C-04: Mathematical models and controller designs for bioreactors

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Biological reactors are classical examples of non-linear systems. Although they can be described by simple non-linear dynamical equations, they exhibit very complex behaviours such as multiple steady states, bifurcation characteristics and chaos. Operating such dynamical processes at the unstable steady states poses challenging problems to the control engineers.

We have studied 2 different types of models that describe the dynamics of bioreactor processes. The first model is the commonly used Chemostat model incorporating the substrate inhibition model. This model has multiple steady states for a given dilution rate, with one of them a saddle point. Operating such bioreactors at these unstable saddle points may be necessary to obtain data for modelling and designing bioreactors or for the optimum performance of serially connected bioreactors in some application.

The second model investigated is the model proposed by Agrawal. This model shows multiple steady state solutions with bifurcation characteristics. When there is a limit cycle, i.e. an oscillatory behaviour, it is a stable one, but both the steady states are unstable, one a saddle point and the other an unstable node. The operation of this bioreactor at the unstable nodes which are of higher conversion compared to the saddle points is useful in achieving optimal performance.

Our control objective was to operate the biological process described by the above models at unstable steady states. To achieve this we employed PI controller with anti-windup compensators, Linear Quadratic state feedback controller, Input- Output Linearized controllers and Robust non-linear controllers. We studied the stability aspects when the nutrients input flow is constrained and observed that by the introduction of the anti- windup compensators in the controller, the domain of local stability which was affected by these constraints can be improved. A comparative study on the dynamical behaviour of the Chemostat model using the above mentioned controllers was carried out.

For Agrawal's model one of the main problems was that for a given value of the cell concentration there were 2 steady states which correspond to 2 different input values. When a desired cell concentration is given, only the Proportional controller and the state feedback controller could stabilise the bioreactor at the unstable node which is inside the limit cycle. Moreover, in the case of P controller the stability margin was very small. More sophisticated control systems, like linearized state feedback and non-linear Robust controller, could not stabilize the system at the unstable node and further analysis showed that this is due to the unstable zero dynamics of bioreactor at this steady state.