Isobutane dehydrogenation reaction in a packed bed catalytic membrane reactor

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A packed-bed catalytic ceramic membrane reactor (PBCMR) was used for the isobutane dehydrogenation reaction. The experimental results have shown that through the use of the membrane reactor one can attain better conversions and yields than in a conventional reactor operating under the same outlet pressure and temperature, and feed composition conditions.

Keywords: Isobutane dehydrogenation reaction; catalytic ceramic membrane reactor

1. Introduction

The membrane reactor concept is not new, for recent reviews see refs. [1,2]. Its origins go back to the late fifties. It is a rather simple concept, especially as it applies to equilibrium limited reactions. For a reaction that takes place in a flow reactor, like a plug flow reactor, which has solid impermeable walls, the maximum possible conversion is determined by equilibrium considerations. The conversion can never exceed the equilibrium conversion calculated based on the outlet pressure and temperature conditions and the composition at the inlet. Membrane reactors, on the other hand, have semipermeable walls, which allow one (or more) of the reaction products to leak out of the reactor, while acting (ideally) as solid barriers for the reactants. A driving potential for the reaction to occur is, thus, always maintained since the rate of the reverse reaction never becomes equal to the rate of the forward reaction. One would then expect to get (and in practice often does) complete conversion, even under conditions for which the corresponding equilibrium conversion is small.

The membrane reactor concept is today finding commercial uses, primarily in low temperature applications, in the field of bioengineering for the production of a number of specialty chemicals. The membrane bioreactors typically use polymeric...
membranes, which are not generally thermally resistant to temperatures above 100°C. A concise review of membrane bioreactors has been recently published [3].

Though membrane reactors have been tried, since the beginning, for high temperature catalytic applications, they have yet to realize a comparable degree of commercial success. The earlier applications involved Pd membranes. Pd, together with a limited number of other metals, is unique in the sense that it allows hydrogen to permeate through, while being virtually impermeable to other gases and vapors. The early pioneering research with Pd membranes was done by Gryaznov and co-workers of the former Soviet Union. Their work is impressive, and has recently been reviewed [4]. Gryaznov and co-workers studied many hydrogenation and dehydrogenation reactions and realized considerable success. Pd membrane reactors have yet to find commercial application, however. The problem lies with the mechanical and thermal properties of these membranes. These membranes are reported to become brittle during thermal cycling in a hydrogen atmosphere. They also have low hydrogen permeabilities and are easily poisoned by sulfur and deactivated by coke. Efforts are currently under way by several groups to deal with some of these problems. These efforts involve the development of composite ceramic/metal membranes, microporous Pd membranes and replacing Pd with other metal membranes, like Pt, which are more resistant to poisoning.

Nonporous oxygen conducting membranes have also found frequent use in catalytic membrane reactor applications. The earlier applications involved the decomposition of various oxygen containing compounds like CO, CO₂, H₂O and NO. More recent applications involve various partial oxidation reactions including direct methane activation to produce C₂⁺ hydrocarbons (for a recent review see ref. [5]). Microporous Vycor glass membranes have also been used in some of the earlier applications involving the decomposition of H₂S and HI. Other efforts have involved the study of cyclohexane dehydrogenation and the oxidative dehydrogenation of methanol. More recent applications with microporous membranes have involved the use of membranes made by sol–gel techniques, most notably composite γ-Al₂O₃/α-Al₂O₃ tubular membranes. Reactions studied involve ethane, ethylbenzene, butane, propane and methanol dehydrogenation, methane steam reforming and the water–gas shift reaction.

Our group has been involved with the study of catalytic membrane reactors for a number of years. The primary focus of our studies has been on the development of effective design methodologies for designing such reactors. The effort has involved the formulation of mathematical models, which have been tested with experiments in catalytic membrane reactors with the ethane dehydrogenation reaction [6]. Two other reactions have also been studied by our group: propane dehydrogenation to propylene [7] and the methane steam reforming reaction [8] for the production of hydrogen for use in chemically recuperated gas turbines.

In this paper we present preliminary results of an experimental study of the isobutane dehydrogenation reaction in a catalytic membrane reactor.