Single Path Travelling Microwave Reactor Design

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Highlights

- Travelling microwave reactor enables the process scale-up.
- The novel coaxial traveling MW reactor is designed to optimize heat generation by avoiding resonance.
- A conical shaped transition is used to keep impedance matching and reduce microwave reflections.
- Simulation results show that standing wave is not formed along the reactor.

1. Introduction

The main goal of this study is to develop an intensified adaptable reactor technology for non-oxidative coupling of methane that will increase the selectivity of methane valorization reactions to C2+ hydrocarbons and liquid fuels, which are cheaper to transport due to higher density and energetic values. For this purpose, a novel type of microwave reactor is designed and optimized. The coupling reaction has exhibited promising results under microwave irradiation, as compared to a conventional packed-bed reactor with a bifunctional catalysts [1]. Furthermore, microwave-assisted process offers several advantages over the traditional ones in terms of reaction acceleration, volumetric heating, improving product yields and selectivity, and reducing undesired side reactions [2]. In addition, operating at a lower bulk gas temperature can lead to a considerable improvement in reaction selectivity that can be maximized by designing microwave-absorbing catalysts. The microwave equipment, used in process engineering laboratories can be divided in three basic categories: single-mode, multimode, and travelling microwave devices. The particular reactor concept investigated in this study is the travelling microwave reactor (TMR), which was first introduced by Sturm [3]. This novel reactor concept, has the potential to enable highly uniform microwave heating by avoiding resonant conditions[4]. The specific purpose is to construct and tune the reactor such that the microwave field inside the reactor travels in only one direction to avoid non-uniform electromagnetic interference patterns and non-uniform heating along the axial direction of the reactor.

2. Methods

Our aim in this project is not only to focus on the microwave transmission line and its control to make the microwave field uniform, but also on development for integration between microwave energy and a chemical processing system and solutions that could find further implementation in these systems. For this purpose, we suggested a coaxial waveguide structure, which has no cut–off frequency for the used transverse electromagnetic mode and is able to carry travelling microwave fields. A cross-sectional schematic of the proposed microwave reactor along the axial direction is demonstrated in figure 1.

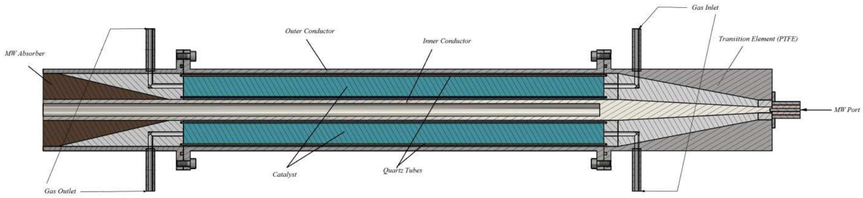

Figure 1. A cross-sectional schematic of the traveling microwave reactor.

The stainless steel inner and outer conductors form the coaxial waveguide structure and their diameters are adjusted such that the characteristic impedance of the waveguide is maintained at 50Ω. The quartz tubes form a sealed toroidal reactor inside the waveguide while playing the role of dielectric insulator in the coaxial waveguide. This provides a way to have a relatively high temperature reactor inside a cooler waveguide structure, while maintaining fluid containment. The catalyst particles/supports are placed in the space between the quartz tubes and the process fluids/reactants flow in the axial direction along the catalyst supports. A conical-shaped coaxial transition part filled with PTFE is also designed to be placed between the microwave generator port and the reactor intersection to adapt the two devices with minimum microwave reflections. With the intention of preventing any microwave leakage upward, we considered a tapered coaxial absorber at the end of the waveguide.

3. Results and discussion

A traveling microwave reactor, comprising the coaxial transition and absorbing load sections, is designed and simulated using the electromagnetic field simulation software of CST Studio Suite. The Finite Integration Technique (FIT) solver is employed for simulations, which is a time-domain method for solving Maxwell equations and obtaining a fast estimation of electromagnetic performance over desired bandwidth. Figure 2 presents the simulation results for the distribution of microwave fields inside the optimized reactor design. From the simulation results, it can be seen that we have indeed a travelling microwave field along the reactor.

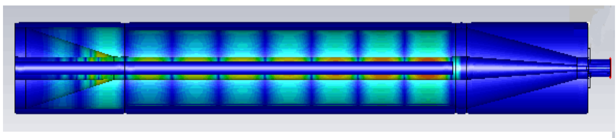

Figure 2. Simulation study of the traveling microwave reactor.

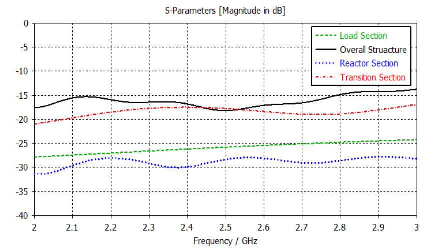

Figure 3. Reflection coefficient of the transition element.

Obtaining proper travelling waves inside the reactor requires good impedance matching between the parts of the structure. Figure 3 demonstrates the simulation results for the reflection coefficient of transition, main reactor, load and overall structure in the frequency range of 2-3 GHz, which all are less than -17dB at the working frequency (2.45GHz). This would be a proof that there is no standing wave generated along the structure.

4. Conclusions

A novel coaxial traveling microwave reactor for methane reforming is proposed to optimize the heat generation by avoiding the resonance. The design of the suggested reactor is done using the electromagnetic field simulation software of CST Studio Suite. A time-domain method is used for solving Maxwell equations and obtaining a fast estimation of electromagnetic performance over the desired bandwidth. Simulation results prove that standing wave is not formed along the reactor and microwave energy travels ahead. Consequently, the heating uniformity in the TMR is expected to improve. To validate that expectation, heating characteristic of different catalysts in the designed reactor are measured and will be discussed in the paper.

References

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Keywords
“Travelling Microwave”, “Uniform Heating”, “Microwave Reflections”, and “Methane Reforming”.