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Feedback induction of limit cycle in a bioreactor: controlling towards scale-down

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Abstract

The feedback stabilization of periodic orbits (induction of limit cycle) via PI-like control is proposed as plausible tool for scale-down studies. An isothermal continuous stirred tank bioreactor (CSTB), with nonideal mixing, is studied. Kinetics is assumed to be governed by Haldane law. The Ready-to-use equations for selecting the control gains are given. Thus, osccilatory behavior with arbitrary frequency and amplitude can be induced into the PI-controlled CSTB.

I. Introduction

Dynamical analysis of reacting systems is now a classical topic in chemical engineering.[14] From its study, oscillatory behavior has been found in reactions which has been atributed to kinetics[18] or the reactor configuration.[2,19] Concerning kinetics, among others, results have been reported on reactions isothermal forced,[20] autocatalityc (self-oscillating)[18,3,21] and electrochemical.[9] In regard reactors, the most studied has been the non-isothermal stirred-tank (see results in[14,2,19,4,6,13]). Oscillations in reactors has already been explained in terms of feedback[6,13] or recycling[7] interconnections.

Currently, the reasearch goal of studying oscillatory behavior in reacting systems is about industry applications. In particular, scientific efforts are directed onto scale-down analyisis of biological reactors. The underlying idea is to reproduce phenomena from production-scale to laboratory- or pilot-salce reactors. Several studies have been done in this sense but two research directions can be identified in open literature:

- *Construct novel bioreactor configuration.* This can be performed in mixing designs (see[15] for an experimental setup) or connected bioreactors (see[12] for numerical simulation). First case, mixing designs, aims to emulate conditions in production-scale reactors (fluctuating conditions). Whereas the connected reactors confuguration search to different conditions (each in a respective reactor corresponding, for example, to oxygen-rich and oxygen-poor conditions). In both mixing-design and copupled-reactors, the prupose is to emulate fluctating conditions species concentration, related to mixing-time-dependent phenomena, and scale-down is suitably studied by modifing stirres. The drawback of constructing reactors configurations is to perform experimental runs with unpredictable results (increasing cost of scale-down studies).

- *Control structure.* Studies are devoted to (i) tracking of oscillatory (arbitrary) signals and (ii) analysis of oscillations induction due to existence of homoclinic orbits (see[13] and references therein). Since proportional-integral controller (PI) is the mostly used in industry to control reactors, the efforts are devoted to study PI-like controlled reactors. Two drawbacks are found in tracking. On the one hand, tracking does not exploit the dynamic nature of the reactor, and as a consequence, since the idea in tracking is to compensate (destroy) the reactor dynamics, large control effort is often required to track the osicllatory signal. The second disadvantage is that a PI-like controller is, by its nature, restricted to track high frequency oscillations. Concerning oscillation induction, the attention is payed on existence of chaotic attractors[6] or bifurcation.[16] Teh problem in thescale-down context is to propose algorithms to induce periodic oscillations with different ferquencies and amplitudes. Actually, chaotic behavior cannot be exploited in this direction because of choas implies wide-band oscillatory beavior. Additionally, bifurcation análisis cannot also be used due to it involves existence of oscillatory behavior. That is, ready-to-use equations towards scale-down analysis cannot currently be found either chaos or bifurcation.

Substrate gradients can be found in production-scale bioreactors,[1] and can be seen as substrate fluctuations around cells into the bioreactor. Henceforth, the induction of oscillatory behavior into bioreactor in lab- or pilot-scale bioreactor can be used to understand kinetic effect (physiological responses) from such fluctuations.[5] In this contribution, ready-to-use equations towards scale-down are derived for a class of biological reactor. The underlying idea is, by exploiting dynamical properties of a PI-like controlled bioreactor, to induce periodic oscillatory behavior with arbitrary frequency an amplitude. The PI-controller does not perform tracking; indeed bioreactor stabilizability is used. Thus, the substrate oscillation into the bioreactor lies in the physical domain of the PI-controlled bioreactor. The class of system includes Cholette's reactors (i.e., an isothermal CSTB) with nonideal mixing and Haldane reaction rate. Haldane kinetics involves inhibitory effects at high substrate concentration. Some studies on Cholette's reactor show that: (i) it can be stabilized by PI-like control[17] and (ii) it is affected by nonideal mixing.[11] Then, the contribution raises from practical problem: *scale-down analysis*.

The problem is addressed from theory of dynamical system.[8] The analysis is done on a 2-dimensional smooth system (the PI-controlled bioreactor) with form $\dot{x} = f(x, u)$, where x is a real scalar that represents the suctrate concentration and u is the control command. The purpose is to study the existence of periodic orbits at domain - of the pair $(x, u) \in R_+ \times R$ near equilibrium the point $(x^*, u^*) \in$ - . The control gains are found such that oscillatory behavior is induced into the PI-controlled bioreactor by using its dynamical properties. In this manner, a guideline is provided to study oscillatory phenomena at bioreactor in the context of the scale-down analysis.

The model and basic assumptions are shown in Section 2. The stability of the PI-controlled bioreactor is also discussed. In Section 3, we give few basic preliminaries on the dynamical systems theory; which are used in main results. The main results are contained in Section 4 and, finally, the text is closed with concluding remarks.

II. Model and stabilization

A. Reactor dynamics

III. Research Bibliography

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