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Infrared imaging of temperature profiles in microreactors for fast and exothermic reactions

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HIGHLIGHTS

- ▶ *Non-intrusive infrared thermometry* is developed for quantification of temperature profiles in a microreactor.
- ▶ Method allows a resolution of 250 data points/cm^2 and precision of 1 °C.
- ▶ Microcapillary with highly exothermic and fast hydrolysis of tetraethoxysilane was characterized.
- ▶ Location and the magnitude of a hot spot was identified.

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ABSTRACT

Though microreactors provide high heat transfer rates, temperature profiles are formed in case of fast and highly exothermic reactions. A method based on non-intrusive infrared thermometry has been developed to track these profiles quantitatively with a resolution of 250 data points/cm^2 and a precision of 1 °C. By placing the microreactor at a pressure of 10^{-2} mbar, convective heat losses are efficiently suppressed which assures well defined boundaries and reproducible results. The temperature profiles of the fast and exothermic hydrolysis of tetraethoxysilane were measured inside a microcapillary at different flow rates via infrared transparent window. In the reactor provided with a cooling system, the heat transfer coefficient was determined by thermal imaging for different operating conditions. The data obtained are in good agreement with the values reported in literature.

1. Introduction

In the last decade, microreactors have been successfully applied to carry out efficiently numerous chemical reactions attracting a growing interest [1–4]. Compared to conventional equipment, they present unique properties due to at least one characteristic dimension smaller than 1000 μm. The main advantages of microreactors are the substantially increased mass and heat transfer properties [5,6]. In the case of a tube with a diameter d_t, the volumetric heat transfer coefficient for laminar flow in a double jacketed heat exchanger is proportional to $1/d_t^2$, which leads to an increase of heat transfer rates by 3–4 orders of magnitude for $d_t \approx 100$–500 μm as compared to conventional tubes ($d_t \approx 2.54$ cm).

Using microreactors, fast and exothermic reactions with characteristic reaction times in the order of several seconds can be carried out isothermally by simply adjusting the reactor diameter to the heat production rate of the reaction [7,8]. If almost instantaneous and highly exothermic reactions are carried out, a temperature profile appears even in microreactors as for practical reasons the diameter is usually limited to about >100 μm [7].

The axial temperature profile within thin channels depends on several parameters, like the kinetics and thermodynamics of the reaction, the design of the reactor, physical properties of the reactants and the quality of mixing achieved. In microchannels the relative importance of some effects is very different as compared to conventional reactors, which is usually referred as "scaling effect". For example, when working with conventional batch reactors with relatively slow reactions, mixing time is negligible compared to reaction time and hence, does not affect the overall rate of transformation. However, reactions carried out in microreactors are generally so fast that they may be influenced or totally controlled by mixing.

So far, only a limited amount of studies on thermal behavior of microreactors are available in open literature. Furthermore, most of the work is done by numerical simulation which can only reflect the temperature profile under ideal conditions.

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