Electrifying Ethanol Dehydration for Emission-free Ethylene Production

Emre Turan[1], Robert Dieckmann[1], Michael Geske[1], Raoul Naumann D'Alnoncourt[1], Michael Bender[2], Benjamin Frank[2], Johannes Bode[2], Frank Rosowski[1,2]*

1 BasCat – UniCat BASF JointLab, D-10623 Berlin (Germany)

2 BASF SE, Group Research, D-67056 Ludwigshafen (Germany)

**Corresponding author: emre.turan@tu-berlin.de*

Highlights

- Successful demonstration of direct resistive heating of catalytic fixed-bed reactor
- Optimized reaction control through e-heated approach results in higher productivity
- Direct supply of heat eliminates the necessity for significant amount of water as heat carrier gas, prevents heat losses and enhances overall process energy-efficiency

1. Introduction

The substantial reliance on fossil fuels to meet global energy demands poses a significant obstacle to achieving climate neutrality targets [1]. A transformative shift is imperative, involving the adoption of renewable energy, advancements in heating technologies, and the utilization of regenerative feedstocks. Electrified catalytic reactors, leveraging technologies such as resistive, inductive, and microwave heating, offer a promising way to expedite this transition. While extensive research has delved into the resistive heating of electrically conductive reactor walls and structured catalysts in high-temperature applications, particularly in Steam-Methane-Reforming [2] and Reverse-Water-Gas Shift [3] reactions, limited attention has been given to resistively heated catalytic fixed-bed reactors [4,5]. Implementing resistive heating in a catalyst bed consisting of granules/particles is technically challenging due to the need for physical continuity and control over the contact area between conductive particles to prevent hot spot formation [6]. Nonetheless, on industrial scale, catalytic fixed-bed reactors involving granules/particles remain prevalent [7]. Our goal is to electrify endothermal reactions, optimizing control through an electrically heated fixed-bed approach for improved economic and ecological impact.

2. Methods

A single quartz glass tube reactor suitable for 5 ml catalyst was employed in the experimental setup to assess the catalyst bed resistivity under reaction conditions. The catalyst bed consisted of a homogeneous physical mixture of electrically conductive graphite particles and a commercial alumina catalyst with particles sizes of 0.5 – 1 mm, respectively. Catalytic investigations, incorporating resistive heating, were carried out in a nearly adiabatic double-tube reactor with radial heat insulation. Further investigations include the demonstration of various operation modes in a 500 ml scaled fixed-bed profile reactor on ethanol dehydration to ethylene reaction.

3. Results and discussion

Resistivity measurements showed that achieving the targeted bed resistivity requires a volume fraction of approx. 30% of conductive particles. The successful demonstration of resistive heating in an electrically conductive catalyst bed for endothermal ethanol dehydration showed that the target performance could be achieved at 325°C. Comparing to the reference isothermal kinetics, the homogeneous temperature distribution is evident, indicating the lack of detectable hotspots among conductive particles. In contrast to the industrial adiabatic process [8], which uses 75 wt.-% water in the feed as a heat carrier to prevent significant axial temperature gradients, the feed in e-heated approach consists of pure ethanol, as illustrated in figure 1. Consequently, significant heat losses in the heat carrier gas are inevitable. Additionally, resistive heating of the catalyst bed allows operation at a significantly higher space velocity ($WHSV_{Ethanol}$) at a comparable gas retention time compared to the industrial process with a large amount of water, responsible for high gas velocity.

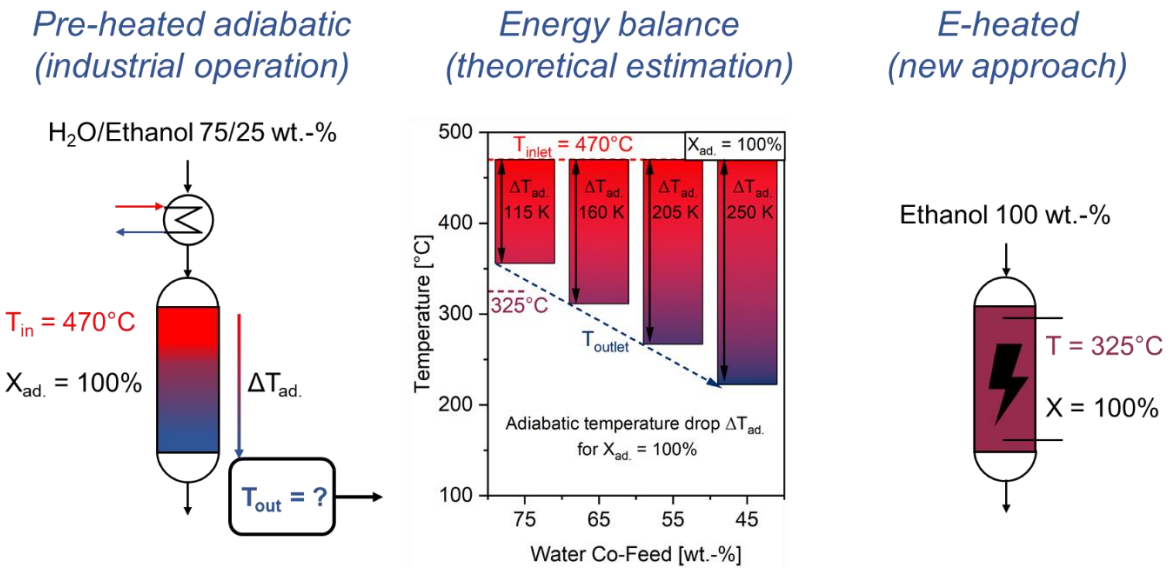

Figure 1. Comparison of the conventional adiabatic process and resistive heating on ethanol dehydration to ethylene

4. Conclusions

In the conventional adiabatic process, the performance is influenced by the heat supplied through gas pre-heating, whereas in case of resistive heating, performance is kinetically controlled. Therefore, the reaction is driven to the catalyst's capacity limit, enhancing catalyst utilization. While the pre-heated process is not able to achieve the target performance in the absence of water, e-heated approach demonstrates the ability to operate in omission of heat carrier. Eventually, resistive heating can enable to run endothermal reactions emission-free, simultaneously increase productivity and process energy-efficiency by preventing heat losses in heat carrier and separation expenses.

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Keywords
Electrification; Joule heating; Decarbonization; Process intensification