Multivariable control of a catalytic reverse flow reactor: Comparison between LQR and MPC approaches

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Multivariable Control of a Catalytic Reverse Flow Reactor: Comparison between LQR and MPC Approaches

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Abstract

This paper is devoted to the MIMO control of the catalytic reverse flow reactor (RFR) which aims to reduce the amount of volatile organic compounds (VOCs) released in the atmosphere. The RFR is characterized by the periodic reversal of the gas flow that aims to trap the heat of reaction inside the RFR. The control issue is to confine the hot spot temperature inside an envelope (in order to ensure complete conversion of the pollutant and to prevent catalyst overheating) in spite of stochastic variations of the inlet pollutant concentration (the input disturbance). The manipulated variables (dilution rate α and internal electric heating Q) have to be optimized. Closed-loop performances of the LQR and the MPC are compared through simulations.

Keywords: Optimal reverse flow reactor control.

Process description

A medium-scale RFR (Nieken et al.) is considered (Figure 1). Cordierite monoliths of square cross sections with channels of 1*1 mm are packed in the reactor. Monolith in the core region is catalytically active and is inert in both end sections. A blower located downstream of the RFR keeps aspiration of the pollutant at a constant flow rate. In the core region, an electric heater maintains ignition temperature, while the temperature in the catalytic layer is decreased by fresh air dilution. The packed layer is adiabatic, except in the core region where heat loss is inevitable due to both the installation for air dilution and the high temperature in this region. High temperatures exist in catalyst bed whereas the inlet and outlet gas stream have ambient temperature. Indeed, through periodic flow reversal, heat released by reaction is first trapped in the packing and then used to heat up the feed. The model considered here for control purpose is obtained from a countercurrent pseudo-homogeneous model (Edouard and Hammouri), accounts for mass transfer limitation and periodic frequency correction: it features one nonlinear parabolic PDE, two algebraic equations, and nonlinear boundary conditions. The nonlinearities are due to the cooling action. The advantages of this model are that it is more accurate and faster to compute than a previous model used for control (Dufour et al., Dufour and Touré).

Process control framework

The input disturbance (characterised by the adiabatic temperature rise ΔT_{ad} (Figure 2)) is assumed to vary randomly between 0 K and 115 K. If no control is applied to the RFR, the hot-spot temperature exceeds both temperature limits (450 K and 600 K). This clearly justifies the need for closed loop control. Few papers are devoted to the control of the RFR. Here, the stochastic input disturbance has a more realistic stochastic behaviour than in the previous RFR control studies (Budman et al., Dufour et al., Dufour and Touré). This disturbance and the temperature profile in the RFR are estimated on-line using a high gain observer based on three temperatures measurements (Edouard and Hammouri). The estimate state is injected in the LQR whereas the MPC is based on the estimated input disturbance. Simulation results allow comparing the closed-loop performances obtained with the LQR and the MPC.

Closed loop performances with LQR

The output constraints are satisfied at any time. Between 500s and 1550s, the input disturbance leads to a decrease of the temperature inside the reactor (Figure 3). LQR correctly tunes the internal heating (Figure 4) such that the temperature stays above the extinction temperature. No dilution is taking place. After 1550s, rich feed induces an increase of temperature inside the reactor. LQR tunes the dilution rate such that the temperature is maintained below the maximum temperature and there is no more heating.

Closed loop performances with MPC

The output constraints are also satisfied at any time (Figure 5). Between 0s and 1300s, ΔT_{ad} is small (Figure 2) and extinction of the process is avoided feeding electrical power into the reactor (Figure 6). In the meantime, there is no cooling action and the maximum amount of gas is therefore treated as expected in these conditions. After 1500s, ΔT_{ad} becomes important and overheating of the process is avoided (see the upper bound constraint on Figure 5) due to the correct use of the cooling action. The drawback is that the controller may sometimes require both heating and cooling actions at the same time (at 3180s e.g.), which should not happen.

Conclusions

In spite of large input disturbance due to the feed concentration, the temperature can be maintained by both observer based controllers inside the specified temperature envelope. Concerning the optimization performances, LQR leads here to better results than MPC since it requires less heating action while treating more gas: $\overline{Q}$ =83.4W and $\overline{\alpha}$ =0.894 for LQR, $\overline{Q}$ =274.6W and $\overline{\alpha}$ =0.849 for MPC (these mean values are calculated from t=0s to t=4500s). This difference is mostly due to the impact of the stochastic variations of the input disturbance over MPC. Indeed, the estimation of the disturbance ΔT_{ad} is directly used in the MPC, where it is assumed constant in the future. This may forces the MPC to overevaluate the need for heating and cooling. Combining this issue with the non minimum phase behaviour of the process, the horizons tuning is uneasy. In the meantime, a switching control structure is used for the LQR: therefore, heating and cooling action are decoupled and can not acting at the same time as expected. The drawback is that it introduces a severe nonlinearity for stability analysis whereas MPC is more suitable than the LQR for general MIMO control problems.

References

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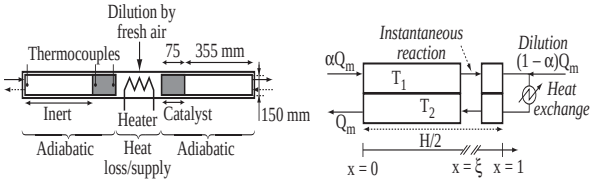

Figure 1: RFR description and RFR countercurrent model.

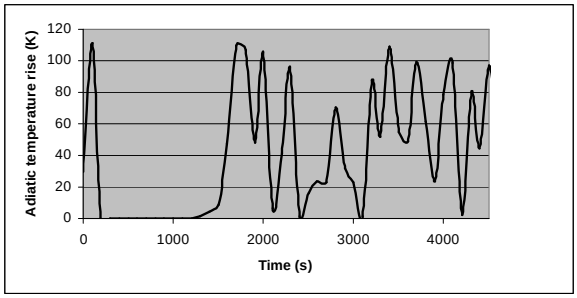

Figure 2: Adiabatic temperature rise.

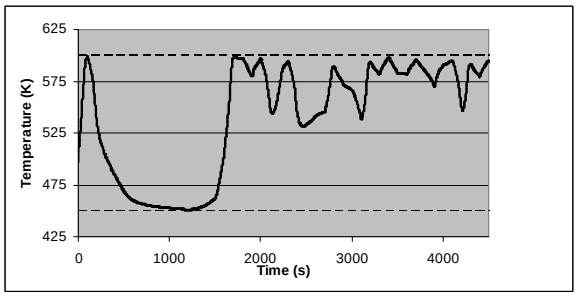

Figure 3: Hot spot temperature (LQR).

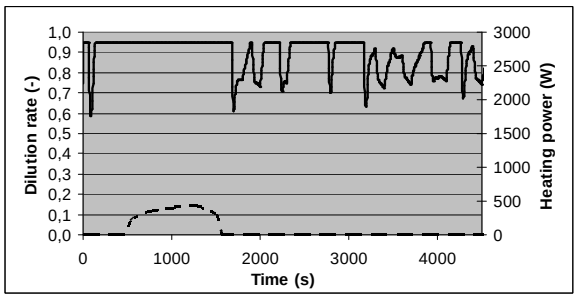

Figure 4: Cooling action (cont.)
and heating action (dashed) (LQR).

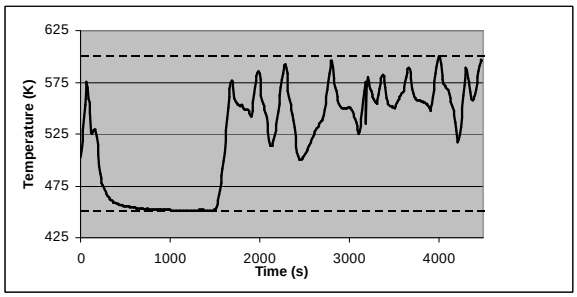

Figure 5: Hot spot temperature (MPC).

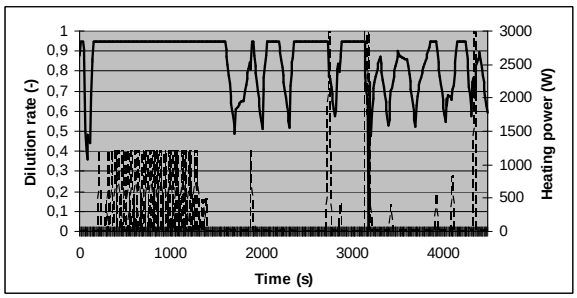

Figure 6: Cooling action (cont.)
and heating action (dashed) (MPC).