Choice Of Ceramic Fibre Insulation In Magnetohydrodynamics Systems

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64. CHOICE OF CERAMIC FIBRE INSULATION IN MAGNETO HYDRO DYNAMICS SYSTEMS.

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Abstract

Ceramic fibre is one of the latest products of ceramics possessing unique high temperature properties for thermal insulation. Generally, the fibres are amorphous in structure and have 2-3 microns diameter with average length of nearly 100 microns. By suitable interlocking of these fibres and forming techniques, wide range of products such as blankets, felts, boards, ropes, papers, vacuum cast products etc. are being manufactured. They possess very low thermal conductivity at elevated temperatures, low heat storage, light weight, good thermal shock resistance, good sound absorbing capacity, good dielectric strength etc which are some of the properties required for thermal insulation in MHD systems. This paper describes the advantages of ceramic fibres when compared with brittle ceramic materials for improved efficiency of MHD power generation and fuel economy.

Introduction

The energy crisis in early seventies has brought with it significant increase in energy costs. Energy in the form of electricity, coal, natural or coal gas, furnace oil, etc is the basic input to generate higher temperatures. It was realised that the conservation of thermal input for the processing is one of the necessary steps to achieve higher fuel economy and reduced consumption of fast depleting natural resources. The fuel input in general is converted to heat energy for the processing which needs efficient management by preventing the loss of high quality heat to surroundings especially for high temperature contexts.1

Magneto Hydro Dynamics

Magneto Hydro Dyamics is one of the latest processes of energy conversion in which thermal energy is directly converted to electrical energy by the interaction of magnetic field on the conducting plasma. MHD power generation requires very high temperatures around 2800 - 3000° K. The heat losses due to conduction, convection and radiation are considerably increased at these temperatures resulting in the reduction of peak temperature and electrical conductivity of plasma. Therefore, additional fuel is required to compensate the heat losses so that the electrical power output can be optimised. In order to achieve higher efficiencies of MHD power generation, the thermal input should be conserved by decreasing wasteful dissipation of heat to the surroundings or to cooling water by suitably installing thermal insulators on the inner surfaces of the metallic shell of air preheaters, hot air duct, combustors, MHD channel, high temperature valves, etc. 2

High Temperature Thermal Insulators

It is well known[3] that no thermal insulator is able to completely stop the flow of energy from higher to lower temperature bodies. However, they reduce energy transfer through the walls limiting the wasteful dissipation of heat. The greater the thickness of insulation, the smaller is the heat loss. However, by increasing the thickness of insulation, the cost of insulation materials will increase proportionately whereas the cost due to heat losses is considerably increased at lower thickness of insulation and there is a marginal saving of cost due to heat losses at higher thickness insulation. Fig. 1 gives the optimum thickness of thermal insulation based on the total cost.

The properties of thermal insulation which influence its effectiveness to retard heat transfer are (1) conductivity, (2) diffusivity, (3) emissivity (4) specific heat, and (5) density. The solid conduction through the material forming insulation which depends on the thermal conductivity and temperature, radiation transfer from solid to solid through voids which depends on emissivity and fourth power of temperature and convection by air or gas within the voids which depends on temperature. The total heat loss per unit area per unit time can be represented by

$$Q = Q_c + Q_r + Q_v$$

$$= k \frac{t_1 - t_2}{l} + C_1 e (T_1^4 - T_2^4) + C_2 (t_1 - t_2)^{5/4}$$

where Q_c = Heat loss due to conduction

Q_r = Heat loss due to radiation

Q_v = Heat loss due to convection

t_1 = higher temperature ($^oC/^oF$)

t_2 = lower temperature ($^oC/^oF$)

T_1 & T_2 = Absolute temperature

e = emissivity

l = thickness of insulation

C_1 & C_2 = Constants

Though conventional ceramics[4] possess acceptable properties for high temperature thermal insulation they have high bulk density, high thermal conductivity and absorbs the heat input. Further, they are brittle and fail under tensile and shear stresses. Therefore, the rate of heating and cooling are to be controlled so that minimum thermal stresses occur in the materials. In general, natural cooling from high temperatures produces tensile stresses on ceramics resulting in crack formation and propagation leading to failure. Thus, their service life is restricted on account of mechanical properties. These problems are mitigated by the recent introduction of ceramic fibres, blankets, boards, vacuum cast products, ropes, papers, etc. which are fibrous in nature and have good mechanical properties for severe thermal environments. Magneto Hydro Dynamics (MHD) Project at Tiruchirapalli is designed with some of the modern thermal insulators for heat conservation.

Ceramic Fibre Products

Ceramic fibres containing 95% Alumina are available upto the service temperature of 1600° C. For special applications such as MHD, Zirconia fibres are available upto the service temperature of 2000° C. The fibrization process differs from manufacturer to manufacturer, but generally consists of pouring a stream of molten alumino silicate at 2300° K onto spinning rotors or in front of a high pressure stream of air or steam. Both techniques, spinning and blowing have the effect of breaking up the stream into droplets and imparting high acceleration to droplets causing them to attenuate into fibres. The silica in the molten bath increases the viscosity and allows fibre as blown to keep their form. Most of the unfibrized particles or "Shots" are removed in washing operation. The fibre is amorphous in structure and the service temperature is limited to the devitrification temperature above which it shrinks, becomes brittle and loses resilience. The fibres are cross locked through a unique forming process without binder to produce a blanket with adequate handling strength. The hot board is a refractory bonded rigid insulation processed and dried on special insulating block equipment. It can be used as hot face refractory where it is fixed over ceramic studs to provide high strength lining, resistance to high gas velocity and mechanical stress. Its high modules of rupture as received and after firing (3-4 Kg/cm^2) makes it an ideal material for use in thermal areas experiencing vibration. The vacuum cast parts are produced by dewatering a slurry of bulk ceramic fibres and special high temperature binders. This manufacturing method permits considerable freedom to vary shape, thickness, density and hardness.

Some of the outstanding properties of ceramic fibres are :-

(a) Low thermal conductivity

(b) Low heat storage - upto 1/10 of insulation brick

(c) Light weight - 1/4 of insulation brick

(d) High temperature stability

(e) Resiliency

(f) Thermal shock resistance

(g) High heat reflectance

(h) Good dielectric strength

(i) No curing or drying required after installation

(j) Excellent corrosion resistance

(k) can be easily installed

(l) can be used in expansion gaps and flange joints

(m) Good vibration damping capacity

The thermal conductivity as a function of temperature for hot ceramic fibre board, ceramic fibre blanket/felt, insulation fire brick and mineral wool is given in Fig. 2. The corresponding wall thickness for the composite thermal lining indicating heat losses, heat storage, weight of materials are shown in Fig. 3. The sound absorption coefficient upto 6000 Hertz is given in Fig.4. It is seen that 70-90% of the noise created by the burners, nozzles, etc. can be arrested resulting in extremely quiet operation. Some of the other useful properties of ceramic fibres are given in Table 1. The performance of Alumina ceramic fibre in comparison with conventional thermal insulators is given in Fig.6.

Application in MHD System

Ceramic fibres are expected to be highly useful in the attempts to achieve improved economics on fuel consumption and better efficiency in MHD power generation. The low thermal conductivity offers thinner insulating walls compared to conventional brittle ceramics making the design more compact for the same thermal input. For the same inner temperature, dense fire brick lining weights 564 Kg/m^2, and insulating fire brick weighs 149 Kg/m^2 in comparison with ceramic fibre weight of 21 Kg/m^2. The light weight feature of ceramic fibres makes foundation work easier with a lesser steel consumption. On account of low heat absorption by ceramic fibres, the system can be heated up and cooled down within short time without fear of thermal damage. The temperatures can be controlled with improved accuracy as the ceramic fibres decreases heat storage within the lining. It has been estimated that ceramic fibres can give reduction in heat losses to the extent of 30% compared to conventional ceramics.

In MHD Plant at Tiruchirapalli, India, ceramic fibre blankets and boards are used in air preheaters[6,7] and hot air duct to study their performance in comparison with conventional ceramics. The expansion joints in ceramics are provided with compressible ceramic fibres to allow free expansion of refractories. The flange joints are filled with ceramic fibres to insulate the flanges so that conventional low temperature gaskets (asbestos or silicon rubber) can be used to prevent the leakage of combustion products. A new design of hot air duct operating at 1600^{o} C has been conceived with hot boards ceramic fibre blankets and mineral wool to replace the existing design with conventional ceramics. This will provide considerable reduction in heat losses and weight of the duct. In addition, expansion bellows can be eliminated from the system. The details of interface temperatures are given in Fig.5. By incorporating ceramic fibre insulation in air preheaters, the heat losses and weight can be minimised. It is expected that there will be a net fuel saving of 10-15% by incorporating ceramic fibre lining in air preheaters and hot air duct. In addition, for Hall potential isolation near the main combustor, ceramic fibre hot boards and blankets can be used without water cooling. The dielectric strength of ceramic fibre is around 3000 v/mm. The vibration in main combustor and air preheater combustors can be absorbed to the extent of 70-90% using ceramic fibre hot boards as back up insulation. Presently ceramic fibre products are available based on alumina upto a maximum service temperature of 1600^{o} C. For special applications, Zirconia fibres are being manufactured in small quantities which can have higher service temperature of 2000^{o} C. This will be very useful for lining MHD combustors and channel which are operated at 2800^{o} K - 3000^{o} K. This installation not only reduces heat losses but also absorbs acoustic vibration to the maximum extent.

Summary

The ceramic fibre insulation in MHD systems increases the efficiency of MHD power generation by conserving the thermal input. These fibres are

already used extensively in furnaces, process industries and iron and steel industries to save fuel to the extent of 20-25%. They are also used as fibre wall modules on existing refractory lining to limit heat losses and heat absorption so that lesser fuel is consumed for the same temperature of operation. In addition, they can be very easily installed in position even in complicated profiles like MHD flow train so that maintenance time can be considerably reduced. Any special shapes or blocks can be easily formed with ceramic fibre and a modular approach to thermal lining can be incorporated in the design for ease of maintenance. Extensive use of such high temperature insulators in diversified applications will substantially bring down the cost of materials on account of large scale consumption.

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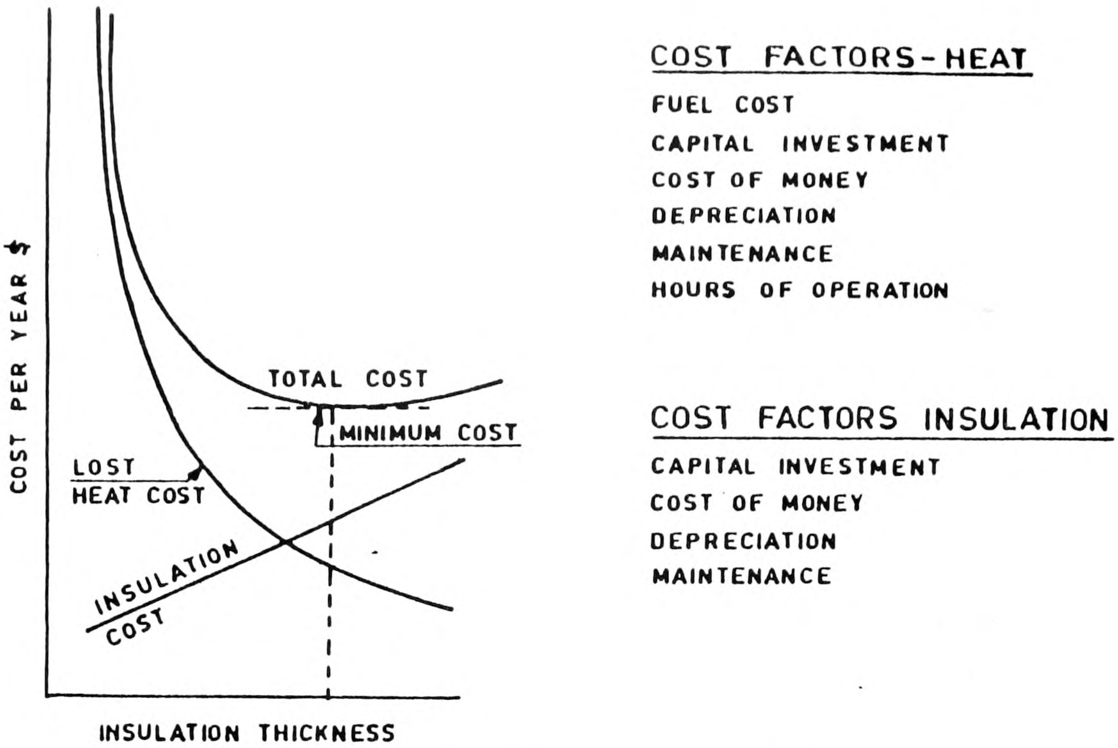
TABLE I

PROPERTIES OF CERAMIC FIBRES

Sl. No.	Particulars	Grade 1260° C	Grade 1400° C	Grade 1600° C
1.	Chemical analysis (%)			
	Al_2O_3	43-47	52-56	74-75
	SiO_2	53-57	44-48	18-19
2.	Fibre Diameter (microns)	2-3	2-3	2-3
3.	Fibre Length (microns)	100	100	100
4.	Density Kg/cm^3 (Boards)	250	225	200
5.	Thermal Conductivity ((W/mk) at 600° C)	0.113	0.102	0.079
6.	Melting Point (° C)	1760	1825	2000
7.	Specific Heat Capacity ((KJ/KGK) at 980° C)	1.07	1.07	1.13
8.	Fibre Tensile Strength (MPa)	1400	1400	--
9.	Youngs Modulus (MPa)	1.2×10^5	1.2×10^5	--
10.	Hardwares (Moh's scale)	6	6	6
11.	Dielectric Strength (KV/mm)	3.3	--	--
12.	Sound Absorption Coefficient (1000 - 6000 Hertz)	0.75-0.9	0.75-0.9	0.75-0.9
13.	Specific Gravity (ASTM C.135)	2.56	2.70	3.3
14.	Colour	White	White	White



FIG·1·ECONOMIC THICKNESS OF INSULATION

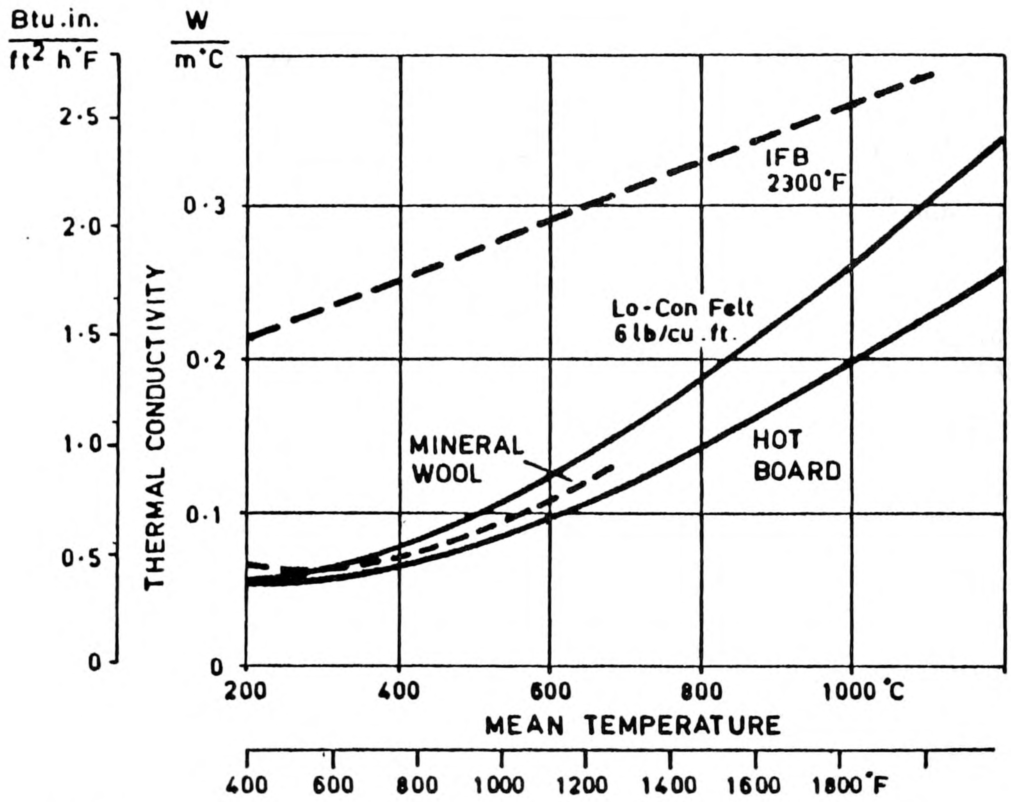


FIG: 2 FIBERWALL INSULATIONS THERMAL CONDUCTIVITY VS MEAN TEMPERATURE PER ASTM C177-63

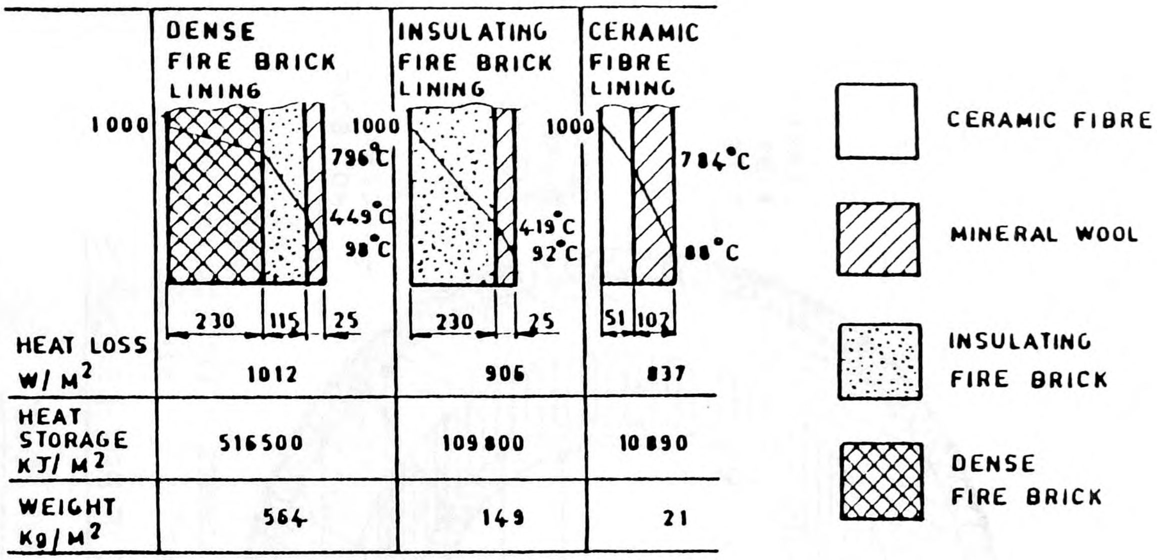


FIG. 3 CERAMIC FIBRE LINING COMPARED TO OTHER WALL CONSTRUCTIONS FOR EQUIVALENT HOT FACE TEMPERATURE

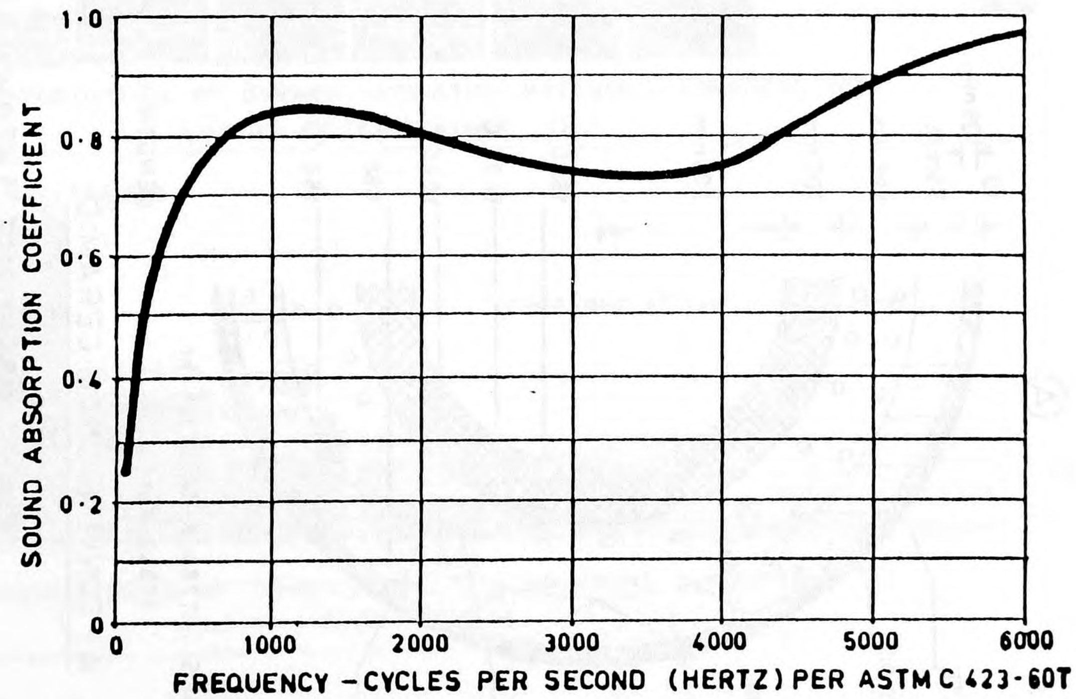
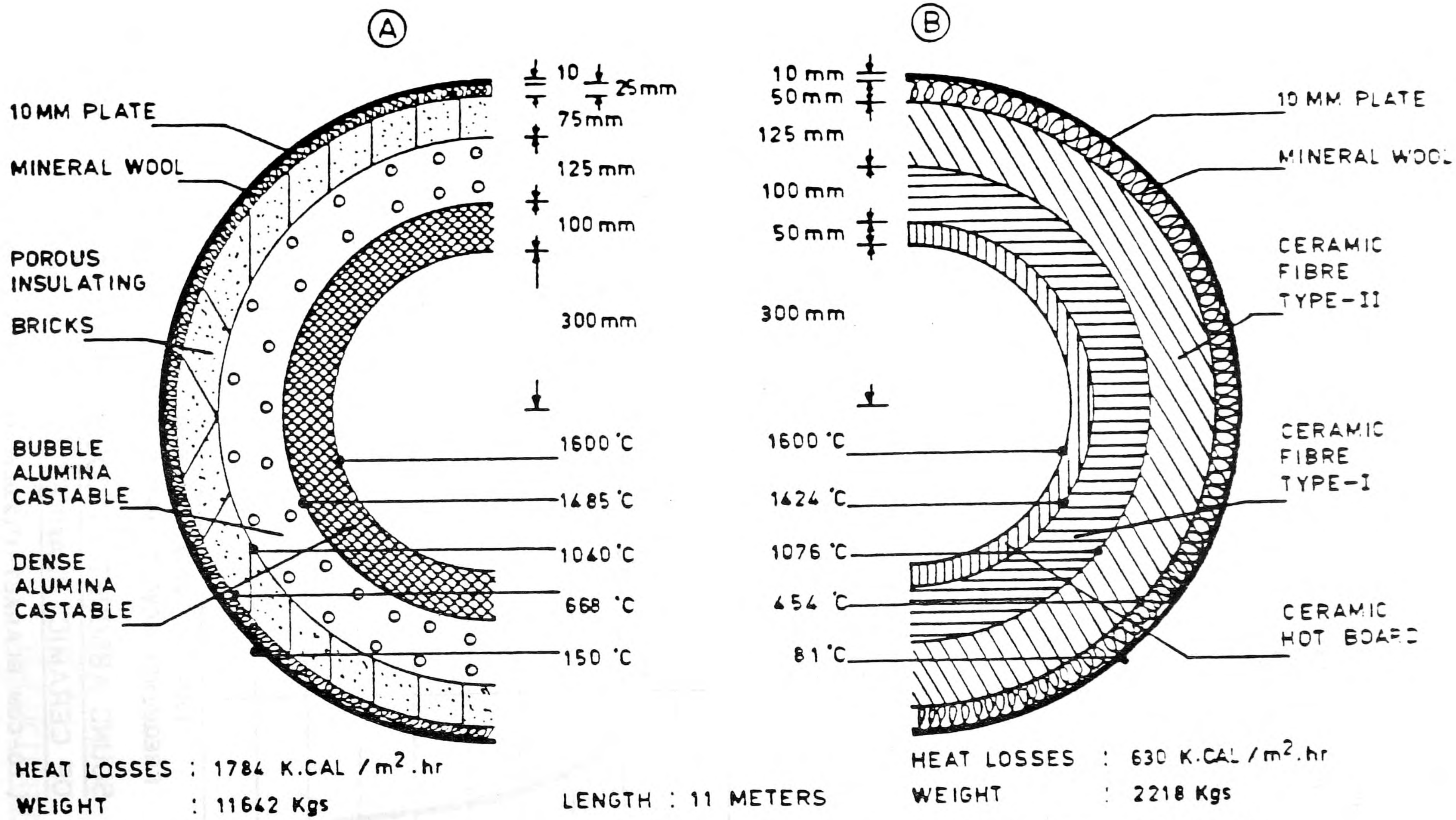


FIG: 4 SOUND ABSORPTION COEFFICIENT VS FREQUENCY OF CERAMIC BLANKET (LO-CON BLANKET – 1" (25mm)

(LO-CON BLANKET – 1" (25mm) THICK 6 lb/cu.ft. (96 kg/m^3))



A-CONVENTIONAL CERAMIC

B- CERAMIC FIBRE PRODUCTS

FIG: 5 COMPOSITE THERMAL LINING OF HOT AIR DUCT

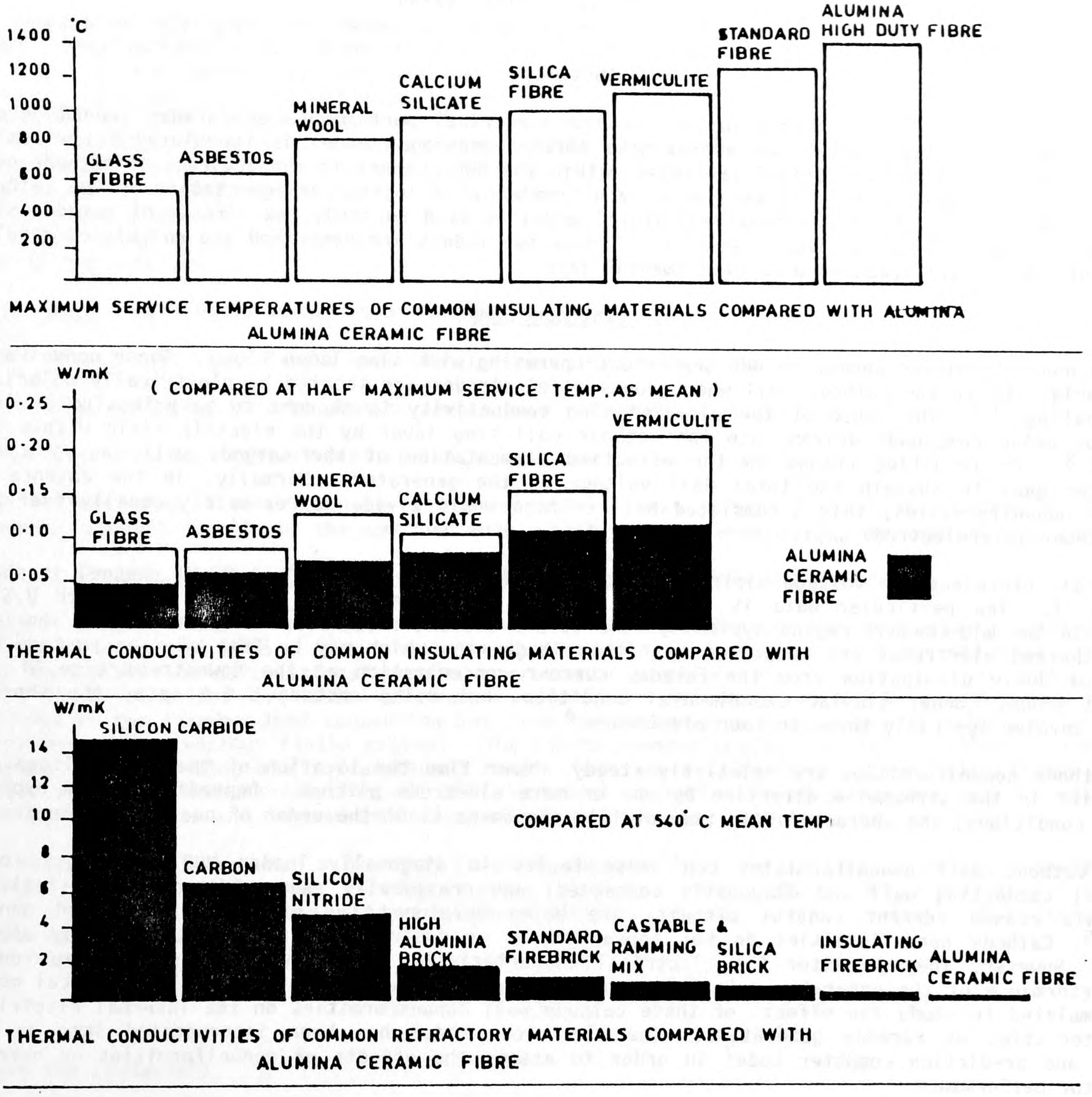


FIG 6 : PERFORMANCE OF ALUMINA CERAMIC FIBRE IN COMPARISION WITH CONVENTIONAL THERMAL INSULATORS