APPLICATION OF MICROWAVES TO CHEMICAL REACTIONS FOR PROCESS INTENSIFICATION

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Abstract

Catalyst research and development has been conducted for more than 100 years with only incremental improvement in recent decades. Once a catalytic process produces near-equilibrium yields, additional improvements can be accomplished through reactor engineering or non-traditional approaches to reaction chemistry. One of these approaches is the application of non-traditional energy inputs, such as microwaves. Microwave fields applied to reaction processes have the potential to improve overall system performance through energy savings and increased product selectivity. This work explores the application of microwaves to several different reactions to demonstrate the potential benefits and examine the variables to be considered in the design of microwave reactors.

Keywords

Microwave field, catalyst, energy processes, chemical production

Introduction

The National Energy Technology Laboratory (NETL) is conducting an effort to better understand and utilize the application of microwave (MW) fields to various chemical reactions. The potential cost benefits and energy efficiency of MW-enhanced processes have yet to be fully explored and quantified. Research on the application of MW fields to chemical processes for enhanced conversion and selectivity has received significantly increased interest in recent years. One noteworthy example is the study by Hunt *et al.* (2013), which proposed a microwave-specific enhancement of the Boudouard reaction.

The benefits of MW application to reaction systems include rapid, selective heating of the catalyst surface and reacting species to promote conversion to desired products at significantly lower, bulk system temperatures. Additional microwave-specific effects are also being explored. The interactions of materials with both the electric and magnetic components of the MW field are being examined using impedance analyzers, vector network analyzers (VNA), and magnetometry. Two microwave reactor systems have been designed and built in NETL's state-of-the-art ReACT Facility: a 2 kW fixed frequency, fixed-bed flow reactor; and a 500 W variable frequency reactor. Techniques are being developed to utilize the VNA with these systems to characterize the materials in-situ to examine the effects of temperature, MW power and frequency, and other reaction conditions on the MW activity of the catalysts.

In present studies, different heterogeneous catalytic reactions are being examined with and without the addition of a MW field. The reactions include coal pyrolysis, Fischer-Tropsch synthesis, methane dehydroaromatization, and ammonia synthesis. Conventional thermal conditions for these reactions were examined first, and the MW parameters varied include power and pulse time. Catalyst and reacted solid materials were characterized, including

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their dielectric properties, to identify ways to modify them to enhance their interaction with the MW field.

Experimental

Microwaves have been applied to several reaction systems to examine their impact on conversion and product distribution. Previous work by Abdelsayed *et al.* (2015) demonstrated conventional Mo and Zn-based catalysts in methane dehydroaromatization (MDHA) for direct conversion of methane to benzene. The experimental details of those studies can be found in the reference. To examine the effect of MWs, similar studies were conducted in a reactor with a magnetron for application of the microwave field to the catalyst bed during reaction. Details of the reactor can be found elsewhere in Abdelsayed *et al.* (2018). The operating conditions for the MDHA studies with the applied MW field are given in Table 1.

Results

The benzene yields from the direct conversion of methane over three catalysts with and without a microwave field are presented in Figure 1. Equilibrium yields at these operating conditions are ~10%, yet rapid catalyst deactivation occurs within the first 30 minutes. These results show a clear benefit to the application of a MW field to MDHA over all catalyst studied. It is believed that the MW field may have reduced the formation of deactivating carbon deposits on the catalyst surface since carbon is a strong MW absorber. This hypothesis was supported by a lower quantity of carbon measured during a temperature programmed oxidation of the spent samples (data not shown here). Another possible explanation that must be considered is that localized heating from the interaction of the MW field with the catalyst and/or surface species provided the opportunity for higher conversions since equilibrium yield at 800°C is ~12%. Further study is necessary to investigate these possibilities.

Conclusions

The potential benefits of applying a microwave field to different reaction processes has been demonstrated under various microwave field and operating conditions. The reactions studied include coal pyrolysis, methane dehydroaromatization, Fischer-Tropsch synthesis, and ammonia synthesis. Not all chemical processes are appropriate for MW field addition, and reactor design and overall system economics must be considered. Nevertheless, the results presented here and in other related work provide significant justification for much more investigation into the potential use of microwaves in chemical processes.

Tables and Illustrations

Table 1. Experimental conditions

Condition	Value
Mass catalyst, g	1.0
Methane flow rate, sccm	50
Temperature, °C	700
Pressure, atm	1.0
MW power, W	300
MW frequency, GHz	2.45
MW pulse, ms on/off	500

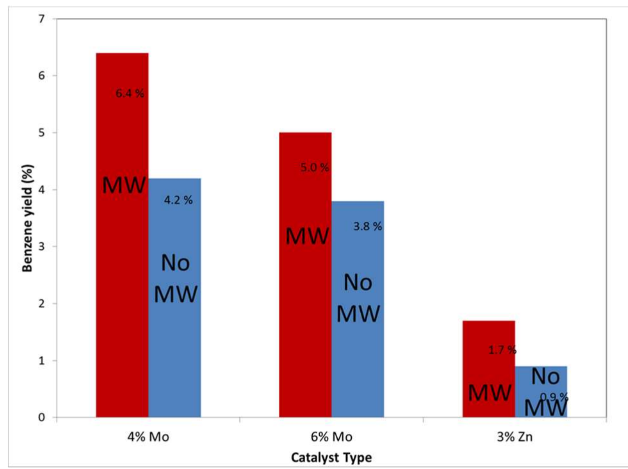

Figure 1. Comparison of benzene yield with and without microwave in MDHA

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