INTRAMICRON

Enhancing Catalyst Performance Through Microfibrous Entrapment

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Optimal performance for a given catalyst can be achieved when its reaction rate is controlled intrinsically; however, heat and mass transfer limitations are often present in catalytic systems that result in decreased performance. These limitations are typically encountered in the most common type of catalytic reactor, the packed bed. This occurs because relatively large particles must be used to minimize pressure drop and packed catalyst beds have low thermal conductivities. While complex reactor designs such as the fluidized bed and slurry reactor are commonly employed in an attempt to overcome these limitations, they face other challenges such as catalyst-product separation, difficult scale-up, and high operating costs. Packed beds are still the most common reactor type because they are easy to construct, model, scale, and operate. Microfibrous entrapment offers a method to reduce or eliminate intra-particle heat and mass transfer limitations using a frozen-fluidized-bed configuration.

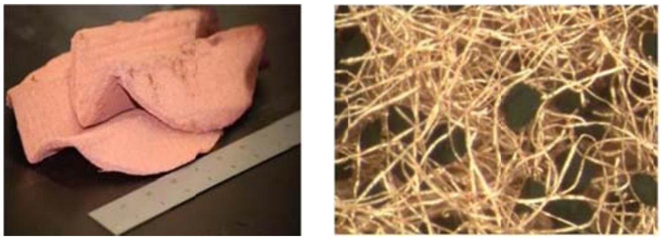

Figure 1. Left: Copper (12 µm) MFM. Right: Fisher-Tropsch Synthesis Catalyst (60-80mesh) entrapped in Cu MFM.

The microfibrous media (MFM), which functions as the catalyst carrier, is prepared by a robust, scalable wet-lay process. This process results in a highly porous structure (~94%) that consists of randomly oriented microfibers that are micro-welded via sintering (Figure 1). The random orientation of the microfibers provides a uniform flow profile throughout the bed which minimizes channeling and assists with mixing. Microfibrous Entrapped Catalysts (MFECs) are prepared using a proprietary method that locks small catalyst particles (0-35 vol.%) within the microfibrous media (Figure 1). The microfibrous structure can be formed from a variety of materials including metals (Cu, Ni, ect.), alloys (stainless steel, brass), polymers, and glass, allowing the support structure to be tailored to a given reaction system. Metals are typically used when enhanced heat transfer is needed (Table 1, Figure 2). Polymeric entrapment can be performed for low-temperature processes where minimizing mass transfer resistance is the primary concern, and glass fibers are the ideal material when enhanced mass transfer and corrosion resistance are required.

Table 1. Radial Thermal Conductivity of Microfibrous Media (MFM) compared to an Al_2O_3 Packed Bed (PB)

	K (W/m-K)	K / K Al_2O_3 PB
Cu MFM	9.7	50
Ni MFM	3.8	20
Al_2O_3 PB	0.2	1

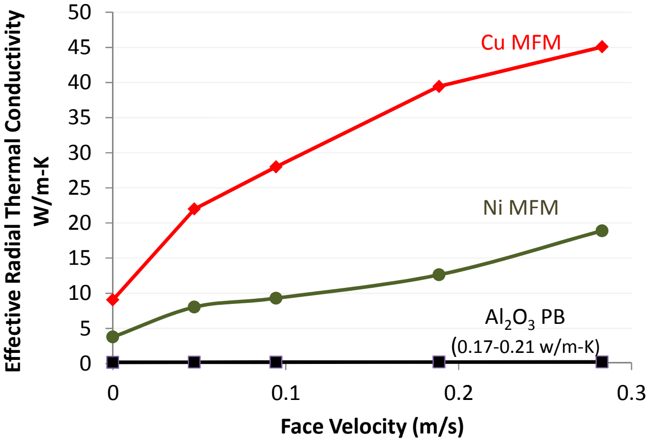

Figure 2. Effective radial thermal conductivity of Cu MFM, Ni MFM, and Al_2O_3 Packed Bed (PB) as a function of face velocity.

The enhanced catalytic performance of MFECs arises from the ability to utilize small catalyst particles (40-300 micron) effectively. For catalyst systems that are pore-diffusion limited, decreasing the catalyst particle diameter decreases the internal mass transfer resistance, thus enhancing the observed reaction rate and effectiveness factor. Depending on the reaction system, a MEFC will typically have an effectiveness factor 2 – 15 times than that of the same catalyst operating in a traditional packed bed, and in many cases intra-particle diffusion resistance can be eliminated completely (effectiveness factor ≈ 1) (Figure 3). This increase in efficiency allows enhanced production from a much smaller volumetric catalyst loading (12-30 volume % for an MFEC versus 60 volume % for a packed bed). Decreasing the volumetric catalyst loading and increasing the effectiveness of the active phase are especially important for catalyst systems that utilize expensive components such as precious metals. Furthermore, the highly porous nature of the MFEC allows the microfibrous bed to have 1/3 the pressure drop of a packed bed of the same length containing only entrapped particles.

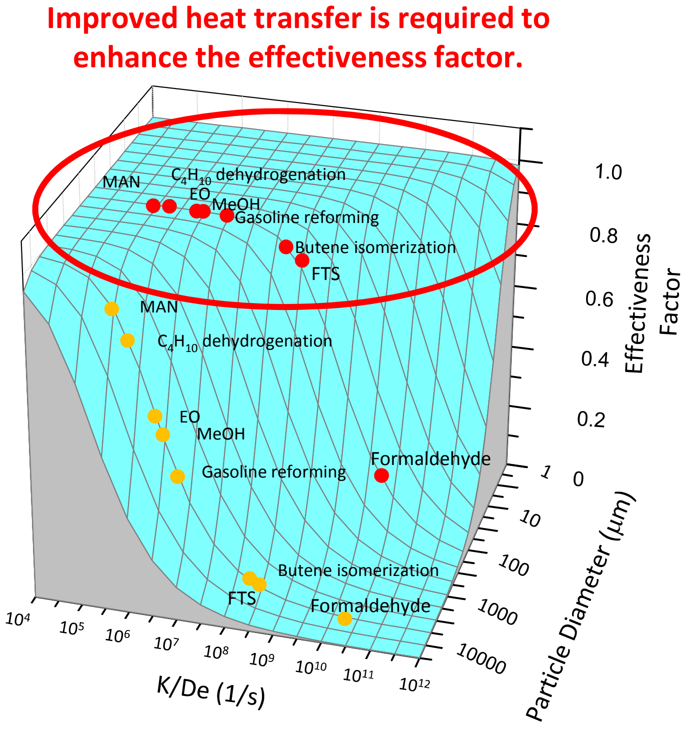

Figure 3. Left: Comparison of the effectiveness factor (observed reaction rate / intrinsic reaction rate) of MFECs(red) and packed bed (yellow) catalysts for several exothermic catalytic processes.

For most energy-intensive processes (exothermic and endothermic), excellent heat transfer is a must for optimal product selectivity, decent conversion, easy operation, and operational safety. MFECs made of thermally conductive materials will have an effective radial thermal conductivity 5 to 50 times that of an alumina packed bed with a 10 fold improvement in the inside-the-wall heat transfer coefficient. The micron-sized fibers also have much higher surface area for heat exchange than the catalyst particles. The enhanced heat transfer of MFECs results in lower radial temperature gradients than in packed bed reactors (Table 2). It also allows the stream flowing through an MFEC to reach thermal equilibrium much faster than in a packed bed reactor. Maintaining a uniform radial temperature profile in the reactor is especially beneficial when catalyst selectivity is extremely sensitive to temperature as is the case in Fischer-Tropsch Synthesis, Mixed-Alcohol Synthesis, and most fine chemical syntheses. When packed bed reactors are used industrially for heat-intensive, temperature-selective reactions, the diameter of an individual reactor tube is often limited to 1-2 in.; however, the enhanced performance of MFECs offers the opportunity to use a larger diameter bed with an improved temperature profile.

Table 2. Radial temperature gradients in Fischer-Tropsch Synthesis for Cu MFEC and Packed Bed.

	Cu MFEC	Packed Bed
Conversion	0.54	0.54
Wall T(^{o}C)	235	225
Average Centerline T	236	230
T-Twall (Average)	1	5

$D_{Reactor}$= ¾”, V_{Bed} = 16 cc, P = 20 bar, GHSV = 830 h^{-1}

Microfibrous entrapment allows catalytic processes to be run at significantly higher volumetric reaction rates than currently possible with enhanced thermal management in a simple, scalable packed bed configuration. These benefits result in enhanced production from a given catalyst system with a reduction in reactor size, enhanced energy utilization, and decreased catalyst cost. Furthermore, MFECs are superior to metal honeycomb approaches because of the ease of the catalyst loading process and the ability to achieve higher catalyst loadings.