HIGHLY EFFICIENT MICROPOROUS INSULATION CAN PROVIDE MANY BENEFITS IN FUEL CELL DESIGN

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The commercialization of fuel cells face many challenges ranging from technical concerns and manufacturing costs, to market acceptance. Thermal management is among those challenges as fuel cell designers strive to minimize equipment heat loss to maintain system efficiencies and ensure components operate as expected. Early consideration of insulation materials is one key to minimizing these obstacles. Selecting the most appropriate material in terms of performance, form and price is the first step. Configuring the insulation material to fit the application runs a close second. If fuel cell design parameters and insulation performance issues are well thought out then the third step, going to production, is accomplished through little/no system modifications during the tooling, quality checks, ramping up production and economies of scale phases.

FEATURES OF MICROPOROUS INSULATION

In high temperature fuel cell applications (>1000°F), microporous insulation type products can meet many/all of the challenges listed above during fuel cell design while offering some very attractive features:

- Very low thermal conductivity
- A proven track record within harsh environments
- Excellent long-term durability
- High compression resistance
- Low heat storage

Leading companies such as Plug Power, Nuvera, Fuel CellTechnologies and FuelCell Energy all employ microporous insulation to meet their thermal management needs. The range of benefits that they have experienced in their fuel cell systems include:

- Increased efficiency through reduced heat loss
- Improved temperature control and consistency
- Increased equipment life on components adversely affected by elevated temperatures
- A reduction in heat up time
- Improved safety conditions around high temperatures processes

Understanding what microporous insulation is, how it can benefit designers, where it is most effective and what configuration options exist are necessary when considering these thermal management systems. A review of this material's capabilities and limitations provides a baseline for addressing a wide array of thermal challenges, and minimizes some of the subsequent obstacles associated with fuel cell commercialization.

BACKGROUND

In the late 1940's, US military scientists were seeking new, highly efficient thermal insulation systems for use on aircrafts. Design considerations for the new insulation included:

- Optimization of thermal performance without the use of a vacuum
- Service temperature use limit up to 1832°F
- Very lightweight
- High compressive strength
- Little or no out-gassing in service

Thermal energy flows through materials by the simultaneous action of several transfer mechanisms; solid conduction, gas conduction, radiation and convection currents. Scientists first defined an optimum theoretical thermal insulation based on minimizing these primary modes of heat transfer and then searched for and designed a product that approached these parameters. After many years of study, a high temperature, lightweight insulation product was developed that delivers excellent thermal performance through a combination of very fine silica particle packing, special material additives and precise production techniques. This novel insulation product was put into two forms, a flexible product and a machinable board. The flexible product, which consists of the microporous core quilted between layers of a high temperature textile, was first employed on the firewalls of aircraft, while the board was utilized to protect instrumentation. These microporous insulation materials have been proven in virtually every Boeing commercial aircraft design of the past 40 years including the fire protection component for flight data recorders enclosures, often referred to as "black boxes". The graph below shows the thermal conductivity advantage of microporous insulation materials such Thermal Ceramics BTU-BLOCK flexible and board materials vs. energy efficient, high temperature insulation paper and blanket products.

HOW BTU-BLOCK MICROPOROUS INSULATION BENEFIT DESIGNERS

The immediate benefits of microporous insulation are obvious. The lower thermal conductivity translates to improved thermal efficiency, less heat loss and improved temperature stability. However, employing microporous insulation can aid the design process in many ways that may not be immediately seen.

Aid in Identifying Heat Paths -The difficulty in insulating smaller components is generally tied to heat paths around the insulation rather than heat escaping through the insulation. A very low thermal conductivity product will actually direct the heat to these energy leaks, making them easier to identify and subsequently eliminate. Further, using the most effective insulation available will both allow and drive designers towards a simple and robust design because the detriments of these joints are generally multiple penetrations and complex seals.

More Space -The obvious selling point for micro porous insulation in most applications is its lower thermal conductivity and hence the need for less insulation. When the components are configured on a bench in the testing lab this may be of little concern, but when the system integration team puts it all together, space is always at a premium. Insulating a 6 inch diameter, 24 inch long cylinder with 1-inch of microporous insulation would require 580 cubic inches of insulation, while using 2.5 inch of a less thermally efficient product would take up 1,700 cubic inches.

Design Flexibility -Assuming a 1600°F hot face design construction, if the target cold face temperature shifts from 200°F to 150°F, 1 inch of microporous insulation would need to be increased to 1.5 inches. While that design change may be minimal, in the same application, 2.5 inches of high efficiency fiber product would need to be increased to 4.25 inches. BTU-BLOCK Microporous insulation is also available in a wide range of forms that allows engineers more design flexibility as the product evolves:

- **BTU-BLOCK Panel** -a lower density product encapsulated in fiberglass textile which provides mechanical protection, flexural strength and a substrate for bonding to walls or other insulation.
- **BTU-BLOCK Board** -rigid product with the highest density and greatest structural integrity of the microporous products. It can be water jet cut into intricate shapes, laminated with a high temperature textile to greatly improve strength and reduce dust, or machined.
- **BTU-BLOCK Flexible** -consists of the microporous core encapsulated between layers of high temperature cloth and quilted in 1 inch squares. The quilting maintains core distribution in high vibration environments and allows the insulation to be wrapped or bent to conform to unique geometric shapes during installation.

Considering microporous insulation early in the design process leaves more options later. As the design matures, if it seems the efficiency of the microporous insulation is excessive, it can be easily replaced with other options including composites or fibers. Conversely, adding thermal efficiency later may require massive design changes involving increased space, unexpected costs, additional production steps and late schedules.

WHERE IS MICROPOROUS MOST EFFECTIVE

Thermal conductivity is a function of temperature and as was seen in the previous graph, at low temperatures most insulators perform comparably. Therefore, microporous insulation is best suited for higher temperature processes above 800°F to 1000°F.

Also, all insulation systems reach a point of diminishing returns with increasing thickness. When there is no space limitation and low cost products can be utilized, the benefit of microporous insulations minimized. However it should be noted that in some case, the cost of installing 4 inches of a low cost product may greatly exceed the cost of installing 1 inch of microporous material.

Generally speaking then, microporous insulation is most appropriate in high temperature fuel cell applications where either space is limited, or the cost of fabricating a thicker insulation system is greater than it would be for a thinner microporous option. The following plots show the energy loss and cold cafe temperature benefits of this insulation compared to both standard high temperature fiber blanket and high-efficiency, high temperature paper at given thicknesses.

Within the fuel cell industry, due to its unique properties, microporous insulation is employed in a number of essential applications. The first major area is heat containment in the hydrogen fuel processing stage where depending on the type of processor, temperatures can reach 1800°F. These can be stand-alone fuel processors or integrated within the fuel cell itself. Microporous insulation is used to insulate and separate the different reformer components either from each other or from adjacent temperature sensitive equipment and controls. Microporous insulation systems are widely used for high temperature (SOFC and MCFC) fuel cells, where they often encase the fuel cell itself. In addition, for combined systems utilizing micro turbines, these products encapsulate the hot areas of the turbine and protect surrounding equipment and controls. Microporous is also used in plant applications around high temperature heat exchangers and piping to improve overall plant efficiency.

SUMMARY

A wide range of high temperature insulation options exist, each with different performance characteristics, product forms and costs. Among the options is microporous insulation, which offers extremely low thermal conductivity, excellent compression resistance, low stored heat and an excellent long duration track record in high temperature, harsh environments. Beyond the immediate benefits, microporous insulation also drives engineering toward a more efficient, simplistic and flexible fuel cell designs, which can speed the path to commercialization. While evaluating insulation options, microporous products should be considered both for the material's characteristics, and for the design benefits it can provide.