Journal of Process Control 50 (2017) 29–39

Contents lists available at ScienceDirect

Journal of Process Control

journal homepage: www.elsevier.com/locate/jprocont

Adaptive local tracking of a temperature profile in tubular reactor with partial measurements

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ARTICLE INFO

Article history:
Received 5 December 2015
Received in revised form 16 October 2016
Accepted 21 November 2016

Keywords:
Adaptive control
Nonlinear distributed parameter systems
Input constraints
Non-isothermal tubular reactor
λ-Tracking

ABSTRACT

In this work, a local constrained adaptive output feedback is presented for a class of exothermic tubular reactors models described by a nonlinear partial differential equations. The considered output is the measured temperature in a fixed zone of the reactor to regulate the temperature throughout the reactor to a ball with radius λ (arbitrarily small) centered at the fixed temperature profile. For a given measurement zone with length given in terms of the desired profile and λ and for initial temperature in a fixed domain, it is shown that the tracking error through the reactor tends asymptotically to a ball of arbitrary prescribed radius $\lambda > 0$, centered at the given temperature profile. Numerical simulations have been performed to illustrate the performance of the proposed approach.

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1. Introduction

In the last decades, an intensive research activity has been dedicated to the control design of linear and nonlinear infinite dimensional systems [9–11,17] and the references therein for linear systems and [8,15,18] for nonlinear systems, especially the nonlinear tubular reactor systems see [1–5].

A question of interest in the control of isothermal tubular reactor is the design of a controller for the temperature with a reference profile control, more specifically in the presence of additional practical considerations like the presence of input constraints typically encountered in the control of chemical processes. As in many control problems where variables need to satisfy constraints and where the output of the controlled process has to track a reference signal, one particular technique that addresses such problems is adaptive λ tracking controller see [13] that achieve the convergence to the desired profile taking into account the state and control constraints.

In this paper we propose an input constrained adaptive output feedback control with partial measurements for a non-isothermal tubular chemical reactor with axial dispersion. The dynamic of such reactors are described by nonlinear partial differential equations derived from mass and energy balances [23].

Our objective is to regulate the reactor temperature in a prespecified neighborhood of a given reference profile. Recently, a constrained adaptive output feedback has been developed for this class of models with same objective [4,5], by using a modified λ-tracking controllers originally developed in a finite dimensional context for a similar problem [2,12,13]. It has been shown that under a simple feasibility assumptions in terms of the reference temperature and the input constraints that the reactor temperature tends asymptotically to a ball of temperature profile with arbitrary prescribed radius $\lambda > 0$. The proposed control law has the shortcoming that it requires access to temperature measurements along the tubular reactor which present a practical limitation of these approaches. To overcome this limitation, we deal in this work with the possibility that the useful temperatures measurements for the regulation are only available via a finite number of zone sensors (without taking their emplacement into account). Installing all the necessary sensors may not be physically possible or the costs may become prohibitive. In other words, we consider only partial measurements obtained by a finite number of sensors.

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http://dx.doi.org/10.1016/j.jprocont.2016.11.006
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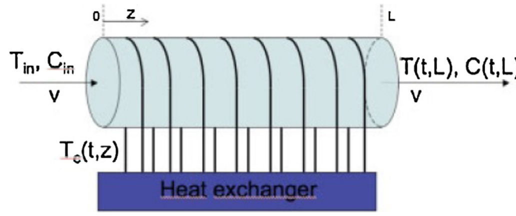

Fig. 1. Schematic view of an non-isothermal reactor with distributed heat exchange.

The paper is organized as follows. In Section 2 we present the basic dynamical model and we reformulate the problem within the framework of the semi-linear systems. Section 3 is dedicated to the development of our main result on adaptive and non-adaptive λ-tracking. An example is presented in Section 4 to illustrate our results via numerical simulation.

2. State space framework and statement of the control problem

Let us consider a non-isothermal reactor (Fig. 1) with the following chemical reaction:

$$A \longrightarrow bB \tag{1}$$

where $b > 0$, A and B are the stoichiometric coefficient of the reaction, the reactant and the product, respectively.

In the present study, along the lines of [15] as well as in line with practical chemical engineering considerations on the use of cascade non-isothermal reactors[1] (see [19]), we consider distributed heat exchange. The dynamics of the process in an exothermic tubular reactor with axial dispersion are readily obtained from energy and mass balances and are given by the following partial differential equations (e.g. [4,15]):

$$\begin{aligned} \frac{\partial T(t,z)}{\partial t} &= D_1 \frac{\partial^2 T(t,z)}{\partial z^2} - v\frac{\partial T(t,z)}{\partial z} - \alpha f(T(t,z), C(t,z)) - k_0(T(t,z) - T_c(t,z)) \\ \frac{\partial C(t,z)}{\partial t} &= D_2 \frac{\partial^2 C(t,z)}{\partial z^2} - v\frac{\partial C(t,z)}{\partial z} - f(T(t,z), C(t,z)) \end{aligned} \tag{2}$$

with the boundary conditions:

$$-D_1 \frac{\partial T(t,0)}{\partial z} = v(T_{in}(t) - T(t,0)) \tag{3}$$

$$-D_2 \frac{\partial C(t,0)}{\partial z} = v(C_{in}(t) - C(t,0)) \tag{4}$$

$$\frac{\partial T(t,L)}{\partial z} = 0 \tag{5}$$

$$\frac{\partial C(t,L)}{\partial z} = 0 \tag{6}$$

In the above equations, t (>0) and z ($\in [0, L]$ with $L = 1 > 0$) hold for the time and the reactor length, respectively. $k_0 = \frac{4h}{\rho C_p d}$ (>0), $\alpha = \frac{-\Delta H}{\rho C_p}$ (>0), T, C, $D_1 > 0$, $D_2 > 0$, $v > 0$, $\Delta H < 0$, ρ, C_p, h, d, T_c, T_{in} and C_{in} are the temperature reactor, the reactant concentration, the energy and mass dispersion coefficients, the superficial fluid velocity, the heat of the reaction, the density, the specific heat, the wall heat transfer coefficient, the reactor diameter, the coolant temperature, the inlet temperature, and the inlet concentration, respectively.

$f(T(t,z), C(t,z))$ represents the kinetics of reaction (1). It is a nonlinear, positive and locally Lipschitz function. The positivity of f is a direct consequence of the standard kinetics rules (e.g. [19]) for the irreversible reaction (1) in which the reactant A is consumed and the product B is synthesized. A typical example of $f(T(t,z), C(t,z))$ is the reaction rate of first-order kinetics with respect to the reactant concentration C and characterized by an Arrhenius type dependence with respect to the temperature T

$$f(T(t,z), C(t,z)) = kC(t,z)e^{-\frac{E}{RT(t,z)}} \tag{7}$$

with $k > 0$, $E > 0$ and $R > 0$ the kinetic constant, the activation energy and the ideal gas constant, respectively.

In order to write the model (2)–(6) in an abstract semigroup formulation in Hilbert space, we consider the Hilbert space $H = L^2[0, 1]$ endowed with the usual inner product:

$$\langle f, g\rangle_H = \langle f, g\rangle = \int_0^L f(z)g(z)\,dz \tag{8}$$

and the usual partial order defined by

$$f \le g \quad \text{if and only if} \quad f(z) \le g(z) \quad \text{for almost every} \quad z \in [0, L] \tag{9}$$

[1] The tubular reactor being then the limit case when the number of tanks in the cascade is large enough.

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