor.

3.2 Design of heating element for combustor:

According to application, cost and comparative lifeKanthal-A1 grade 14-swg (thickness 2mm) wire is selected. Comparative life of various heating elements is shown in **Figure 2.** From Kanthal Catalogue; specifications of A1 grade 14-swg wire are shown in Table 1.

Maximum operating temperature	1400˚C
Density	7.10 g/cm^3
Thermal conductivityat20˚C	13 Wm^{-1}K^{-1}
Temperature factor (C_t) at 800˚C	1.03
Resistance/meter for 14-swg	0.462 Ω/m
Weight/meter for 14-swg	22.30 g/m
Resistivity at 20˚C	1.45Ω mm^{2}m^{-1}

Table 1. Kanthal-A1 grade 14-swg specifications

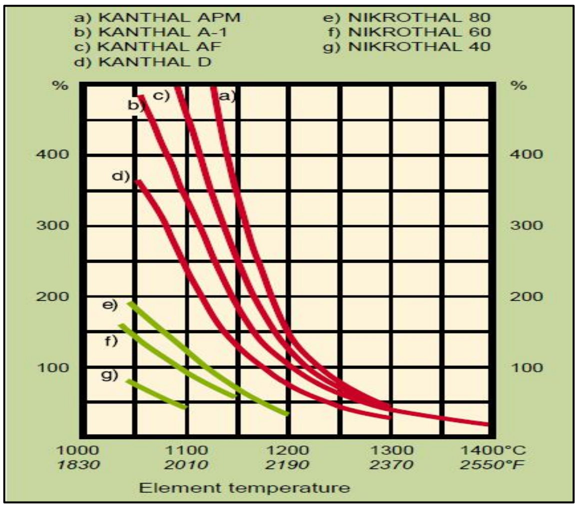

Figure 2; Comparative life (Courtesy from Kanthal Handbook)**.**

a) Hot Resistance (Rh) $= \frac{V}{I}$ =20.91Ωb) Resistance at 20˚C(Rc) $= \frac{Rh}{Ct}$ = 20.30Ω

c) Length of wire required (Lw) $= \frac{Rc}{0.462}$= 44md) Weight of wire required (W_W) = 44 × 22.30 = 981.2 g

e) Diameter of mandrel (Dm) = 4 mmf) Coil diameter (Dc) = Dm + (2 × Dw) = 8 mm

g) Total number of turns on mandrel $= \frac{Lw}{\pi(Dm+Dw)}$ = 2334 turns

h) Total number of turns on FBC Main body = $\frac{\text{FBC length}}{(Dm+Dc)}$= 34 turns

Now length of coil in stretched condition;

i) Stretch length (SL) = Perimeter of FBC × Total number of turns on FBC= 33112.39 mm

j)Unstretched length (UL) = (No. of turns on mandrel × Dw) = 4668 mm

k) Stretch ratio = $\frac{SL}{UL}$= 7.09

l) Total uncovered length = [FBC length – (Total number of turns on FBC × Dc)] = 128 mm

m) Width of each space between coil is, $\frac{\text{Total uncovered length}}{\text{Total number of turns on FBC}}$ = 3.76 mm

Now, ratio of $\frac{\text{Width of each space between coil}}{\text{Diameter of mandrel (Dm)}}$= 0.94

This is in agreement with desired ratio (i.e. in between 0.75 to 1) therefore; this design of heating element for FBC is ok.

4. Heat transfer in FBC

4.1 Heat loss by conduction for radial heat transfer in thermal sand reclamation system:

Material for FBC is SS-310 so, at maximum temperature 800˚C with thickness 4mm and thermal conductivity is 10.8 W/m˚C heat per unit area (Q/A) generated in FBC is calculated;

$Q_{generated}$= 2160×10^3 W/m^2(2)

In sectional view of FBC **Figure 3;**

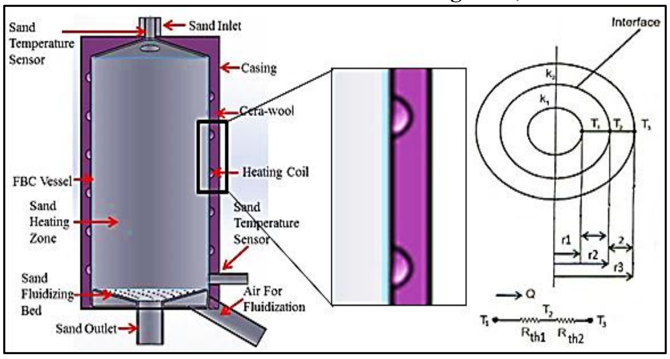

Figure 3;Sectional View of FBC.

Thermal conductivity of cerawool(K_1) = 0.0549 W/m˚C; Thermal conductivity of MS (K_2) = 50.2 W/m˚C, Heating Coil temperature (T_1) = 800˚C; Interface temperature (T_2); Outside temperature (T_3) = 30˚C; r_1 = 0.155 m; r_2 = 0.180 m; r_3 = 0.182 m

As; $Q_{conduction} = \frac{(\Delta T)overall}{\sum Rth}$(3)

$Rth_1 = \frac{r2-r1}{4\pi\ K1\ r2\ r1}$= 1.2988˚C/W(4)

$Rth_2 = \frac{r3-r2}{4\pi\ K2\ r3\ r2}$= 9.6777 × 10^{-5}˚C/W(5)

from equation (4) and (5) ∑Rth = 1.2989 ˚C/W

from equation (3)

$Q_{conduction}$ = 592.81 W/m^2

As; $T_2 = T_1$- ($Q_{conduction}$ × Rth_1) (6)

Interface temperature (T_2) =30.06˚C

As, $Q/A_{conduction} = \frac{(T1-T3)}{(\frac{L1}{K1})}$(7)

Where, L_1= thickness of cerawool; from equation (7)

Therefore; thickness of cerawoolwill be 72 mm.

4.2 Heat loss by convection in thermal sand reclamation system:

$Q_{convection}$ = h × ΔT(8)

Where, Q = Heat flux per unit area in W/m^2

h = Heat transfer coefficient in W $m^{-2}k^{-1}$

Heat transfer coefficient (h) for fluidized bed chillers and freezers [4] is 50-250 W $m^{-2}k^{-1}$.

Therefore; assume (h) = 150 W $m^{-2}k^{-1}$

from equation (8)

$Q_{convection}$ = 115500 W/m^2

Total Heat loss (Q_{loss}) = $Q_{conduction}$ + $Q_{convection}$

(Q_{loss}) = 592.81 + 115500

Total Heat loss (Q_{loss}) = 116×10^3W/m^2(9)

Total heat consumed for thermal sand reclamation of 20 kg sand is calculated;

$(Q_{consumed}) = (Q_{generated} - Q_{loss})$

So,from equation (2) and (9)

$Q_{consumed} = 2044\times10^{3} W/m^{2}$

5. Analysis of FBC

Thermal simulation plays an important role in the design of many engineering applications, including internal combustion engines, turbines, electronic components and heat exchangers.For simulation, finite element, finite difference and finite volume methods are used. Finite element method (FEM) is a computational method that subdivides CAD model into very small but finite-sized elements of geometrically simple shapes and the collection of all these simple shapes constitutes called as finite element mesh. FEM can be used for all kinds of structural analysis, heat transfer, chemical engineering, electromagnetics, multi physics and CFD. Finite difference method is themost direct approach to discretizing partial differential equation. This method is not used for irregular CAD geometries but can be used for rectangular or block shaped models. Finite difference method (FDM) is widely used for weather calculations, astrophysics and for special effects. Finite volume method(FVM) is similar to finite element method in which method begins with generation of cells instead of elements. FVM is best suited for CFD, heat transfer and chemical engineering. Generally all methods are used in commercial software as well as in academic environments,but FEM is mostly used due toeasy achievement of higherorder of the elements so that, the physics fields can be approximated very accurately. Also, we can combine different kinds of functions that approximate the solution within each element, which is called as mixed formulations.

CFD modeling is a powerful tool for the development of new ideas and technologies. With the continual enhancement of computational capabilities, it is easy to do such modifications to determine optimum design and operating conditions before experimental modifications. Researchers have been using CFD to simulate and analyze the performance of thermo chemical conversion equipment's such as fluidized beds, fixed beds, combustion furnaces, firing boilers, rotary kilns and rotating cones. CFD programs predict fluid flow behavior, heat and mass transfer, phase changes and mechanical movement of rotating cone reactor.So, CFD analysis is used to analyzethe FBC for thermal flow behavior inside the combustor, which will support experimental investigations. CFD provides a qualitative prediction of fluid flow by means of mathematical modeling (partial differential equations), numerical methods (discretization and solution techniques) and software tools (solvers, pre and post processing utilities)(Ambesange and Kusekar,2017).

For this analysis ANSYS fluentmoduleis used. It contain wide range of physical modeling capabilities which are used to model the flow, reactions, turbulence and heat transfer for industrial application. Features of this software are mesh flexibility, multiphase flow, reaction flow, turbulence, dynamics and moving mesh, post processing and data export.This software has two solution methods pressure based solution method and density based solution method.

In Pre-processing, engineering data SS-310 material is given to FBC main body, cerawool material for insulation and for outer casing of FBC mild steel material is given along with respective thermal conductivity for all materials. Geometry of FBC main body, cerawool insulation and outer casing of FBC is imported in software.As this software provides mesh flexibility. It has ability to solve flow problem using unstructured mesh. By using standard meshing technique disintegration of model is done,which saves the meshingtime. 800˚Ctemperature for FBC main bodyand convection heat transfer coefficient 150 W $m^{-2}k^{-1}$ is applied as aninitial constraints (Reddy *et al.*, 2015).

During processing, finite element method is used by software and elaborates the results. In post processing of modelfluent software creates contours plots, path lines, vector plots and animations to display data.According to this analysis, the results are plotted in **Figure 4** to 7 and seem to be satisfactory.

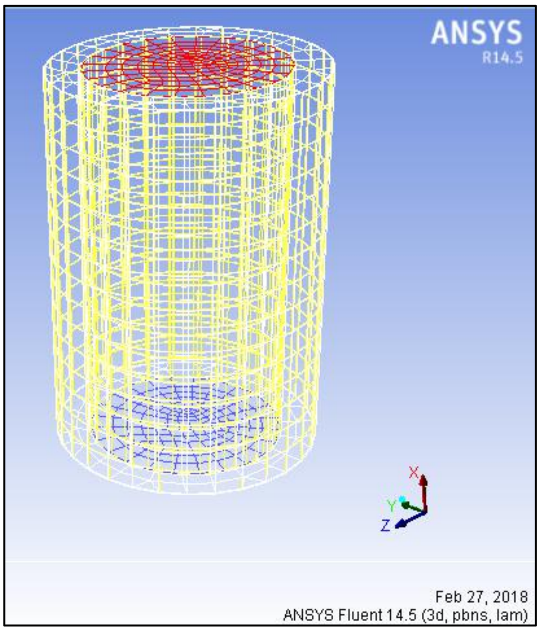

Figure 4; Meshing of FBC**.**

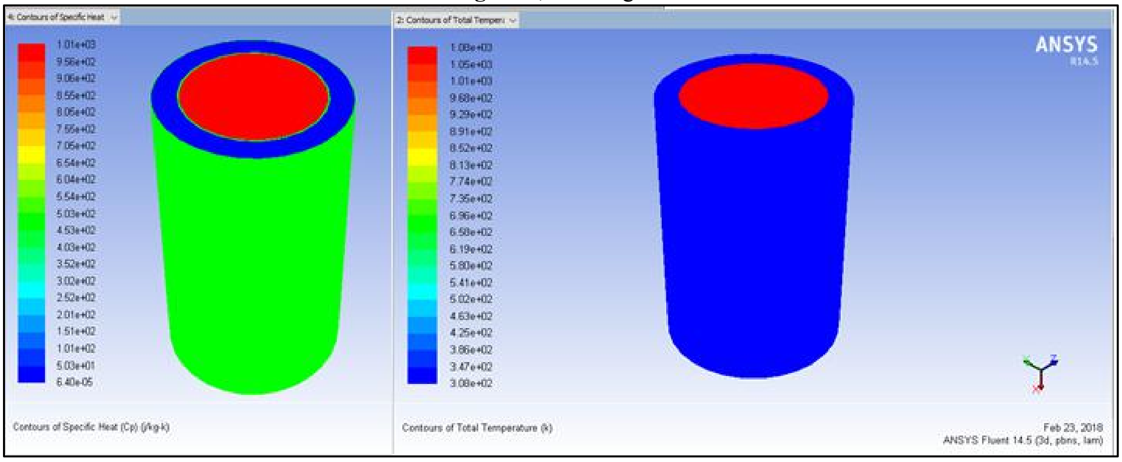

Figure 5; Contours of Specific heat and Total temperature**.**

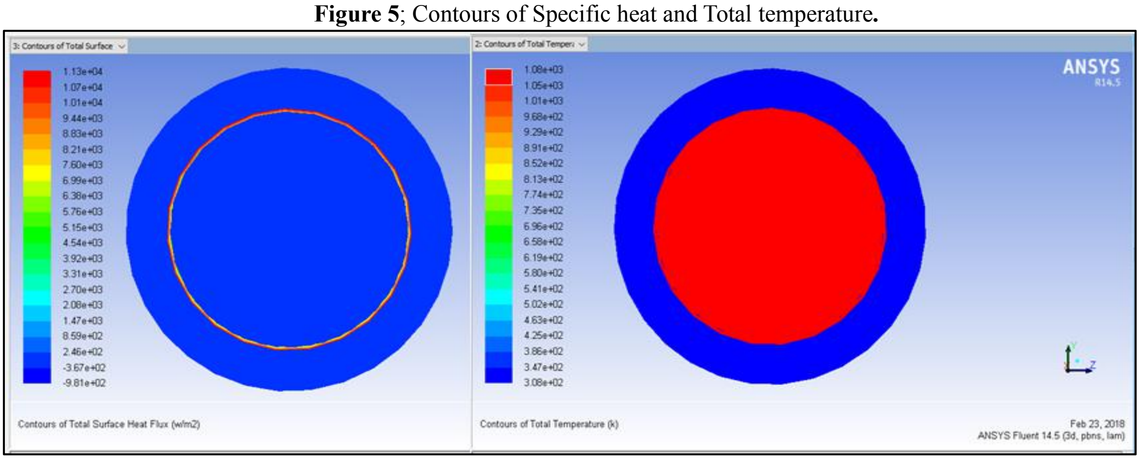

Figure 6; Counters of Total Surface heat flux and Total temperature (Top view)**.**

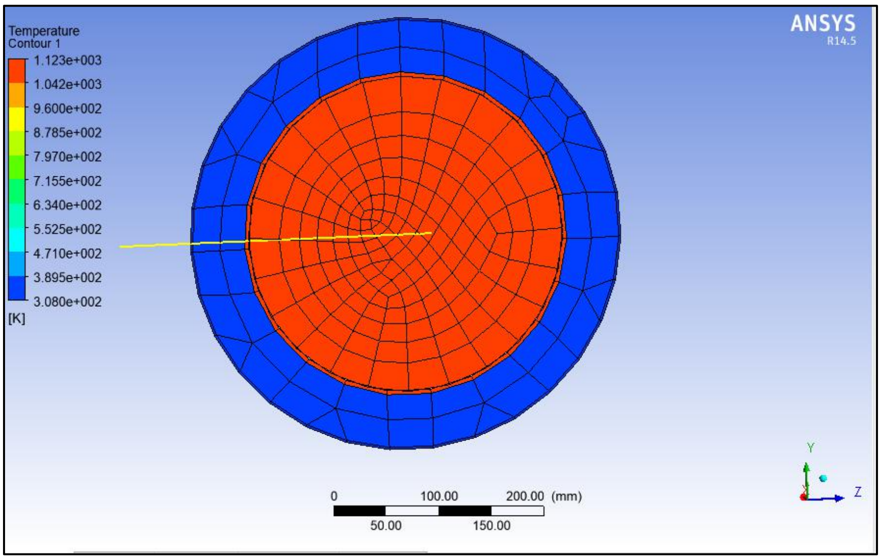

Figure 7; Cut section of FBC with meshing: Temperature distribution**.**

For performing the simulation in ANSYS fluent, the typical numerical procedures are;

Create and mesh the geometry model

Import the geometry into ANSYS fluent

Define the solver model

Define the turbulence model

Define the species model

Define the materials and chemical reactions

Define phases: primary and secondary phase

Define phase interactions such as drag force, heterogeneous reaction etc.

Define boundary conditions with region adaptation and patching

Initialize the calculations

Iterate until convergence is achieved

Post processes the results.

6. Results and Discussion

As this designedthermal sand reclamation unit is for small capacity (20 kg),the efficiency of system is higher with maximum cost. This cost will be reduced when system is designed for large capacity or mass production.

Cerawool is used as refractory fiber blankets and backup insulation application in furnace, which are formed from alumina, silica and other refractory oxides. To minimize heat loss by convection, we can use cerawool refractory insulation also on top side of FBC.

For better results, cerawool can be replaced with phenolic foam, which has lower thermal conductivity than cerawool.

Heatthrown away by convection can be sent back to the system through blower for effective energy utilization.

CFD is a powerful tool used for prediction of fluid flow behavior, heat and mass transfer by enabling a proper design of such system.

As thickness of cerawool insulation increases heat loss per unit area of system decreases, effect of insulation thickness on heat loss is shown in **Figure 8.**

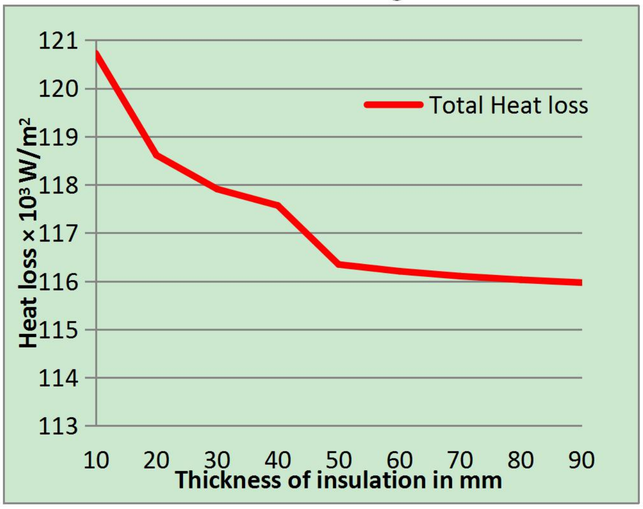

Figure 8; Effect of insulation thickness on the heat loss from combustor**.**

Effect of insulation thickness on temperature of outer casing of FBC is shown in **Figure 9.**

As simulation results are satisfactory, fabrication of FBC is done according to design as shown in **Figure 10.**

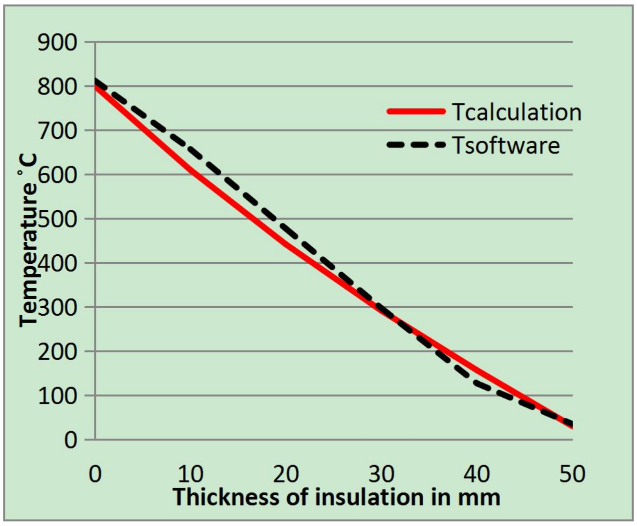

Figure 9; Effect of insulation thickness on temperature of outer casing of FBC**.**

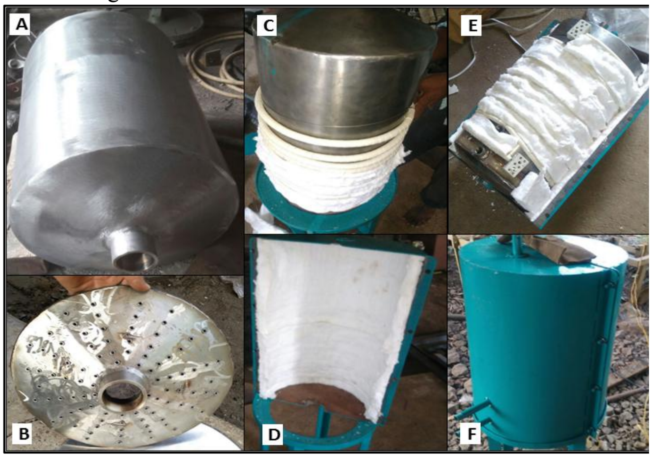

Figure 10; Fabrication of FBC:A] FBCVessel B] Fluidization Bed Bottom C] Heating Coil on FBC D] Outer Casing of FBC E] Cerawool Insulation on FBC Vessel F] Assembly of FBC Unit**.**

7. Conclusion

Thefoundries needs to reclaim the sand to minimize fresh sand utilisation in foundries and to avoid disposal costs. The sand reclamation processing can be done by using either cold or hot reclamation process.To make reclamation processing energy efficient, the analysis of sand reclamation system is required. Selection of sand reclamation system depends on fuel availability, required applications in the market, innovation spill over and competing technologies.

From the analysis of heating system in FBC of sand reclaimer following conclusions are drawn; For higher safety, higher efficiency, uniform heating of sand and for small volume (i.e. 20 kg sand) thermal reclamation with electric heating system is beneficial. According to design, it is found that,for thermal reclamation of 20 kg sand, the required heating coil is of 6 kW. The Thermal CFD based Simulation was conducted to predict the performance of heating system of FBC. The heat loss is foundminimum with 72 mm insulation thickness ofcerawool, at reclamation temperature of 800˚C. The simulated results are matching with designed results.to be satisfactory so, fabrication of FBC is done. Heating efficiency of thermal sand reclamation system experimental setup gives 94.63% with total heat loss of 5.37%. According to experimental trials conducted with sand reclamation system, thickness of insulation plays effective role on overall temperature behavior of system which controls heat losses in FBC.

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