ASSESSMENT AND CHARACTERIZATION OF GEOMENTRIC PARAMENTERS ON PERFORMANCE OF A ROTARY FURNACE

[1]ASHA SATURDAY, [2]EJEHSON PHILIP SULE, [3]AGWUNEDU.C. RICHARD, [4]MALIK DANIEL, [5]IFEZUE O. GODWIN

Scientific Equipment Development Institute SEDI, BOX 3205, Enugu, Enugu State, Nigeria

Abstract: **Furnaces operate in aggressive environments, where several components—molten metals, furnace linings, atmospheric gases, and products from combustion of fuels—coexist at extremely high temperatures. Furnaces as rotary mixers are the bed rock or heart foundry operations . As a synequano to casting or foundry processes, there should be need to characterize the operating and geometric parameters of a rotary furnace for improved thermal efficiency and performance through even distribution of heat flux. This work focuses on hot gases back pressure increase and flow velocity reduction with regard to geometric or shape orientation are investigated in a bid to optimized and improve decrease in resident time of scraps in the furnace, in order to reduce cost and energy lost implications. An exit cone length to inlet cone length of 0.65 to 0.58 ratios is established for known cylinder diameter ,and the two cones external diameters which must be equal .**

Index Terms: **geometric characterization, exit and inlet cone lengths ratios, back pressure increase, speed reduction, improved thermal efficiency and performance, Rotary furnace**

I. Introduction

The foundry operations and its effectiveness is a function of good casting conditions. The furnace is the back bone whose thermal efficiency affects casting and casted products. This comprises the stability of melting and pouring temperatures of the molten metal in the furnace, guaranteed through appreciable thermal efficiency.Furnaces are used based on capacity, types of materials to be casted (ferrous or non-ferous). Hence rotary furnace is used for the casting of low volume of work (cast). The existing 50kg rotary furnace design in NASENI, Nigeria was investigated, the operating parameters, and the geometric parameter were optimized to improve on the thermal efficiency and performance of the existing rotary furnace with the use of CAD and CAE.

Every rotary tube furnace is designed for the customer's unique specifications. Innovative solutions to designs are brought for continuous processing of advanced materials such as granular, powder, or particulate aggregates in high purity and specialty atmosphere environments at temperatures up to 2400°C. offering exceptional versatility, reliability and energy efficiency with features that enable better mixing, resulting in improved heat transfer and mass transfer, support system provides a simple, reliable, robust design that enhances scalability and the tumbling action of the product within the chamber of the cylinder results in high degrees of temperature uniformity and gas-solid contact, producing a more homogenous product, reducing processing times or resident time and increasing production rates.Rotary furnace is one of the suitable furnaces for the production of irons. However, conventional furnaces for producing ductile iron are: induction furnaces of different types, electric arc furnace and cupola furnace. Due to difficulty in operating air furnaces producing a low carbon, malleable cast iron and as a result of wasteful in fuel, rotary furnace was designed [1]. Rotary furnaces have cylindrical barrel which revolves completely at the rate of about one revolution per minute. Their capacity ranges from few kilograms to several tonnes, there is a single burner at one end of the barrel; they are fired by oil or pulverized coal. High temperature flame melts and superheats the charge in the furnace barrel. The waste gases that pass out at the other end of the barrel can be directed through a series of recuperation tubes on their way to the chimney [1]. This can be use to pre heat the incoming cold air in order to increase the efficiency of the furnace [1].

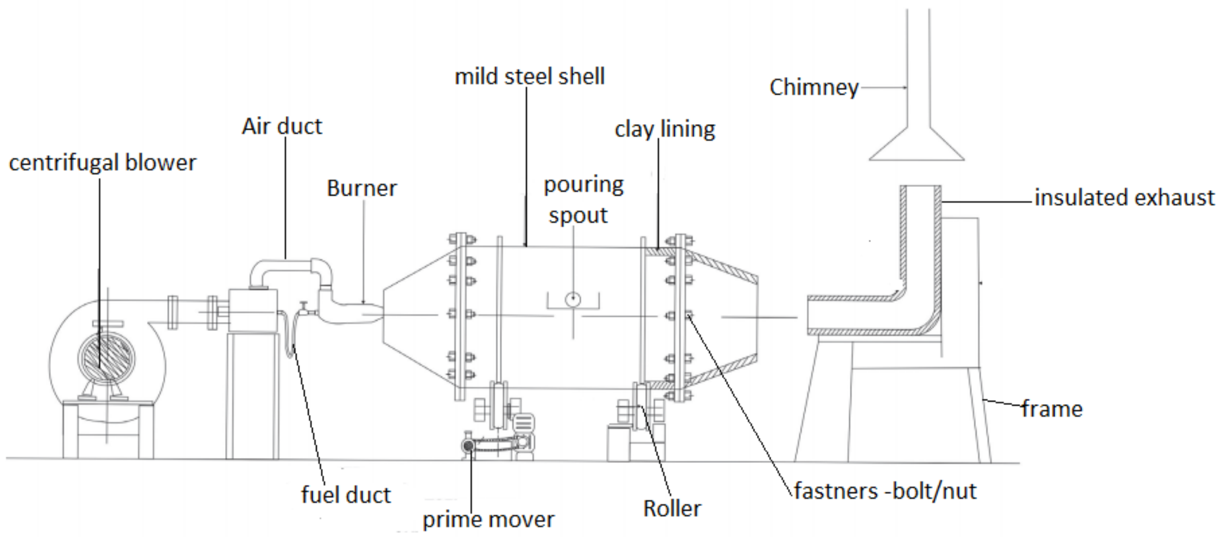

Fig1. Schmatic diagram of rotary furnaces and its major component

II. Scope

This paper focuses on the optimization of the operating and geometric parameters of a rotary furnace. The characterization of these parameters is aimed at improving the thermal efficiency and performance through a reduced resident time.

III. Statement Of Problem

This research is necessitated owing to the cost and energy implication involved in operating a rotary furnace. The lost of man hour, fuel and electrical energy through long resident time provoke this work since no research has been done to investigate the effect of the shape of the rotary drum on the thermal efficiency and performance of the rotary furnace.

IV. Aims And Objectives

The paper is researched on rotary furnace bearing the following aims and objectives in mind.

1. To improve thermal efficiency of further designs of rotary furnace.
2. To reduce resident time of further designs
3. To exhibit the operating parameters and geometric parameters that can improve the performance and efficiency of rotary furnace through the use of CAD and CAE
4. To establish the a design ratio be lengths of exit cone and inlet cone for optimum design having established the volumetric capacity of the furnace

V. Significance

Improve thermal efficiency and performance of a rotary furnace is necessary for the casting of materials to save cost and energy and achieve good products with little or no defects through well detailed CAD and CAE analysis of the geometry of the rotary furnace besides other factors.

VI. Description

The rotary furnace is used for melting of cast iron or iron scrapes. It has the furnace housed on rollers which is driven by a high torqued geared motor. The rotary drum insulated with bricks. It comprises the frame, rollers and pinions, nozzle or burners, chimney and blower.

Cone: The cones are the Divergent and convergent parts of the rotary drum system. The length, volume and taper angle of the first cone (divergent) influence the amount of pressure that can be built in the drum . A sudden peak pressure is produced with short, steeply (sharp) taper cone of divergent but gently tapered first cone (divergent) helps for gradual pressure generation and could be best for heat generation and conservation for high and improved thermal efficiency and heat flux, the divergent or the megaphone is used to build up pressure to sustain and increase waiting time of heat and flue gasses before arriving at the final cone where pressure is dropped to increase speed of flue gasses and heat. This is the inlet cone of the burner flame.

Belly: This is the cylindrical section between the Divergent cone and convergent cone. It is characterized as the mid-section where the length or volume adjustments are made to compensate for capacity of the entire furnace system. This mid-section can be enlarged, shortened or lengthened to bring about some results in most designs .the housing capacity of the furnace is determined by the volume influence by the length and diameter.

Final Cone : Controlling the pressure built in the rotary drum it is necessary to adequately increase flow of the hot stream of gases, moderating or minimizing heat lost ,incomplete combustion and dangerous gaseous media and particle liberation are influenced or are made possible by the convergent part of the configured section, a relatively longer, gently tapered converging cone will give more of these while a short and steep cone give less. Loss of heat energy through exhaust and poor thermal performance are critical issues of engineering design in this regard. This is the exit cone leading to chimney

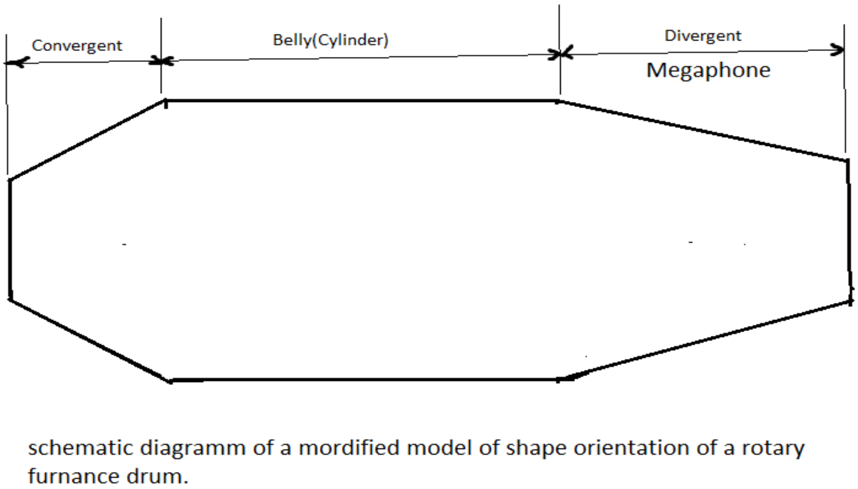

Fig 2.descriptive shape of the rotary drum

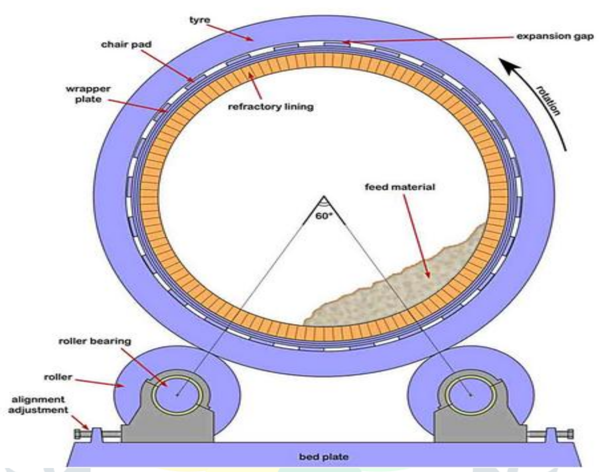

Fig 3 rotary drum on rollers

VII. Design Focus

The design conditions to be focused in the furnace should be such that the heat flow to the surface of material is at its maximum and that it can be absorbed completely with built up pressure to reduce out flow of flue gases and heat through shape and volume optimization, recuperation , slow speed and complete combustion. This can be possible by the followings;

1. Fuel should be burned completely and combustion should occur within the furnace space where melting of scraps takes place with maximum shape orientation
2. Gases in the furnace space should be made to circulate vigorously, mainly under the action of air fuel jets from burners through non pulsating action resonated from current supply by the blower with the help of the geometric orientation of the furnace
3. The supplied heat should extensively be of maximum heat utilization within the furnace space through optimum shape orientation
4. The design of a pressure conditions in it should be such as to minimize the contact of furnace atmosphere with the surroundings(Dryden 1982)

VIII. Rotary Furnace Shell

Design and re-design to get the necessary dimensions and ensure that the process specifications with respect to both heat transfer and pressure drop are met. (Robert and Don 1984).The need for shape optimization through geometric analysis of the rotary furnace shell is necessary. The lining assumed the shape of the shell hence the design to determine the size of the furnace is Compressive Strength of the Lining: Let the Compressive strength be σ as used by Dryden 1982

$$\sigma = \frac{\delta \Delta t_C E_C}{r_2(r_2-r_1)}\left\{1+\frac{\Delta t_C E_C}{(r_2-r_1)E_L}\right\} \qquad (1)$$

Where

δ= lining shrinkage allowance (m) ,Δtc is thickness of the cylindrical shell without the lining (m)

Ec isYoung's modulus of cylinder (Pa) ,and E_L= Young's modulus of lining (Pa)

Conduction

Heat Transfer by conduction through the lining

$$Q_C = \frac{\pi K_L(r_2+r_1)(T_1-T_2)(L_1-L_2)}{r_2-r_1} \quad (2)$$

K_L= thermal conductivity of the lining (W/mK) ,r_2= junction radius = internal radius of the shell without the lining (m) ,r_1= internal radius of the shell with the lining (m) ,T_1 = average temperature in the furnace (K) ,T_2= outside (surface) temperature of the shell (K) ,T_0 = room temperature (K) ,L_1= length of the shell (m) ,L_2 = slant length of the conical frustum (m),t = total time taken (h)

Heat required to heat and melt the charge ch:

$$Q_{uh} = M_{ch}[C_{Pch}(T_1 - T_0) + L_{ch}] \quad (3)$$

M = mass of the charges (kg/h) ,Cm= specific heat capacity of the charges (KJ/kgK) ,T_1 = melting point temperature of the charges (K) ,T_0 = initial temperature of the charges (K) ,L_{ch}= Specific latent heat of melting of the charges (KJ/kg)

Manipulation of all the equations above gives

$$2r_2\left[E_L - E_L\left(\frac{Q_C-0.69\pi LtK_LT_1}{Q_C-0.69\pi LtK_LT}\right)\right] + t_CE_C = \left[\left\{t_C^2E_C^2 + \frac{4\delta t_CE_CE_L}{\sigma}\left[E_L - E_L\left(\frac{Q_C-0.69\pi LtK_LT_1}{Q_C-0.69\pi LtK_LT}\right)\right]\right\}\right]^{0.5} (4)$$

Hence the radius of the shell without the lining ,r_2

$$r_2 = \frac{\left[\left\{t_C^2E_C^2+\frac{4\delta t_CE_CE_L}{\sigma}\left[E_L-E_L\left(\frac{Q_C-0.69\pi LtK_LT_1}{Q_C-0.69\pi LtK_LT}\right)\right]\right\}\right]^{0.5}-t_CE_C}{2\left[E_L-E_L\left(\frac{Q_C-0.69\pi LtK_LT_1}{Q_C-0.69\pi LtK_LT}\right)\right]} \quad (5)$$

$$\Delta t_L = r_2 - r_1 \quad (5)$$

$$r_1 = Ur_2 \quad (6)$$

This is to determine the thickness of the material –steel shell and lining and the length of the drum, megaphone and cone part as previously discussed are not determine but are necessary for the volume determination as it is a measure of the furnace capacity

IX. Effect Of Furnace Shape

The thermal performance of a furnace to some extent depends on its shape, which alters the ratio of stock area to total internal area, the radiation beam length and the combustion gas flow pattern (not allowed for in single zone calculations). Too low a roof reduces the mean radiation beam length and also the refractory to stock area ratio, and thus reduces the heat flux to the stock. Nevertheless, a very high roof gives no thermal advantage (absorption of wall radiation by gases plus low temperatures in vicinity of roof due to gas flow) and a ratio of roof height to furnace width of 0.75 to 1.0 is probably sufficient. High temperature processing of raw materials in metals production and recycling often involves complex multiphase fluid flow and heterogeneous chemical reactions at various scales. A good understanding of the process physics and chemistry is crucial for process operation and process development.The furnace geometry affects the flow of gases, radiant flames and heat flux with the variation of velocity and pressure of the flow system. Hence ,to minimize heat loss through gaseous and hot air stream from the furnace through the exhaust chimney the shape or geometry need to be optimized. Consider fig 4 a typical sketch of a rotary furnace drum with inlent cone ,cylindrical drum, and the exit drum,with α_1 and α_2 as base angles of the inlet cone and exit cone respectively,D_1 , D_2 and D_3 are cylinder ,inlet and exit cone diameters respectively. The D_1 determine the volume capacity with L_{melt} . all these parameters describe geometry of the furnace rotary drum.

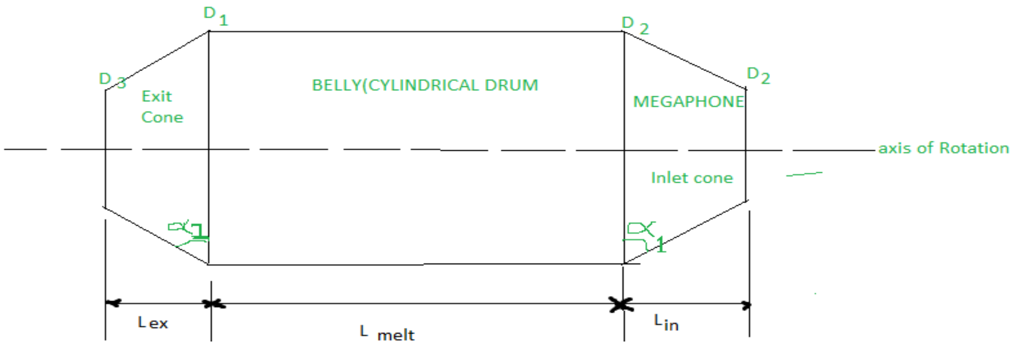

Fig4 Geometric parameters of the rotary drum

Having described the parameters that make up the geometry of a rotary furnace drum, the capacity of the furnace is based on the designer or end user ,previously it was said that D_1 and L_{melt} determine the capacity of the furnace in terms of volume where the melting of the scraps takes place. It implies their values will be constant if a capacity has been chosen. In the course of the geometric optimization these two parameters will be held constant. The inlet and exit cones characterize flow properties hence they will be varies in the simulation.

Simulation

α_1=base angle of megaphone, α_2=base angle of the exit cone , L_{in}=height of the megaphone frustrum, L_{exit}= height of the exit cone, D_2=diameter of the megaphone, D_3=diameter of the exit cone , D_3=diameter of the exit cone , D_1=diameter of the cylinder , L_{melt}=Length of the melting drum(cylinder)

Assumption

The following assumptions are made

I. No slip in the flow at the boundary between the wall and the hot stream

II. The shell geometry is being considered here because the linning is made to assume the shape.

Models

The flow in a 3-D model of the rotary drum will be investigated using velocity profile

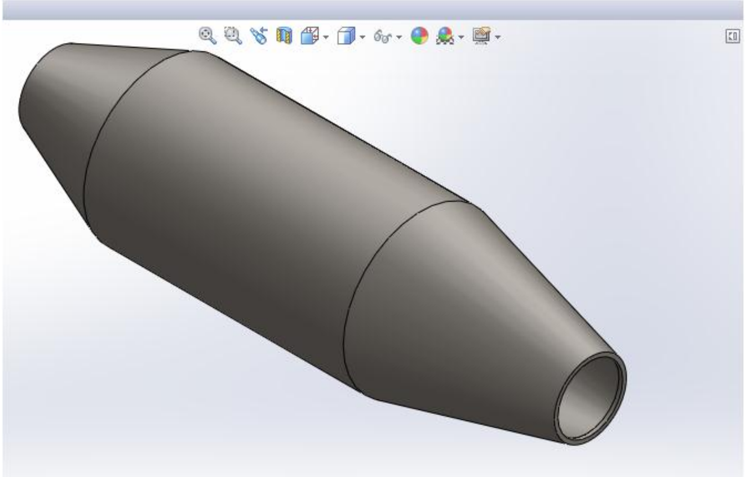

Fig.5. 3-D Isometric View of the rotary drum

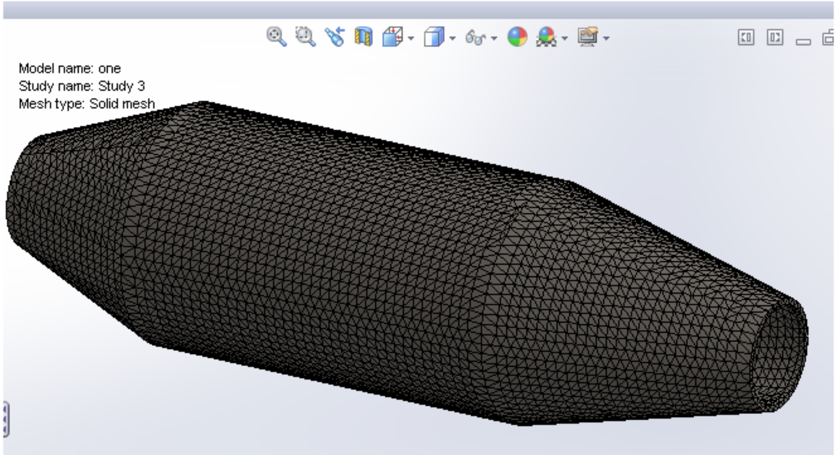

Fig.6.3-D Mesh of the rotary drum model

1. **When the lengths of the inlet and exit cones are equal,**

$$L_{in} = L_{exit}$$

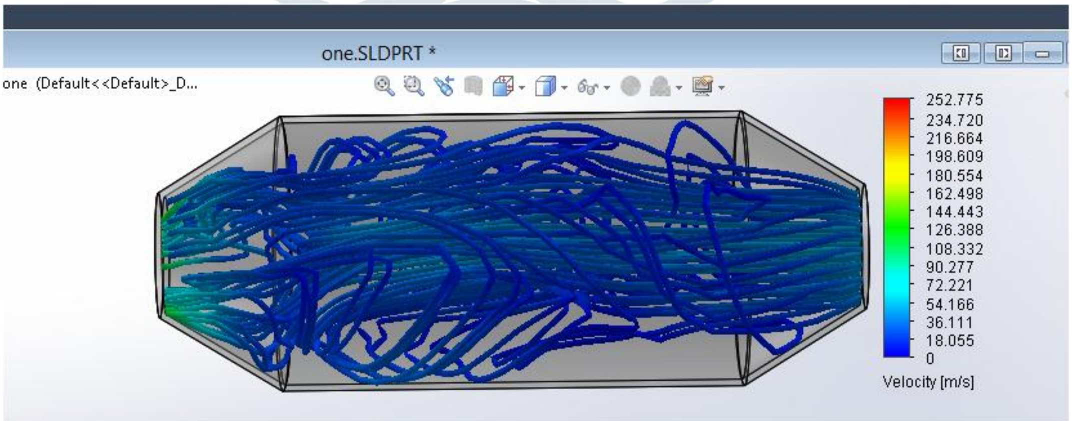

Fig7 .steep tapper short equal lengths

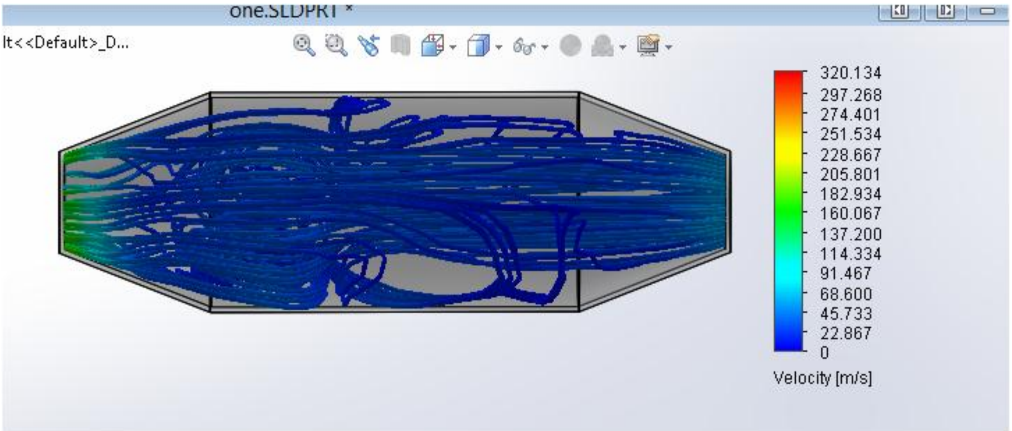

Fig.8 steep tapper and moderate length

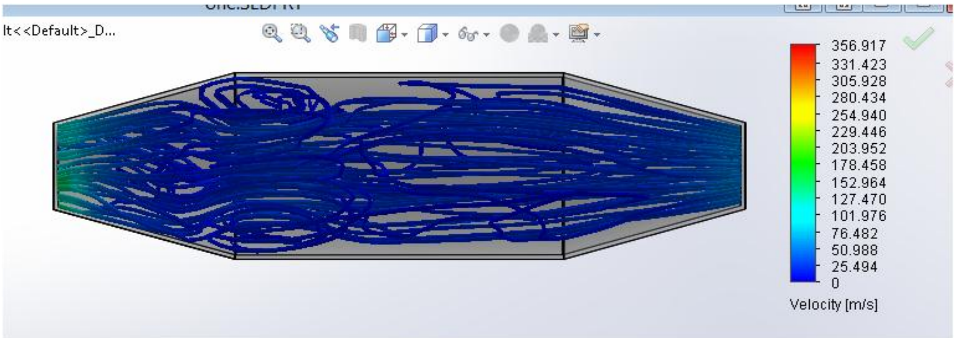

Fig9. Gentle tapper and equal long lengths

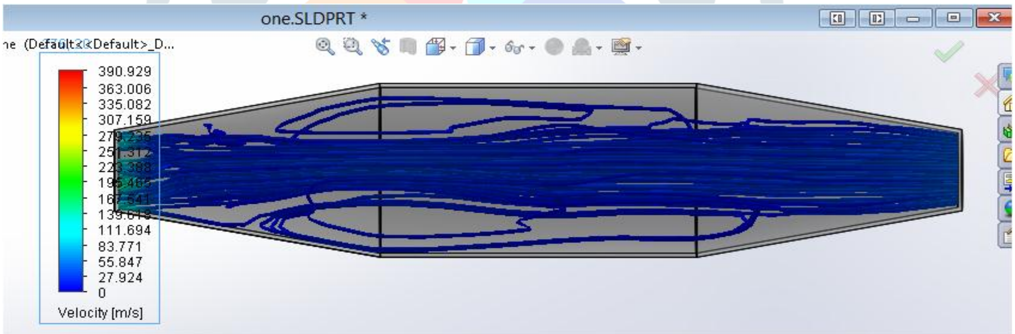

Fig 10. Gentle tapper and equal long lengths

2. When the lengths of the inlet and exit cones are not equal

$L_{in} \neq L_{exit}$
$L_{in} > L_{exit}$

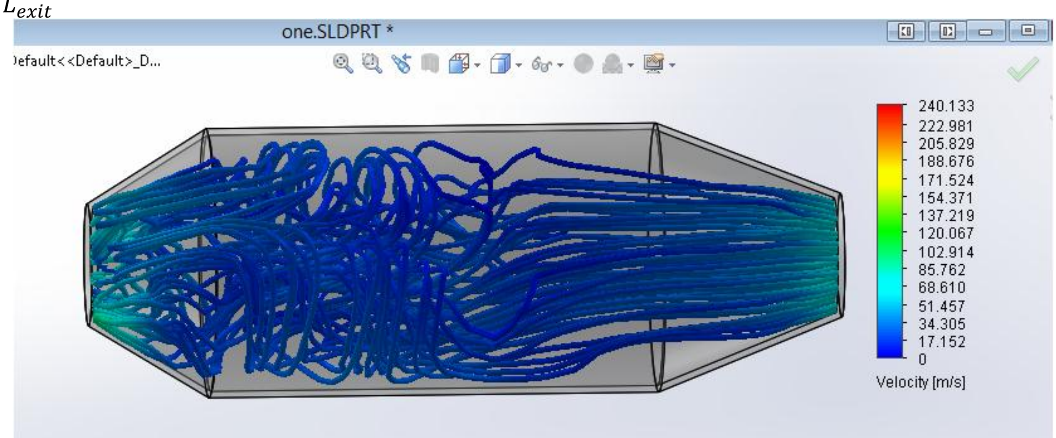

Fig 11. Steep tapper short exit cone and steep tapper inlet cone

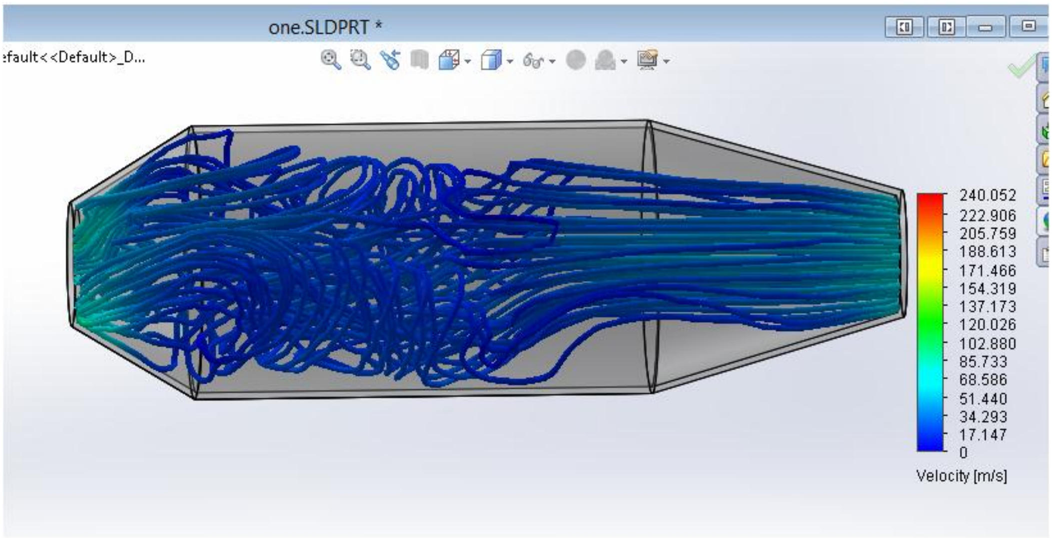

Fig12.Steep tapper short exit cone and steep tapper long inlet cone

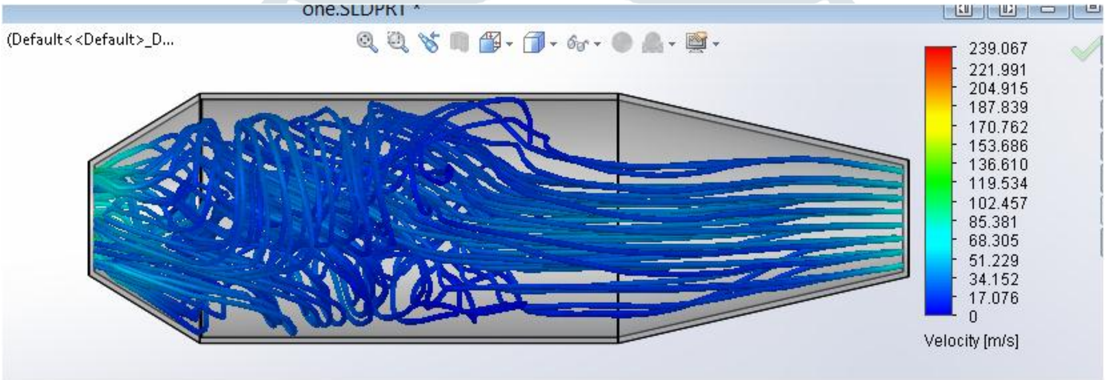

Fig.13. Steep tapper short exit cone and gentle tapper long inlet cone

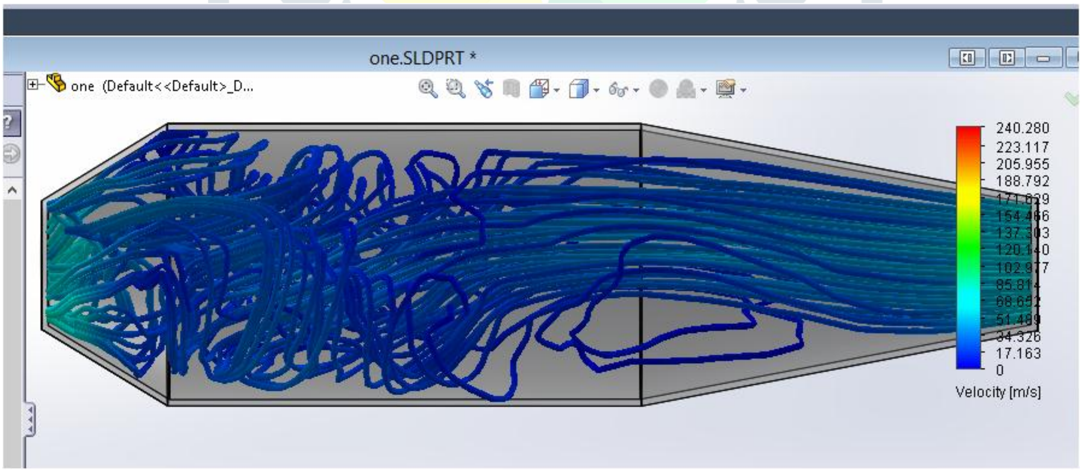

Fig.14 .Steep tapper short exit cone and gentle tapper long inlet cone

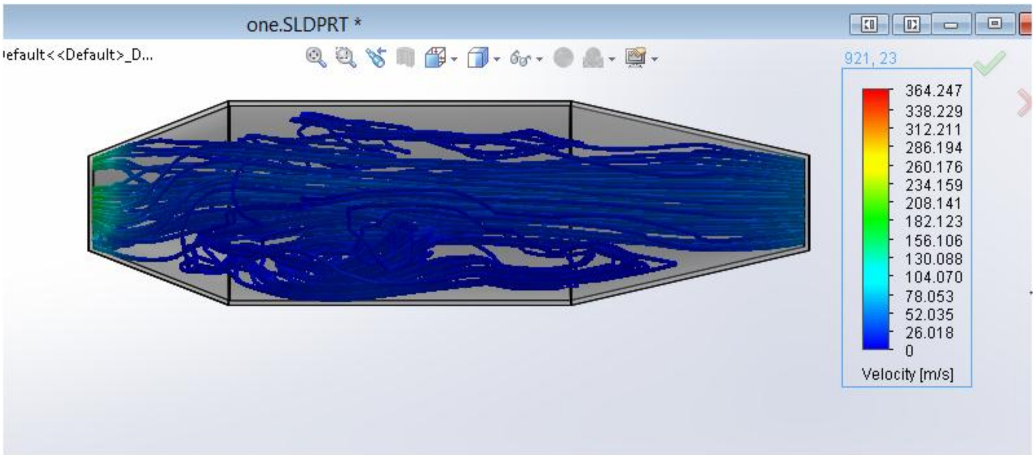

Fig.15.Steep tapper long exit cone and gentle tapper long inlet cone

3. when exit length greater than inlet length

$$L_{in} \neq L_{exit}$$

$$L_{exit} > L_{inlet}$$

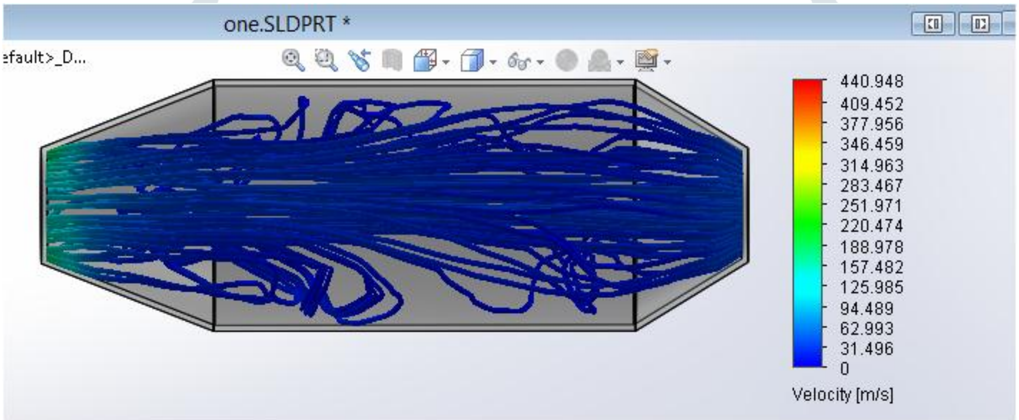

Fig 16. Steep tapper long exit cone and steep tapper short inlet cone

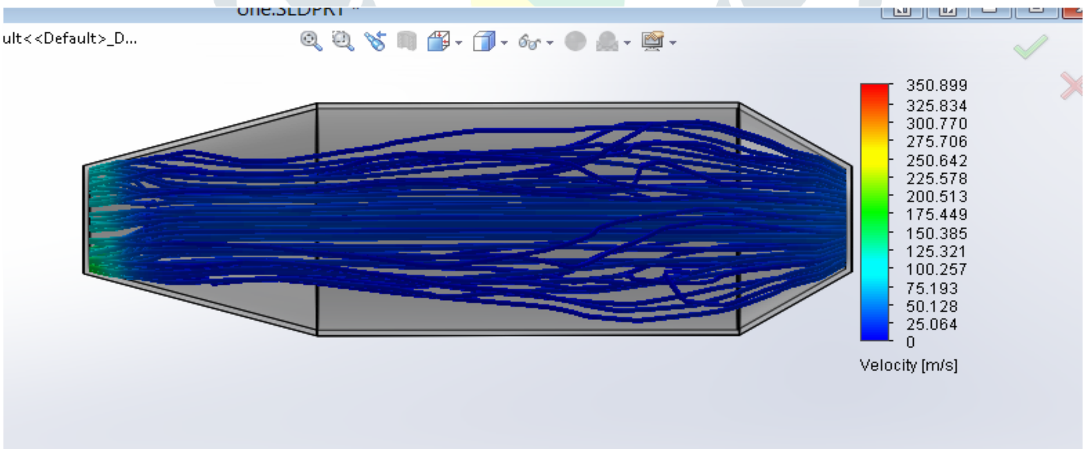

Fig 17. Steep tapper long exit cone and steep tapper short inlet cone

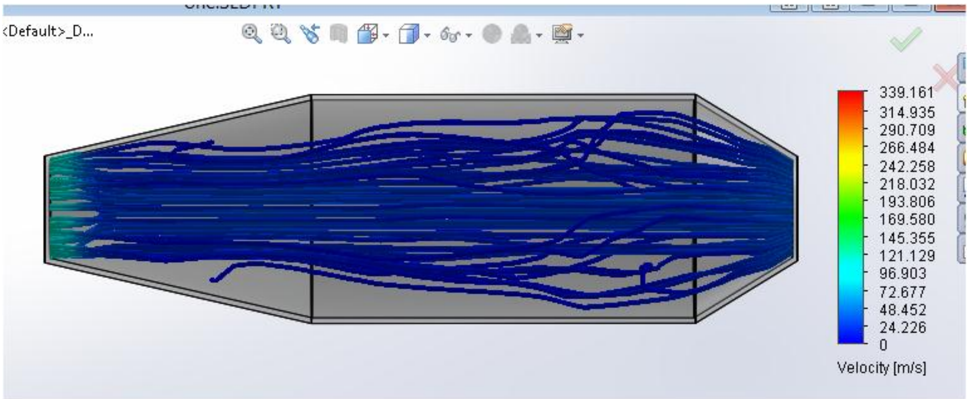

Fig 18. Gentle tapper long exit cone and gentle tapper short inlet cone

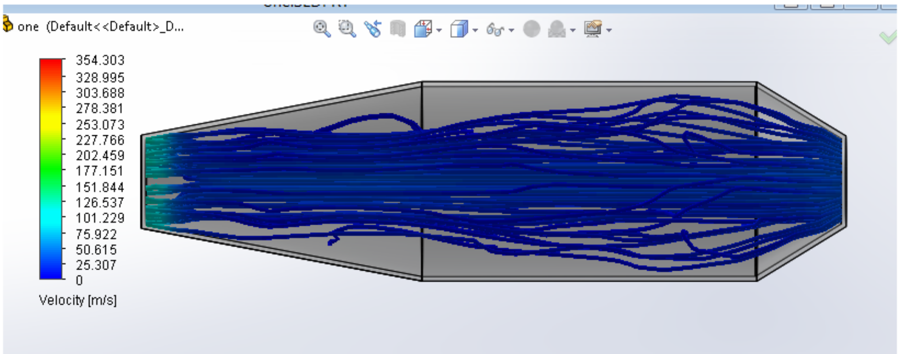

Fig 19. Gentle tapper long exit cone and gentle tapper short inlet cone

Establishing Ratios

The establishment of ratios between the exit and inlet cones will help in optimum geometry high performance in the rotary drum of the rotary furnace. From the simulations it shows that

$$\frac{L_{exit}}{L_{inlet}} \leq 1$$

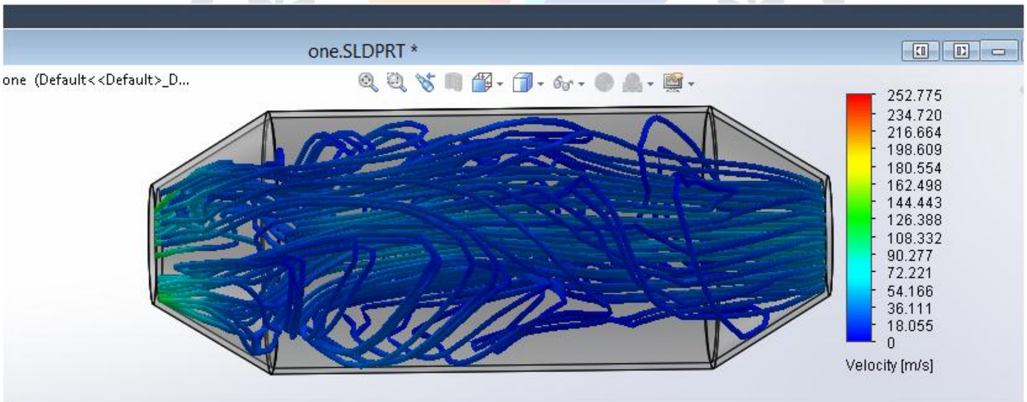

Fig 20. steep tapper with equal lengths

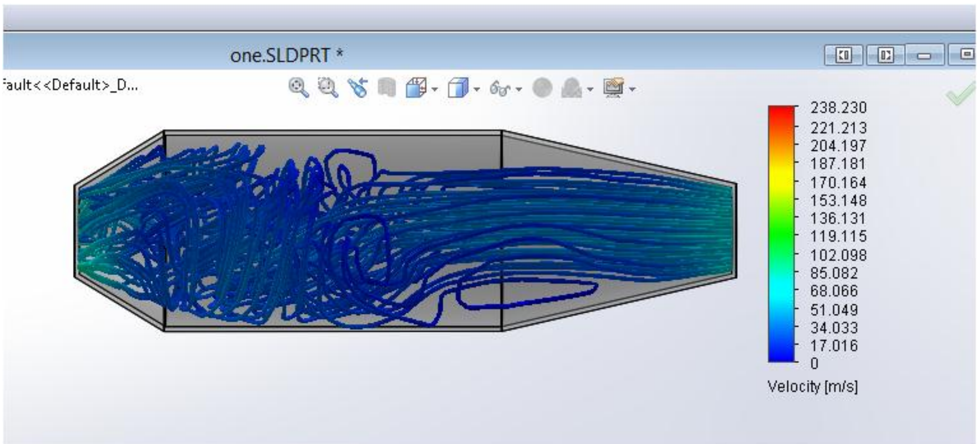

Fig 21.Steep tapper short exit cone and gentle tapper long inlet cone

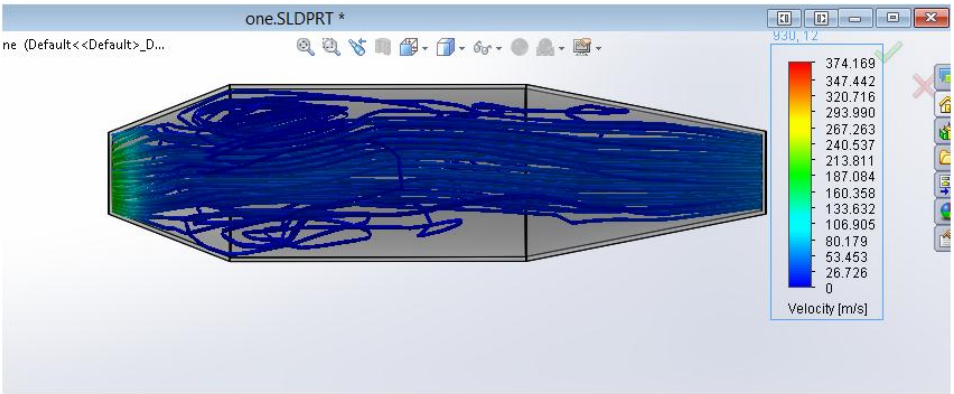

Fig 22.steep tapper long exit cone and gentle tapper long inlet cone

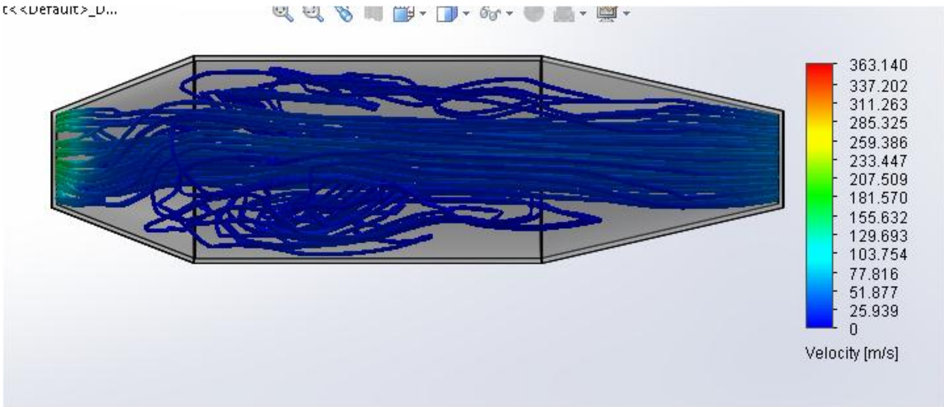

Fig 23. steep tapper long exit cone and gentle tapper longer inlet cone

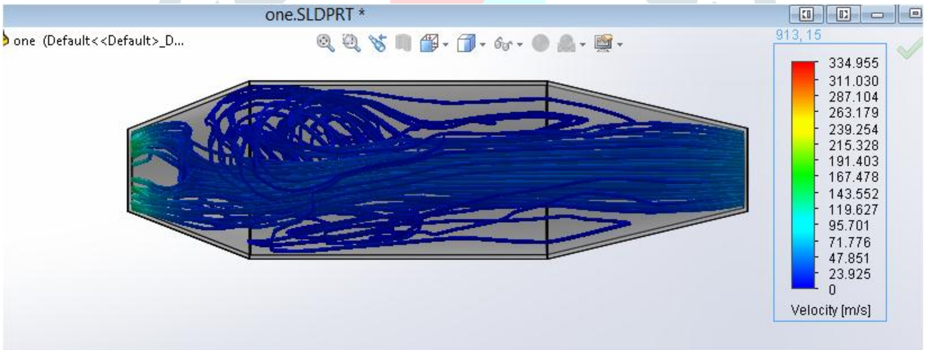

Fig.24.Steep tapper long exit cone and gentle tapper long inlet cone

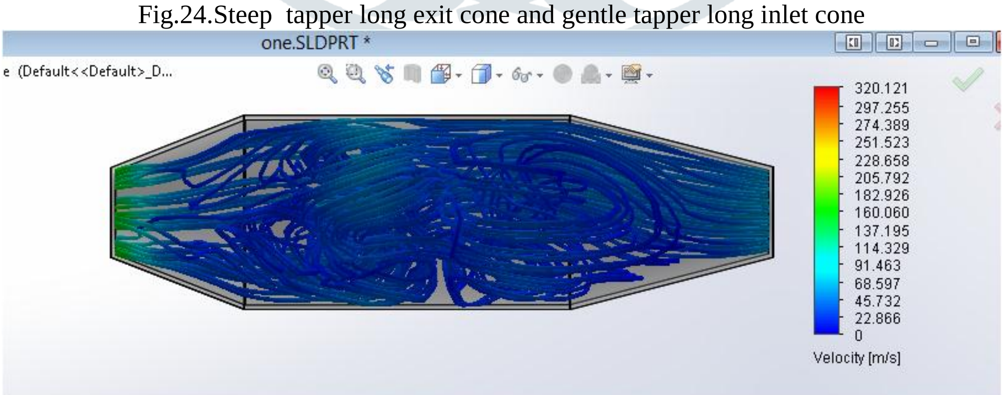

Fig 25. Steep tapper long exit cone and gentle tapper moderate inlet cone

From the velocity profiles studied the ratio suitable for lies between 0.58 and 0.65

$0.65 \leq \frac{L_{exit}}{L_{inlet}} \geq 0.58$

The ratios will be based on the volumetric capacity of the furnace having chosen the diameter of the cylinder and established the exit and inlet cones diameter, the flow characteristics are determine by the height (length) of the cones which are fuctions of their angle of tappers

X. Discussion

From the three categories of the models it is seen that the model where the exit cone is made greater than the inlet cone is not feasible because of the of the velocity profiles of the flow but making the two cone lengths and tapper angles equal as in model 1, has some appreciable pressure and air distribution, pressure is built with long gentle tapper inlet cone ,hence making the inlet cone length greater than the exit cone length favours good distribution of air and heat ,hence it is feasible in design . An exit cone length to inlet cone length of 0.65 to 0.58 ratios is established when the cylinder diameter ,the two cones external diameters are known and must be equal .

XI. Conclusion

Heat loss through exhaust of gaseous flue is enormous rotary furnaces . Quite a large number of rotary furnaces are found to perform below the expected capacity, most especially in terms of thermal efficiency, mainly because of non-standardization of designs and more often than not, non-inclusion of a heat exchanger .Stephen [2000]. Even in the heat exchangers there are loses and incorporating it in design has increase the furnace manufacturing cost as against it affordability. The loss of energy through exhaust gases is better tackled through good shape orientation that favours minimum pressure drop across the rotary drum, pressure built in the drum allow maximum heat utilization as the speed of flow is reduced across the drum. . An exit cone length to inlet cone length of 0.65 to 0.58 ratios is established for known cylinder diameter ,and the two cones external diameters which must be equal .

XII. Acknowledgement: we are thankful to National Agency For Science And Engineering Infrastructure –NASENI, Abuja,Nigeria for this rear privilege.

REFERENCES

[1] Agarwal, R.L., Banga, T.R. and Nanghnani, T. (1981) Foundry Engineering. Khanna Publishers India, New Delhi, 150-280

[2] Dryden, I.G.C. (1982). The Efficient Use of Energy. Butterworth, Surrey, England.

[3] Oyelami, A.T.; Oshodin, T.E.; Alasoluyi, J.O.; Olaniyan, O.O.; and Idowu A.S. (2003) Computational Modeling of a Rotary Furnace. Paper presented at the Nigerian Materials Congress 2003 at EMDI, Akure, Nigeria.

[4] Becker H. B., (1977)A Mathematical Solution for Gas-to-surface Radiative Exchange Area for a Rectangular Parallelopiped Enclosure Containing a Gray Medium, ASME, Journal of Heat Transfer, vol. 99, 1977.

[5] Gray W. A., Muller R., (1974)Engineering Calculations in Radiative Heat Transfer, Pergamon Press Ltd., Vol. 13, 1974, p. 1-75.

[6] Guruz H. K., Bac N., (1976),Mathematical Modeling of RotaryCement Kilns by the Zone Method, The Canadian Journal of ChemicalEngineering, Vol. 59, No. 4, 1976.

[7] Kreith F., (1976)Principles of Heat Transfer, IEP-A DUN-DONNELLEY, 3rd Edition, pp. 219-281, 1976.

[8] Patankar S. V., Spalding D. B., (1972), Mathematical Models of Fluid Flow and Transfer in Furnaces: A Review, Paper 2, 4th Symposium on Flames and Industry, 1972.

[9] Tucker R. J., (1986),Direct Exchange Areas for Calculating Radiation Transfer Rectangular Furnace, Journal of Heat Transfer, ASME, vol. 108, 1986, p. 707-710.

[10] Stephen, D.C (2000). Iron Melting Cupola Furnaces for the Small Foundry. Santillana, Jacksonville, FL, USA

[11] Jain R.K., Singh R, (2008)- “Modeling and optimization of rotary furnace parameters using Regression & Numerical Techniques” proc. 68th world Foundry Congress, Feb7-10, 2008, Chennai. Pp 178-185

[12] Riverin, G., Stevens, W., Bristol, D. and Kocaefe, Y. (1997) ‘Impact of good metal circulation and furnace operation for increased performances for sidewell furnace’, in Huglen, R. (Ed.): Light Metals 1997, TMS, Warrendale, PA, USA, pp.731–736.