



Ceramic Fiber Technical Bulletin

July 18, 2011

Introduction

Unifrax is a leading producer of high-temperature fiber insulation products which provide innovative heat management solutions to industries across the globe. Fiberfrax ceramic fiber products, Insulfrax and Isofrax soluble fiber products, and other high performance insulation products provide significant improvement in thermal performance, save thousands of dollars in energy costs, and reduce the environmental footprint of operations.

Unifrax's insulating products come in a variety of product forms; blankets, boards, modules, papers, ropes, felts and more. The large selection of products enables Unifrax to engineer the perfect solution for any heat management need. In addition, the company has an excellent and experienced customer service department to provide product information or assist in material selection/design.

There are many critical factors that affect the product choice for a particular design. This section covers important technical aspects relative to ceramic fiber materials which must be taken into account when designing a lining system and choosing a product.

Thermal Conductivity

Thermal conductivity is a measure of a material's ability to transfer heat energy through its mass, and is measured in Btu-in/hr ft² °F. A low thermal conductivity is required for a material to be a good insulator. Design engineers need a basic understanding of thermal conductivity mechanisms in order to maximize the benefits of ceramic fiber insulation. Heat transfer has three primary modes; conduction, convection, and radiation.

Conduction

Heat conduction occurs when vibrating atoms or molecules bump into and interact with adjacent particles as can be seen in figure 1. Conduction takes place in the air space between fibers, as well as through the fiber and shot particles themselves. Since ceramic fiber insulation is a scattering of discontinuous fibers conductive heat transfer can not easily take place. Conductive heat transfer is the primary heat transfer mechanism at lower temperatures such as below 1000°F.

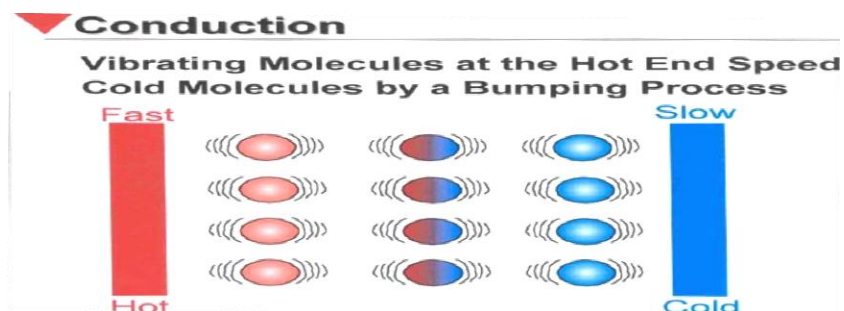


Figure 1

Convection

Convective heat transfer needs a medium such as liquid or gas to carry heat from hot to cold surfaces. In ceramic fiber products the pore size is small and therefore the individual air pockets are smaller than what is typically required for convective heat transfer to be apparent.

Radiation

Thermal radiation is electromagnetic radiation (a form of energy that travels through space exhibiting wave-like behavior) generated by the thermal motion of charged particles. This is the primary mode of heat transfer at high temperatures such as above 1000°F. Radiation has a major impact at high temperatures because it is proportional to the fourth power of the temperature differential between the surfaces involved. Ceramic fiber insulation does an adequate job of blocking radiative heat transfer because the large scattering of fibers provides a treacherous path for the waves to pass through.

Figure 2 shows the impact of the different modes of heat transfer on the thermal conductivity as a function of temperature.

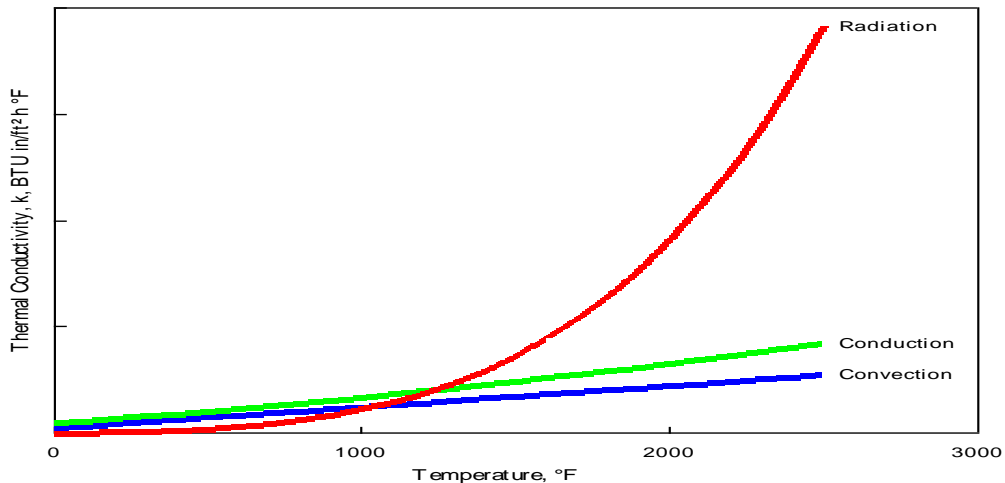


Figure 2

Effect of Shot on Thermal Conductivity

To form ceramic fiber a stream of molten glass is fiberized using either a high-pressure blowing method or a spinning method. Neither of these processes are able to fully convert all of the raw materials to fiber, and unfiberized particles called “shot” remain. The actual number of shot particles is small compared to the number of fibers, but in terms of mass the amount of shot and fiber are nearly equal. “Fiber Index” is the weight percent of fiber, and is also used to express the relative amount of shot. A product with a high fiber index has very little shot on the basis of weight. Since shot reduces the amount of ceramic fiber within a given volume it decreases the thermal performance. The primary method of removing shot is by washing the fiber. During this process the fiber is spun in a centrifuge with water allowing the heavier shot particles to fall out of the suspension. Traditional fiber manufactured by

blowing or spinning has a fiber index of 45%-55%, washed fiber has a fiber index of 60%-80%, high surface area products have a fiber index of 95% or higher, and Fibermax which is manufactured via a sol-gel process is essentially free of shot. Figure 3 shows the impact fiber index has on the apparent thermal conductivity.

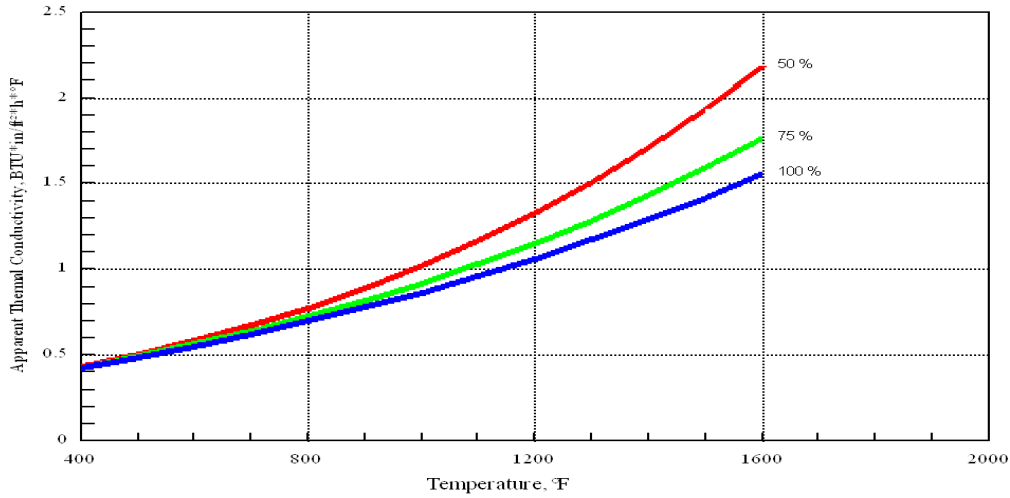


Figure 3

Shrinkage

Ceramic fiber shrinkage begins when the fiber is heated and is continual; however the majority occurs within 24 hours of the initial temperature exposure. Unifrax engineers lining systems to account for shrinkage and maximize life. Module compression, parquet installation patterns, batten strips for unidirectional installation patterns, and overlaps help accomplish this objective. Figure 4 below shows the amount of shrinkage in the first 24 hours versus temperature for a one inch thick blanket with an 8 PCF density.

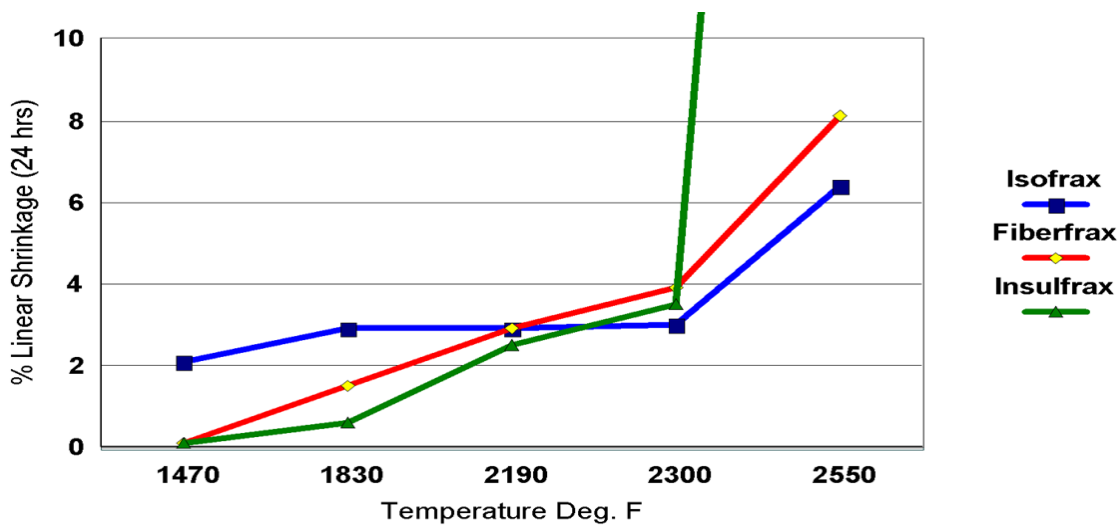


Figure 4

Ceramic fiber is amorphous or vitreous, meaning it lacks the orderly structure of a crystal. Ceramic fiber precipitates crystalline mullite, and then precipitates cristobalite (SiO_2) after further heating. Mullite precipitates at approximately 970°C (1778°F). Once amorphous alumina is consumed to form mullite, there is only silica left in the amorphous state so the precipitation of cristobalite begins. Therefore, there is a time/temperature relationship relative to the precipitation of cristobalite. For ceramic fiber chemistries cristobalite precipitation starts after 3,000 hours at 1100°C (2012°F), 300 hours at 1200°C (2192°F) and 50 hours at 1300°C (2372°F).

Extended time and elevated temperature cause growth and coarsening of the fiber crystal structure, which results in the loss of fiber flexibility. Once the crystals are rough and large, fiber tends to become bonded thermally and the product becomes rigid and fragile as a whole, which leads to deterioration of the ceramic fiber. None of this deterioration should take place if temperatures do not exceed the product's maximum service temperature over the course of thousands of hours.

When crystallization begins, the density of the fiber changes. This leads to curling and collective fiber shrinkage. The progress of crystallization up to the precipitation of cristobalite does not have a direct relation to the progress of the shrinkage. Shrinkage typically progresses very slowly over the passage of time. Fluxing agents may accelerate fiber shrinkage and are discussed in subsequent pages of this article.

Figure 5 is an alumina silica phase diagram and helps visualize the crystallization process.

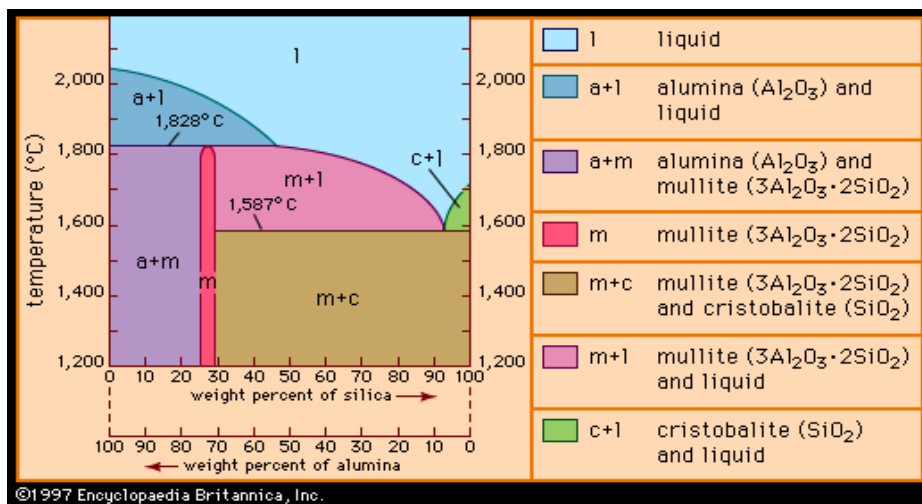


Figure 5

Environmental Factors

Environmental factors have an impact on the performance of a ceramic fiber lining system. These factors include ambient temperature, external wind speed, emissivity and hydrogen content. When determining the heat flow for a lining the default parameters typically used are; wind speed of 0 MPH, ambient temperature of 80°F , hydrogen content of 0% and 0.9 emissivity.

Emissivity is the ability of a surface to emit energy by radiation. It is expressed as a ratio of the radiation emitted by the particular surface to the radiation emitted by a blackbody (a perfect emitter). In an insulation system the cold face temperature will be at its lowest as emissivity approaches one. Typical furnace shell castings are represented by an emissivity value of 0.9.

Hydrogen gas is often used for thermal processes where Unifrax products are used, such as high temperature metal processing. The thermal conductivity for a ceramic fiber product is determined by the thermal conductivity of the ceramic fiber itself and of the gas contained within the fibers. Therefore, changing the atmosphere alters the thermal conductivity value of the refractory product being used. The change depends on the thermal conductivity of the gas, and the porosity of the ceramic fiber product.

The following table shows how changing any of these four variables affect the heat profile. Anchor-Loc 2600 modules with a density of 9.3 PCF and a thickness of 8 inches were used on furnace sidewalls with a hot face of 2450°F to generate the data.

| Ambient Temperature (°F) | Wind Speed (MPH) | Emissivity | Hydrogen (%) | Heat Loss (BTU/ft ² /hr) | Surface Temperature (°F) | Heat Storage (BTU/ft ²) |
|--------------------------|------------------|------------|--------------|-------------------------------------|--------------------------|-------------------------------------|
| 80 | 0 | 0.9 | 0 | 502 | 275 | 2227 |
| 70 | 0 | 0.9 | 0 | 502 | 269 | 2239 |
| 90 | 0 | 0.9 | 0 | 502 | 281 | 2215 |
| 100 | 0 | 0.9 | 0 | 502 | 287 | 2203 |
| 80 | 5 | 0.9 | 0 | 504 | 215 | 2175 |
| 80 | 10 | 0.9 | 0 | 504 | 195 | 2157 |
| 80 | 15 | 0.9 | 0 | 505 | 183 | 2147 |
| 80 | 0 | 0.7 | 0 | 502 | 297 | 2246 |
| 80 | 0 | 0.5 | 0 | 501 | 327 | 2272 |
| 80 | 0 | 0.3 | 0 | 499 | 371 | 2310 |
| 80 | 0 | 0.1 | 0 | 496 | 446 | 2375 |
| 80 | 0 | 0.9 | 5 | 520 | 275 | 2227 |
| 80 | 0 | 0.9 | 15 | 556 | 288 | 2238 |
| 80 | 0 | 0.9 | 25 | 591 | 297 | 2246 |
| 80 | 0 | 0.9 | 40 | 645 | 309 | 2257 |
| 80 | 0 | 0.9 | 75 | 770 | 340 | 2283 |
| 80 | 0 | 0.9 | 100 | 859 | 362 | 2302 |

Key

| | | | | |
|---------------------|---------------------|---------------|------------|---------------------|
| Standard Conditions | Ambient Temperature | External Wind | Emissivity | Hydrogen Atmosphere |
|---------------------|---------------------|---------------|------------|---------------------|

Table 1

Ambient temperature, external wind velocity and emissivity have large impacts on the surface or cold face temperature, however the hydrogen content not only influences cold face temperatures, but the heat loss of the furnace as well. Understanding this table is crucial to recommending the proper insulation system.

Chemical Attack

Sulfuric Acid

Sulfuric acid is an oily, odorless, corrosive, colorless liquid. Ceramic fiber is largely resistant to sulfuric acid attack and typically performs well in sulfuric acid containing environments. A reaction will occur at the hot face layer, creating a layer of aluminum sulfate. This formation is normal and has no negative impact on fiber integrity or thermal performance. In fact, in some cases, it is even protective, preventing acid from reacting with the underlying fiber.

However, there is a second mechanism which is more concerning. As mentioned, sulfuric acid commonly reacts with metals. To prevent module or layered blanket hardware corrosion a bitumastic or stalastic furnace shell coating is commonly used. A back-up layer of blanket and a foil vapor barrier is commonly incorporated. Proper engineering design of the ceramic fiber insulation system is needed to maintain the hardware interface temperature above dew point of sulfuric acid (temperature at the vapor barrier must be greater than 400°F) to prevent acid condensation and hardware corrosion. Hence, Thread-Loc/Thread-Loc₂ module attachment systems that use a pre-welded anchoring stud are required due to their unique compatibility with such designs.

If the hardware system does corrode, the aluminum sulfate layer will react with the byproducts of the metallic corrosion. Condensed vapors from the corrosion process will expedite this reaction which results in the erosion of the once protective aluminum sulfate surface layer. This process will continue over time and may potentially lead to fiber degradation adjacent to the module anchoring hardware resulting in failure of the system. Therefore, sulfuric acid environments must use SS304 grade module attachment and internal hardware as a minimum grade. In conclusion, when the correct hardware is used, ceramic fiber is appropriate for sulfuric acid environments.

Alkali

Alkali, alkali metals, and alkali metal slags affect the chemical stability of ceramic fiber which may result in high shrinkage rates, fiber embrittlement, and in some cases destruction of the fiber lining system.

Common alkali metals are: sodium, potassium, lithium, rubidium, and cesium. Sodium and potassium are the two most common for industrial applications; lithium, rubidium, cesium, and francium are not often encountered.

Their oxides, mainly those of sodium and potassium are strong fluxes which attack and damage ceramic fiber. By definition, a fluxing agent is an element which chemically reacts to lower the melting point of a material. By attacking the fiber these oxides form low melting eutectics that lead to sintering of the fibers at lower temperatures. When fibers sinter (bond) together, the shrinkage within the individual fiber has a greater affect on the shrinkage of the RCF product since the fibers can no longer slide past one another. Alkali attack is most profound at the hot face surface of RCF products where a sintered crust forms and eventually deteriorates to expose fresh fiber to further and continued alkali attack. The extent of a fluxing reaction is a function of the concentration of fluxing agent present and service temperature. As a general guideline, fluxing agents should be maintained at 0.2% or less by weight.

Alkaline earth metals are named so because their oxides form mildly alkaline solutions. Magnesium and calcium are the two that are most commonly react with ceramic fiber.

The compositional breakdown of slags varies but all contain metal oxides. Oxides common to most slags in varying amounts are Fe_2O_3 , V_2O_5 , CaO , K_2O , Na_2O , and MgO . All these metal oxides are highly volatile and some are more aggressive attackers of ceramic fiber than others.

Hydrofluoric and Phosphoric Acid

Fluorine attacks ceramic fiber more aggressively than any other chemical. Small amounts of hydrofluoric acid will attack the silica, and form gaseous silicon hexafluoride, completely destroying the structure of the ceramic fiber. At moderate temperatures (below 1800°F) a fluorine enhanced environment may lead to low temperature recrystallization. Fluorine tends to outgas, or release after it has attacked, and therefore is many times hard to identify in failure analysis. Phosphoric acid has similar damaging affects on ceramic fiber.

Summary

Many technical aspects relative to ceramic fiber materials must be taken into account when designing a lining system and choosing a product. This article covered the basics of thermal conductivity, shrinkage mechanisms, environmental factors, and chemical attack. All these factors are closely related and together explain ceramic fiber performance across a whole spectrum of applications.