Design and verification of adiabatic pilot plant reactors

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Highlights

- A pilot size adiabatic reactor was constructed featuring vacuum heat insulation.
- Heating of both reactor ends is required to minimize heat losses in the axial direction.
- The measured temperature rise deviates 7% from the adiabatic temperature rise.

1. Introduction

Many industrial packed bed reactors are adiabatic as the volume to external surface area ratios are large and the amount of reaction heat that is exchanged with the environment is negligible compared to the total reaction heat involved. The opposite is usually the case for laboratory setups and heat losses of the reaction mixture to the surroundings lead to non-adiabatic operation, and even to quasi-isothermal operation if the scale is small enough. It is difficult to operate either adiabatically or isothermally at an intermediate scale, especially in processes that are highly exothermic or endothermic. This is the case for pilot scale reactors, which should operate similar to the industrial sized reactors. As a result, temperature profiles, hence chemical equilibria and reaction rates, are different from commercial units. This affects both the activity and selectivity of the conversion process. In the pilot phase of a new process design or a new catalyst implementation, it is crucial to assess process controllability, catalyst deactivation and product composition throughout a catalyst cycle. A careful design is required to prevent a too large deviation from adiabatic operation.

Pilot reactors or other smaller sized reactors can be designed to behave adiabatically by preventing heat flow between the reacting mixture and the equipment. This can be achieved in the radial direction by using heat insulation that is on the outside heated to a temperature close to the reactor temperature [1-2]. Depending on the axial temperature profile it will be necessary to install a certain number of heaters and control loops in order to minimize radial temperature differences at all axial positions in the bed. Heat conduction along the wall of the reactor is the main concern in the axial direction. The outer ends of the reactor are often not heated and connected to the support mechanism in pilot setups. These parts are therefore susceptible to significant heat losses. By keeping the top and bottom of the reactor at inlet and outlet temperature respectively, the heat losses along the wall can be minimized. The axial heat flow through the reactor wall within the reaction zone is another concern, especially if endothermic and/or exothermic reactions cause large axial temperature gradients in the catalyst bed. This can result in significant deviation from adiabatic operation even when net radial heat losses from the reactor zone are kept at a minimum. Since the wall thickness is set by safety requirements for the operating conditions, the most straightforward way to minimize the impact of axial heat transport is to adjust catalyst bed length and flow rates such that the heat flow of the reaction mixture by convection is sufficiently larger than that of axial conduction along the reactor wall and catalyst bed.

A pilot setup has been constructed to perform adiabatic tests at SABIC Geleen. This work involved the design and validation experimentation of the unit both in non-reacting conditions as well as in a gas phase exothermic hydrocarbon conversion process. We are evaluating different approaches to achieve adiabatic behavior of pilot scale reactors and compare their performance to calculated temperature profiles based on reaction kinetics. We present the performance of one of these designs in this abstract.

2. Methods

The adiabatic pilot reactor consists of a tube of 1.2 meter length, an inner diameter of 50 mm and a wall thickness of 5 mm. The reactor is loaded with 0.6 kg of catalyst giving about 500 mm bed height. A thermowell of 6 mm outer diameter and 7 thermocouples on different axial positions is centered in the catalyst zone. Figure 1 shows a schematic of the reactor. The adiabatic behavior is achieved by minimizing radial heat flow using a vacuum heat insulation. Heat losses by radiation are minimized by keeping the vacuum tube outer wall at the inlet reactor temperature and the average reactor temperature by two heaters. The unit is operated at a flow rate of 3.5 kg/hr in order to have fluid heat convection as the dominant mode of heat transport in the axial direction. Furthermore, the heat losses over the vacuum heat insulation are small at this flow rate even at higher temperature differences over the insulation.

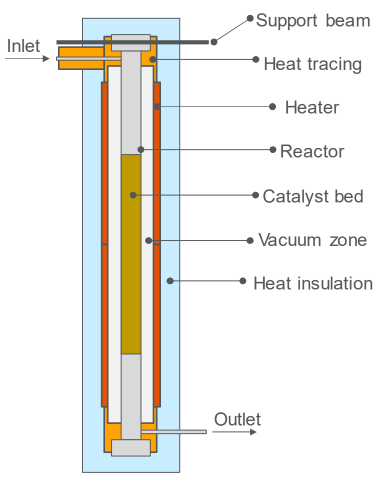

Figure 1. Schematic of the pilot reactor

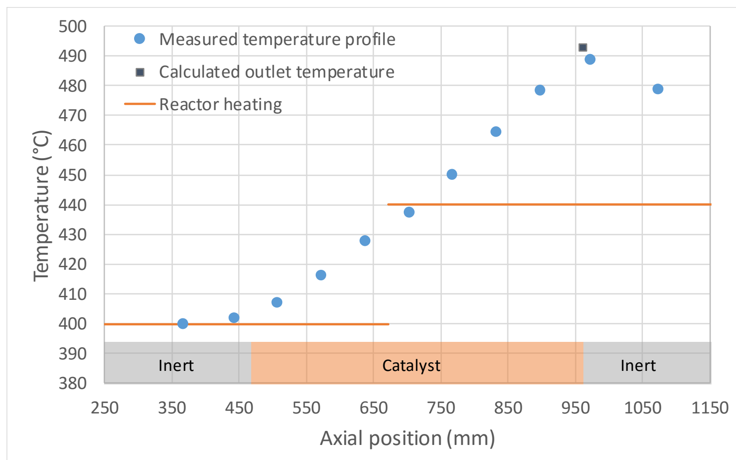

Figure 2. Axial temperature profile and calculated outlet temperature

3. Results and discussion

Figure 2 shows the central measured axial temperature profile during hydrocarbon conversion with an inlet temperature of 400°C. The two horizontal lines represent the temperature and location of the two vacuum insulation heaters. The square data point shows the calculated adiabatic outlet temperature based on the enthalpy of the effluent with measured composition. The measured temperature is about 7 K lower, which is an error of 7% on a total ΔT of 96 K. Under non-adiabatic conditions, the temperature associated with the product composition would be significantly lower than the outlet temperature measured at the radial center of the reactor.

4. Conclusions

An adiabatic pilot reactor has been constructed featuring a vacuum heat insulation and heat tracing at the top and bottom end. The initial tests show good adiabatic behavior. An outlet temperature was observed of about 7% below the calculated temperature based on the product composition in an exothermic hydrocarbon conversion process.

References

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Keywords
Pilot plant; adiabatic testing; heat transfer