Fibre insulation refractories in reheating furnaces

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Use of insulation in industrial furnaces results in considerable savings in fuel energy. Reheating of steels for rolling and forging consumes 8-10% of heat needed for the production of a ton of steel. Special insulating materials if used in building reheating furnace for example fibre blanket in tandem with mineral wool as the back up insulation the saving in heat energy is substantial as compared to conventional fireclay insulating bricks. The low thermal mass of fibre makes it specially attractive in making batch type forging furnaces. This paper reviews the recent developments in the use of fibre as the lining for reheating furnaces and focusses some of the combinations of insulating materials as the possible economic viable proposition in designing industrial furnaces.

Introduction

Reheating furnaces are the heart of a rolling and forging shop. Primary steel ingot in changing shapes into blooms, billets, bars, rods, slabs, plates, sheets, strips, rails, angles, channels and tubes has to be heated into pyroplastic stage at 1200—1320°C in a reheating furnace. The temperature is dependent upon the steel composition and rolling/forging technique. Hardy and Titterington[1] has dealt with the refractories of reheating furnaces. At this temperature enough iron oxide scale formation takes place due to which the hearth of the furnace has to bear the corrosive action of molten iron oxide and the walls, oxide atmosphere. In the heat treatment furnaces for annealing, normalising, hardening or stress relieving, the temperature is never more than 1020°C and is generally around 780°C. But unlike reheating furnaces the atmosphere is either reducing or neutral without any suspension of inorganic material. Except for its hearth which has to bear the load of the work pieces, all the walls and roof has to withstand and conserve the heat only. Industrial furnaces like ceramic glazing, biscuit firing, building brick making furnaces or even drying oven are to conserve heat only at service temperatures not exceeding 1200°C. Energy crisis has changed the thinking of furnace designers all over the world. Every possible care is taken to save heat energy to the maximum extent possible by means of insulation, regeneration, recuperation[2] and or using improved and newer refractories for furnace lining. Reheating furnace alone consumes 8 to 10% of heat needed for a ton of steel. Heat treatment and sintering processes also take substantial amount. Ceramic fibres have become a revolutionary new refractory lining in such industrial furnaces. During the last five years over 8000 industrial furnaces are lined with ceramic fibres in continental countries replacing conventional linings. Reason being fibres are only 3-10% in weight than brick. Its heat storage capacity is also hardly 15%. Besides it has high resilience, thermal shock resistance, good high temperature strength, low thermal shrinkage and easy manoeuvreability. This can be cut by ordinary scissors and processed into rope, sheet, braid, board, tamping mixes or castables in as many as 40 different forms. Unit weight varies between 4 to 12 pounds and thermal conductivity within 0.5 to 3 Btu/ft.^{2}/hr. Special zirconia base fibres can serve upto 1600°C. But the common aluminosilicate variety serves upto 1260°C. It is resistant to oil and steam in oxidising conditions. It cannot be wetted by molten zinc or aluminium. However it is not used in corrosive environment. As, once the fibres are wetted the low thermal mass property is lost. Fibre blankets can be easily set by unskilled workmen on furnace shell in only one fourth the time needed for normal brick lining by skilled workers. Alternatively furnace walls could be factory made and transported to job site. Use of such materials in heat treatment and other industrial furnaces judiciously could record saving in energy bill and time cycle. Particularly so in case of batch type intermittent heat treatment furnaces. Since the fibres are very light and have low heat storage capacity only one fourth number of burners are required in a furnace than normal brick lined industrial furnace. Ceramic fibre is not going to be used in steel reheating furnaces (except in enveloping water cooled skid rails) to minimise heat loss as the conditions prevailing is hostile to ceramic fibres. But for heat treatment furnaces nothing but insulation be used. Depending upon the temperature, mineral wool, fibre blanket, foam insulation and insulating brick in two or more combinations should be used. Highest economy will be gained by fibre blanket-wool combination. This paper records the properties of ceramic fibres from the available literature as a possible aid to industrial furnace designers. Methods of computing the wall thickness of a furnace of known working temperature is also given. To arrive at this the knowledge of thermal conductivity of the wall materials atleast at two mean temperatures are necessary.

Properties of fibre refractories

Refractory fibres are made by either blowing a molten mass or spinning a molten stream on a fast rotating disc[3]. These fibres have mean diameter of 2.8 microns and 10 inch in length[4]. The random arrangements of such fibres

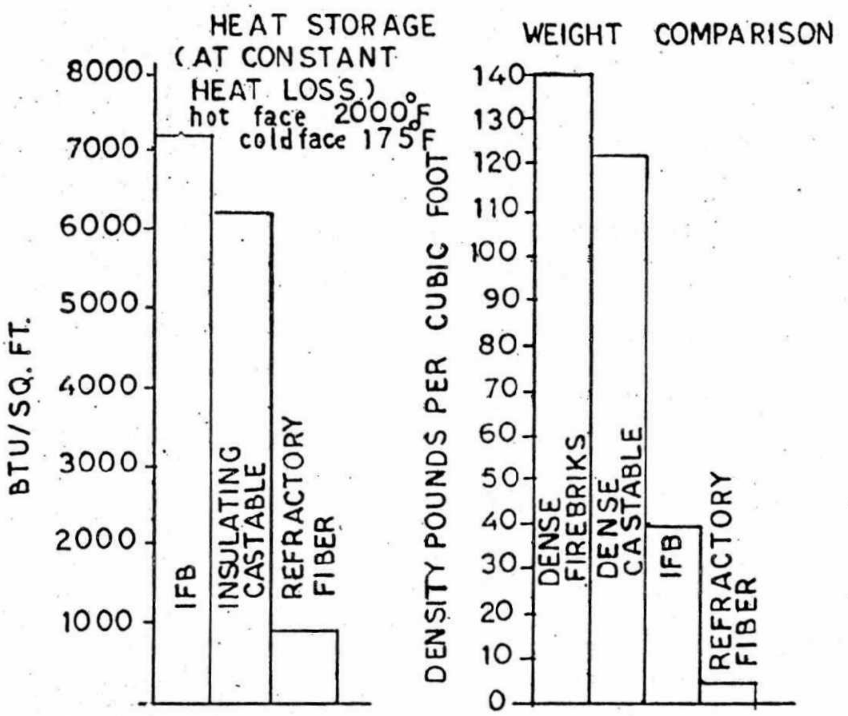
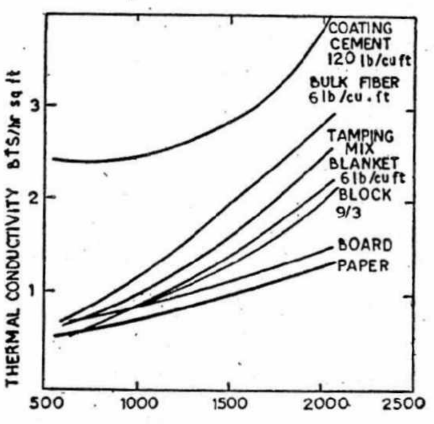
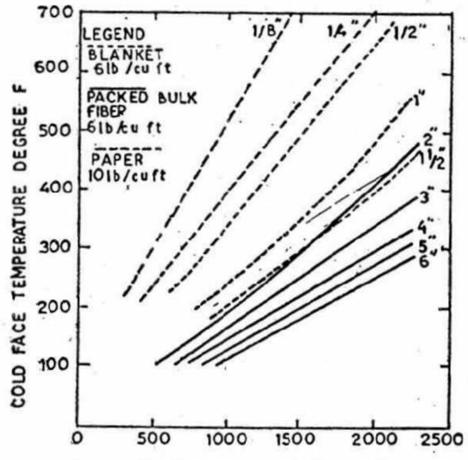


FIG. 1. COMPARATIVE PROPERTIES OF REFRACTORIES AND FIBERS



THERMAL CONDUCTIVITY OF VARIOUS FIBERS.

Fig. 2a



TEMPERATURE OF HOT AND COLD FACES OF VARIOUS DIMENSIONS OF FIBERS.

Fig. 2b

give it sufficient strength snd resilience. Its service temperature is a material constant. Silica, alumina-silicates, alumina[5] /zirconia fibres could serve upto 1000°C, 1400°C and 1600°C respectively. But the common alumino-silicate fibres serve upto 1260°C. Its chemical composition is shown in Table I. The

TABLE I

Chemical analysis of alumino-silicate fibres

Oxides	Parcentage
Al_2O_3	43 — 54
SiO_2	43.5 — 54
Fe_2O_3	0.6 — 1.8
TiO_2	0.1 — 3.5
CaO	0.1 — 1.0
Na_2O & K_2O	0.2 — 2.0
B_2O_3	0.08 — 1.2

alumina fibres are 95% Al_2O_3 the rest are SiO_2. Zirconia fibres likewise contain 8% Y_2O_3. Small amounts of MgO, ZrO_2 and trace amounts of other oxides are added to impart improved thermal and mechanical properties to the fibres. Its thermal conductivity varies between .5 to .3 BTU/ft²/inch depending upon the thickness and temperature. The service temperature of the fibres could be enhanced by changing the ratio of the oxides upto 1600°C. X-ray studies however has shown that fibres devitrify[6] beyond 850°C. This change is nominal upto 1260°C and considerable above that temperature [7,8,9]. Devitrified fibres retain insulating properties alright but some of their thermal shock resistance, thermal stress, erosion and vibration resistance are lowered. The testing of fibres is given by Wisnosky[10]. Fibres like metals are anisotropic[11] in nature. Table II shows the difference in thermal conductivity in normal and parallel directions of fibres. As a reference mention should be made to the heat transfer of insulating refractory materials through its pores[12]. It is seen large pores produce high conductivity by increasing the radiative heat transfer. This heat loss can be very approximately related mathematically as

$$qr = \frac{AdT^3}{(2/E)-1}$$

where qr = relative heat transfer per unit area
A = Constant
d = pore diameter
T = working temperature
E = Emissivity

Fibres now number in over forty forms, like bulk fibres, paper, sheet, net, rope, braid, blanket, felt, board, laminates, tamping mixes and castables. Besides all these what makes refractory fibres more versatile is their light weight and low thermal capacity. It weighs only 3% as compared to dense fire brick and 10% than that of an insulating fire brick. Secondly the heat capacity is only 15% of an insulating fire brick. Fig. I and Table III shows[13] the comparative data of fibres with other refractories. Fig. 2a shows the thermal conductivity of various forms of fibres and 2 (b) shows the hot and

TABLE II

Thermal conductivity of anisotropic materials

Materials	Density gm/cc	Thermal conductivity CGS Normal to fibre	Parallel to fibre
Flax	0.155	0.268	0.861
Glasswool	0.567	0.266	0.527

TABLE III

Relative properties of fibres and other refractories

Materials	Specific heat cal/gm °C	Typical Density Kg/m³	Heat capacity cal/m³ °C
Saffil Zirconia	0.14	96	14
Saffil alumina	0.25	96	24
Insulating firebrick	0.23	650	150
Dense firebrick	0.22	2000	440

cold face temperature of various fibres. The shrinkage[14] behaviour of fibres is shown in Fig. 3a. Fig. 4a gives a comprehensive heat storage at a constant heat loss of 285 BTU/ft/hr. It is understandable that higher the cold face temperature higher the heat loss. Normally 12″ lining of castable refractory results in loss of 520 BTU/ft/hr, with a hot and cold face temperature of 2000 and 275°F. A new 3″ fibre lining to the above lining for the same service temperature lowers the heat loss, heat storage and surface temperature. This is shown in Fig. 4a. Fig. 5 shows the advantage of fibre lining in a furnace over fire brick and insulating fire brick. The economics are as clear as the dimensions in the figure.

Ease of installation

The fibre bankets are very easy to instal. The blankets are available in 2′ x 24′ in length and thickness from ½″ to 4″. These can be cut by ordinary scissors. This is fastened to the metal

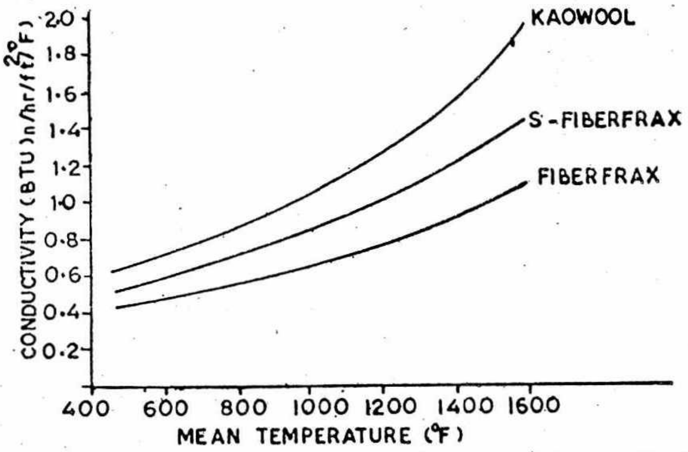


FIG 3 b THERMAL CONDUCTIVITY FOR 6 P C F BLANKET AND FELT.

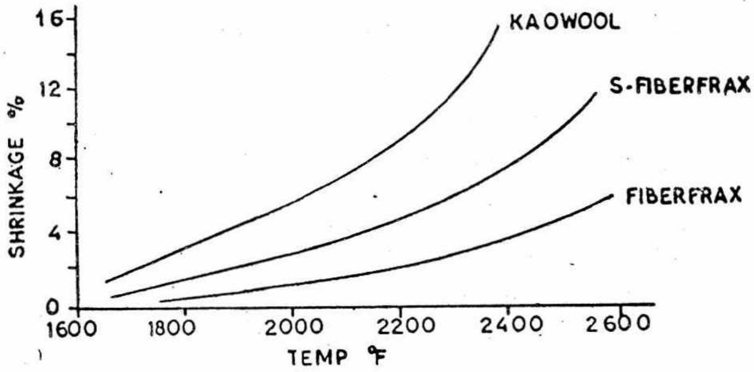


FIG 3 a THERMAL SHRINKAGE AFTER HEAT TREATMENT FOR 24 Hrs OF BLANKET AND FELT.

shell with 601 inconel studes or ASTM 301 stainless steel studs (25% Cr, 20% Ni). For low temperature service, fasteners Fig. 6 are used. But for high temperature ceramic cups Fig. 7 are used. The space in the cups is filled by fibre tamping mixture. Another method of fibre blanket lining is Z-block system[15] in which no fastener is exposed. Yes it is very compact and durable than others.

In conventional brick lining practice of an industrial furnace, three weeks are needed to reline it, whereas a fibre wool lining takes only 5 days for the same job. Industrial economy is time and availability of a furnace. Ceramic fibres is a fitting answer to both of these. Fibres are amendable to localised repair also. A worn out portion of a furnace could be patched by fibre blanket with an additive which set the fibre in place.

Modern trend in fibre furnace design

It is already seen that higher mass

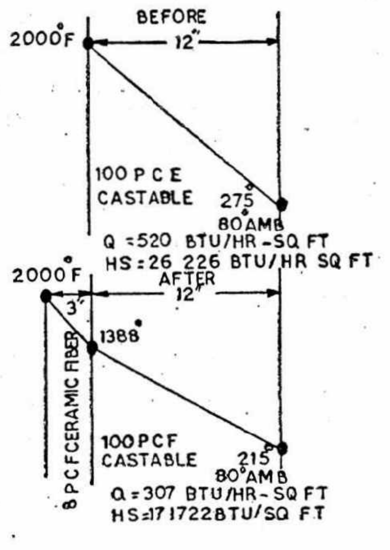


FIG 4 (a) EFFECT OF CERAMIC FIBER ON HEAT LOSS AND HEAT STORAGE

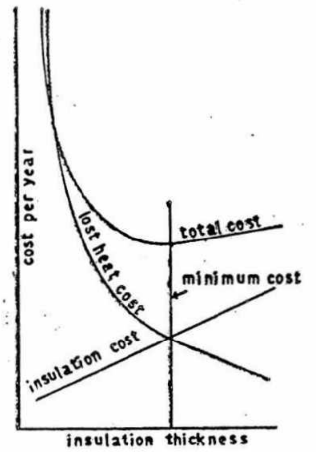


FIG 4 (b) ECONOMIC THICKNESS OF INSULATION

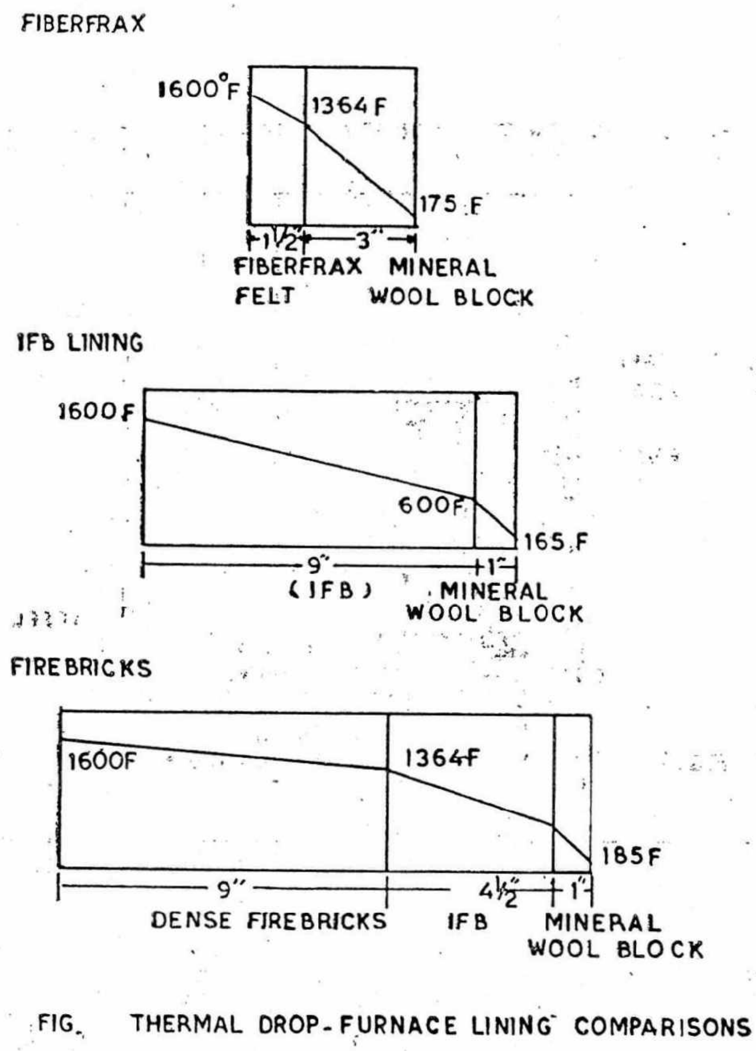


FIG. THERMAL DROP-FURNACE LINING COMPARISONS

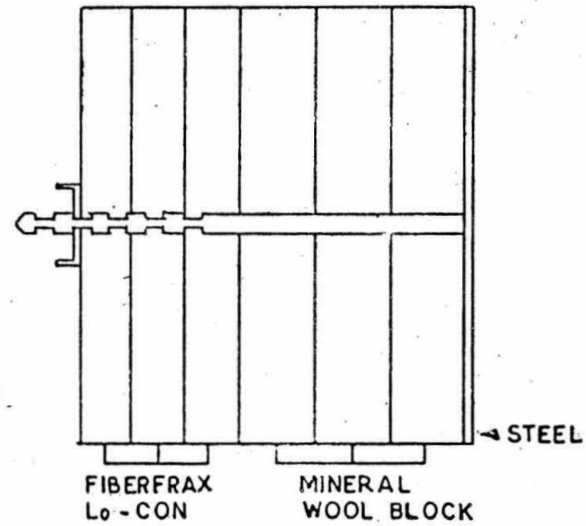


FIG 6 INSULTWIST ANCHORING SYSTEM

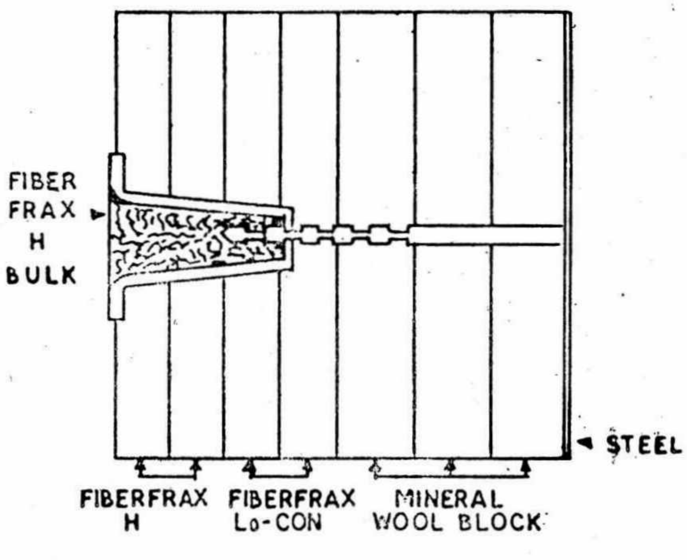


FIG. 7. CUPLOCK ANCHORING SYSTEM

(i. e. high thermal capacity) and volume (larger radiative surface) means greater energy loss.. The modern trend in designing furnaces has been lighter, thiner and campact structure. It is the fibre refractories which has filled engineers need. Report shows[16] an existing 14 ton cooling hood comprising metal shell, 4½″ of firaeclay facing bricks and 9″ of back up insulating brick has been reduced to only 2400kg; all inclusive, with one inch of fibre lining and a back up of 7″ of mineral wool. Resilience, flexibility and low thermal shrinkage of fibre refractories has made it possible to fabricate individual wall of a furnace at the factory[17] (without expansion joints) and then assembling it at the service site; instead of conventional practice of making the heavier furnace shell fast and then lining it at site. Preformed castable lining of water cooled skid rails gives rise to loss of 10,000 BTU/ft²/hr. The latest innovation[18] has been the fibre blanket lining of the skids first and then castable enveloping. This system results only loss of 3600 BTU/ft²/hr over the same work performances.

Heat transfer through furnace walls

Adiutori [19,20] has given the latest formulae on heat transfer. He has given a relation which could be applied equally for conduction, convection and radiation. Heat transfers have been taken as transport processes and are given by

$q = f_1$ (system properties) x f_2 (Temperature i. e. the driving force)

This looks analogus to Fourliers equation on heat transfer.

$$hq = \frac{(Tl-Tn+l)}{\sum_{i}^{n} \frac{Y_i}{K_i}} \quad \text{....... (1)}$$

Where T is the phase temperature, Y the wall thickness and K the respective thermal conductivity. The forced convection is given by $Nu = .023\ Re^{0.8}\ Pr^{0.8}$ where Nu, Re & Pr are Nurst, Renolds and Prends numbers respectively. But Adiutori relates this heat transfer, with a third power relation taking into account the effect of other variables on temperature. Other workers [21,22] have also dealt with heat transfer through walls. But as Adiutori professes, "Supposing is good, but finding out is better", a practical method of computing the lining thickness is given[23].

Computation of furnace wall thickness

Every refractory including insulating materials has a characteristic linear relation between its thermal conductivity k, and mean temperature, t_m i. e.

$$K = mt_m + b \quad \text{... (2)}$$

Where m is slope and b the intrecept at t_m=O. Therefore if the thermal conductivity of a refractory brick/material over two mean temperatures are determined the line is generated and its intercept with k axis gives b as well.

From equation I, $h = K \frac{dt}{dy}$

Integration over the entire thickness,

O to L and hot and cold face temperatures t_h and t_c

$$hdy = [mt_m + b]dt$$

$$\text{ie } HL = \frac{m}{2}(t_h^2 - t_c^2) + b(t_h - t_c)$$

Rewriting for L

$$L = \frac{m}{2H}\left(t_h + t_c + \frac{2b}{m}\right)(t_h - t_c) \qquad \ldots\ldots (3)$$

The heat flow from the outer surface of the walls of a furnace to the surrounding ambient air is known as the emissivity, E. This E by a modified Stefan Boltzman law is given by

$$E = 0.155\left[\frac{(To+460)^4}{100} - (Ta+460)^4\right] + 0.25\,(To - Ta)^{5/4} \qquad \ldots. (4)$$

Where,

To = temp of the outer wall surface in °F

Ta = temp of the ambient air in °F

Therefore either by knowing the emmisivity of the outer wall or by calculating it from equation 4 the optimum thickness L could be ascertained from relation 3.

Conclusions

The foregoing pictures show that amongst all refractories fibre-blanket and fibre wool combination is the best economic combination for industrial furnace wall and roof linings for service upto 1250°C. However, the hearth has to be of solid refractories. In case of reheating furnaces high alumina refractories are most suitable as is evident from literature[1]. The best however is hanging castable roof block and hearth of fusion cast high alumina refractories. The condition prevailing in steel reheating furnaces is more severe than ceramic fibre could with stand and in heat treatment furnaces, non-ferrous process furnaces (like magnesium, zinc) and ceramic furnace conditions are akin to it. Ceramic fibre lining should be used in such furnaces. At present fibre blankets are not manufactured in India and it is opportune time for the local entrepreneurs to start manufacturing it. As a close approximation to ceramic fibres; insulation of foam type or 70% +porosity good quality insulating brick be used. The appropriate furnace thickness could be calculated from the relations 3 & 4.

Acknowledgement

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