INSULATING REFRACTORIES

Insulating refractories are thermal barriers that keep heat and save energy. Furnaces used for melting, heat treatment, heat regeneration or for any other purpose demand maximum heat conservation so as to minimize heat losses for maximum heat efficiencies. As the cost of energy has increased, the role of insulating refractories has become more important. The use of considerable quantity of refractories is socially and economically justified. With today's energy costs at such higher levels has come the development of a wide range of new *insulating refractory materials* and technology of *high-temperature insulation*.

The function of insulating refractory is to reduce the rate of heat flow (heat loss). Although it is not possible to totally prevent the flow of heat energy when there exists a temperature differential between two points, but it can be retarded. There are three mechanisms of heat transfer that we must understand. These are *conduction*, *convection*, *and* *radiation*. We must consider all these three mechanisms when we study the overall conductivity of a given material.

Heat transfer by ***Conduction*** occurs via the transfer of energy from atom to atom (or molecule to molecule) in a material. Atoms vibrate faster in higher temperature as they possess more energy. This energy will be passed to the adjacent atoms having lower energy. Since atoms and solids are bonded to one another and are in close contact, conduction in solids is higher than in liquids. Metals, especially, have high rates of conduction because both the atoms and their electrons conduct the electrons much more rapidly. Liquids generally have lower conduction rates than solids because of their lack of regular structure and strong bonding. Gases have much lower rates of conduction since their molecules exist at much lower concentrations and are in relatively infrequent contact. So, within metals, dense ceramics, and dense refractories *Conductivity* is the main mechanism of heat transfer.

Energy transfer by ***Convection*** relies on the mass movement of a fluid. The moving fluid may be either a liquid or a gas. Convection does occur horizontally; but it depends on the gravitational force of the earth. Again, in case of dense refractory bricks heat transfer through this process can not happen since there is no fluid for convection

Radiation process of heat transfer does not require the presence of any material. Radiation occurs most readily through empty space. The sun radiates energy through space to earth. Similarly all hot bodies radiate heat, and if they are hot enough they also radiate visible light which we call as *glow*.

When one studies heat transfer mechanisms in industrial processes, all three modes of heat (or energy) transfer must be considered. In a high temperature furnace or kiln, for example, energy is transferred from the heat source i.e. a burner to the material being heated and to the surrounding furnace refractory walls by all the three processes. The amount of energy transferred by radiation increases dramatically as the temperature increases. It is the dominant heat transfer mechanism at high temperatures. The load and the refractories of the furnace wall absorb energy, get hot, and re-radiate energy.

The moving hot gases transfer it when they come in contact with cooler solid. A small amount of gas conduction occurs, and conduction is the main process of transferring energy or heat from the surface of the solid or liquid.

One of the prime roles of a refractory is to withstand the effects of heat usually in a hostile (hot, acidic or basic, under load etc.) environment. **That is why for the selection of refractory and its designing *Thermal Conductivity* is one property which one has to consider.**

Usually one would like to have a refractory with low thermal conductivity so that heat may be more effectively contained within a furnace or kiln.

Sometimes, however refractories and materials having high thermal conductivity are desired. For example, a protective muffle in certain ceramic kilns is designed to prevent combustion gases from reaching the ceramic ware. It must transfer as much heat to the ware as possible, so conductive ceramic materials like *silicon carbide* are often used for muffles.

Since insulation refractories find application in processes involving thermal energy, an understanding of thermal properties especially, thermal conductivity of these refractories is quite important.

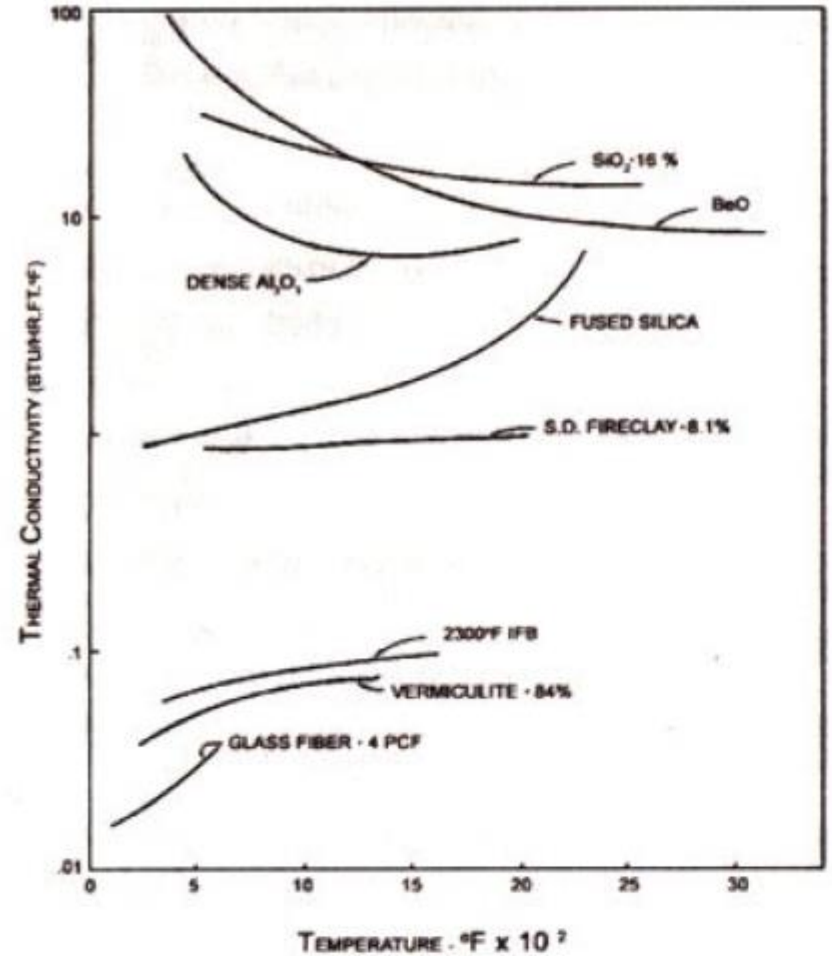
Thermal Conductivity of a refractory material, *k*, is a measure of the amount of heat that it will allow to pass under certain conditions. Thermal conductivity can be defined as the quantity of heat transmitted through a material in unit time, per unit temperature gradient along the direction of flow and unit cross sectional area (W/mK) (remember W=J/s)

First, let us understand the material conditions affecting this thermal property of a refractory brick whether it is insulating or normal brick, and then the most common method used to measure (or calculate) the same. While there are many factors affecting the thermal conductivity of refractories, some of the most important are ;

1. Temperature
2. Complexity of structure (crystal and microstructure)
3. Defects (impurities, solid-solution, and stoichiometry)

J.E. Burke, Progress in Ceramic Science, Vol. 2, Ed., Pergamon Press, Chapter 4, 1962

The temperature dependence of thermal conductivity of several materials is shown in the figure. The structural features such as, anisotropic arrangement of ions, relative mass difference between anion and cation, pores, and grain boundaries etc. do affect thermal conductivity of a material.



Spinel ($MgAl_2O_4$) for instance, has a thermal conductivity lower than that for either MgO or Al_2O_3. Another example is reducing the thermal conductivity of a solid by introducing porosity and this is the most common technique of manufacturing insulating refractories

Fortunately, the thermal conductivity of a refractory material is ordinarily measured in such a way as to account for all of the heat transfer processes operating in that material.

We will discuss only the simplest of calculations. This will be enough to enable you to select among various insulating refractories and also to measure what will be the refractory lining thickness.

Imagine a large flat wall of refractory, whose hot face (hot side), is at some fixed temperature, T_h. Its cold face (cold side) perhaps in contact with a steel shell, is at some lower temperature, T_c. We will call the thickness of the refractory as X.

Let us assume that the heat is supplied to the hot face at some fixed rate by process fluids, and that heat is removed from the cold face (may be by the steel shell and the air outside it) at exactly the same rate. Two things then happens:

(a) heat flows through the refractory at exactly the same rate as well and

(b) temperatures T_h and T_c do not change with time. This is called *Steady State* situation.

If we call some amount of heat H flows in time interval t then the rate of heat-flow Q would be H/t. This rate of heat-flow or heat transport has to be proportional to the area of refractory wall, A, through which heat is flowing

One mathematical equation connects all of these things at once is:

$$\frac{H}{t} = Q = \frac{A(Th-Tc)}{X}.k$$

where, *k* is the value of thermal conductivity

The unit of heat energy, the BTU (British thermal unit), is defined as the amount of heat that will raise the temperature of 1 pound of water by exactly 1^{O}F. The unit of time will be hour (hr). We shall take units of area *A* in square feet (ft^2), the thickness *X* in inches (in.) and temperature in ^{O}F.

If the situation described by *A*, *X*, T_h, and T_c is held fixed but different materials are studied, the rate of heat transport (*Q or H/t*) will be proportional to the *k* of each material. Since *k* is a property of each material, we can get different values for the rate of heat transport by choosing different materials or mixtures of them. Thermal conductivities i.e. values of *k* for different materials are measured in the laboratory and published. We can use them in calculations.

k is numerically equal to the rate of heat transport when the slab area (here, area of the refractory or furnace wall) is exactly 1 ft^2 and the temperature gradient is exactly $1^{O}F/in$

The table lists some of the typical values of thermal conductivity (k) for different solid materials: some metals, some ordinary "working" refractories, some insulating and some highly conducting refractories.

Refractories / Materials	k (BTU.in/ft^2.^{O}F.hr)
Metals (dense solid)	
Copper	2500
Aluminium	900 - 1500
Gold	2060
Silver	2900
304 Stainless Steel	113
310 Stainless Steel	96
1020 Carbon Steel	360
Dense Refractories	
Silica Brick	13
Superduty Brick	9.5
Periclase	20 - 50
High Alumina	10 - 40
Chrome - magnesite	14
Zirconia	5
Insulating Refractories	
Insulating firebrick 2800	2.5 - 3.0
Insulating firebrick 2600	2.0 - 2.5
Insulating firebrick 2300	0.9 - 1.3

Suppose we have a furnace lined with Superduty refractory brick, and the total wall area of this furnace is 1350 ft^2 and also suppose the refractory lining thickness is 12 inch. Say, the process we are conducting in this furnace keeps its hot-face temperature at $3000^{O}F$. With thermocouples we find that the cold-face is at a steady temperature $600^{O}F$. Then, what will be the rate of heat loss through all the walls of this furnace ?

We find from the table that *k* for Superduty brick is 9.5. Then by putting all the given numbers into our heat transfer equation mentioned above we get the rate of heat flow (heat loss) *Q* as

$$\frac{H}{t} = Q = \frac{A(Th - Tc)}{\chi} .k$$

$$\frac{H}{t} = Q = \frac{1350\ (3000 - 600)\ 9.5}{12}$$

$$= 2{,}565{,}000 \text{ or } 2.56 \text{ million BTU/hr}$$

If we can use, an insulating refractory firebrick whose thermal conductivity (*k*) value is 3.0, also taken from the table. Suppose that this insulating brick can survive at 3000^{O}F. Here we will find out the required thickness of the insulating brick lining for which we first rearrange the heat transfer equation to be explicit in *X* so that we can solve it for the refractory thickness. Then by putting all the given numbers into the equation except 3.0 for *k*, we get

$$x = \frac{A(Th - Tc)}{Q} . k$$

$$= \frac{1350\ (3000 - 600)\ 3.0}{2.56 \times 1000000}$$

$$= 3.79 \text{ in.}$$

That is 3.8 inch of insulating firebrick has the same heat transfer resistance as 12 inch of conventional Superduty refractory firebrick !

If we were to keep the refractory lining thickness at 12 in. for example, and solve our heat transfer equation with k = 3.0, we would find that the total rate of heat loss is only 810,000 BTU/hr., instead of 2,565,000 BTU/hr.

Now imagine how much thousands of dollars we could save per month in fuel costs !

However, on practical ground or real - life, calculations are never this simple for numerous reasons. For ex, the value of thermal conductivity itself changes with temperature as the relative contributions of conduction, convection and radiation change. The second, in most cases the refractory lining of a furnace or kiln is done with several refractory layers of varying qualities:

1. A working face of refractory layer or, interior layer of refractory lining that is exposed to the process;
2. The refractory lining between the furnace or kiln shell and working lining, often referred to as the *Safety Lining or Insulating Lining*.

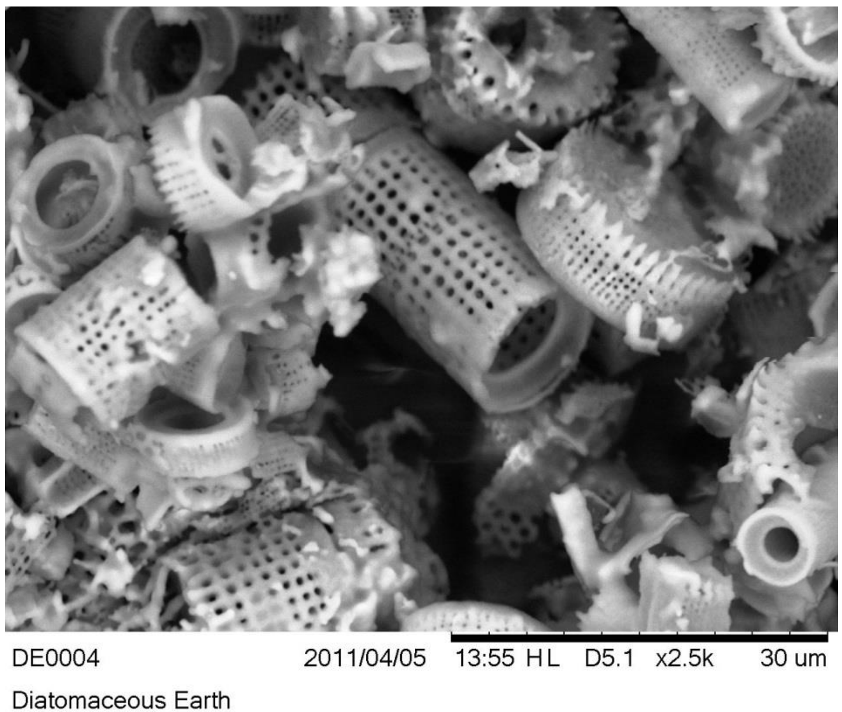
Insulating linings are used to limit heat loss and to maintain the vessel (furnace) shell temperatures at reasonable levels.

Such refractory lining arrangements definitely complicate the heat transfer calculations. But even with the simple introduction about insulating refractories what we have given above, you can appreciate that a process operator can intelligently design a refractory lining that will endure its use temperature and chemistry, and at the same time meet the restrictions on refractory lining thickness or on heat loss that are specified for the situation.

Insulating materials greatly reduce the heat losses through walls. Insulation is effected by providing a layer of material having a low heat conductivity between the internal hot surface of a furnace and the external surface, thus causing the temperature of the external surface reduced. The insulating materials may be classified into the following groups;

- Insulating bricks
- Insulating Castables
- Ceramic fibre
- Calcium silicate
- Ceramic coating

One of the most widely used insulating materials is diatomite, also known as kiesel guhr which is made up of a mass of skeletons of minute aquatic plants deposited thousands of years ago on the beds of seas and lakes. Chemically this consists of silica contaminated with clay and organic matter.



A wide range of insulating refractories with wide combinations of properties are now available. The important physical properties of some insulating refractories are shown in the table below:

Type	Thermal conductivity at 400^0C	Max. safe temperature^0C	Cold Crushing Strength Kg/cm^2	Porosity %	Bulk density Kg/m^3
Diatomite Solid Grade	.025	1000	270	52	1090
Diatomite Porous Grade	.014	800	110	77	540
Clay	.030	1500	260	68	560
High Aluminia	.028	1500-1600	300	66	910
Silica	.040	1400	400	65	830

Castables and Concretes

Monolithic linings and furnace sections can be built up by casting refractory insulating concretes, and by stamping into place certain light weight aggregates suitably bonded. Other applications include the formation of the bases of tunnel kiln cars used in the ceramic industry. The ingredients are similar to those used for making piece refractories, except that concretes contain some kind of cement, either Portland or a high-alumina cement

Ceramic Fiber

Ceramic fiber is a low thermal mass insulation material, which has revolutionalised the furnace design lining systems. Ceramic fiber is an alumino silicate material manufactured by blending and melting alumina and silica at temperature of 1800 – 2000^{o}C and breaking the molten stream by blowing compressed air or dropping the melt on spinning disc to form loose or bulk ceramic fiber. The bulk fiber is converted to various products including blanket, strips, veneering and anchored modules, paper, vacuum formed boards and shapes, rope, etc. for insulation applications.

Fibers are usually produced in two temperature grades based on Al_2O_3 content. A recent addition is ZrO_2 added alumino silicate fiber, which helps to reduce shrinkage levels thereby rating the fiber for higher temperatures. Continuous recommended operating temperature for fibers are given in the following Table

Continuous Recommended Operating Temperature for Fibres			
	Al_2O_3	SiO_2	ZrO_2
1150°C	43 - 47 %	53 - 57 %	-
1250°C	52 - 56 %	44 - 48 %	-
1325°C	33 - 35 %	47 - 50 %	17 - 20 %

These fibres are generally produced in bulk wool form and needled into blanket mass of various densities ranging from 64 to 190 kg/m^3

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