How to find the optimal sensor location for distributed parameter systems?

An intuitive approach.

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Introduction

Monitoring and control of chemical processes is an important task. The product (output) should always satisfy defined specifications. Different sensors at different positions and various points in time can be used. Question is how to monitor in the optimal way: where to place the sensor, when to measure?

Theory

Steady state processes → the optimal sensor position independent of time

Non-steady state processes → the optimal sensor position dependent of time

The new approach can be used for every (steady or non-steady state) process whenever a process model is available.
The main idea is to place the sensor at that position where the states of the process are the most distinguishable (Figure 1).

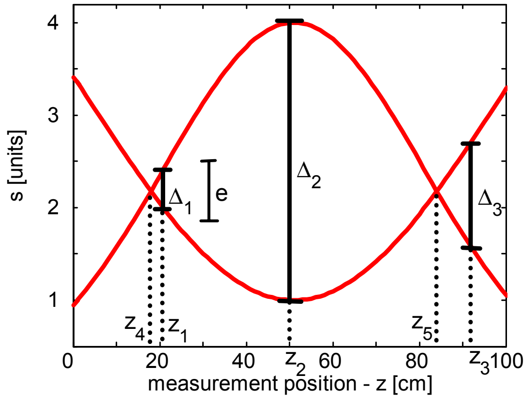

Figure 1. Differences between two states (s) measured for two different times.

z_4 & z_5 – states are undistinguishable

$\Delta_1 < \Delta_3 < \Delta_2 \Rightarrow$ optimal sensor position = z_2

In a dynamic process the states are changing with time. The most difficult task is to distinguish between states at almost the same point in time ($\Delta t \to 0$).

$$\underset{z}{\operatorname{argmax}} \left| \left[\lim_{\Delta t \to 0} \left(\frac{s(z,t) - s(z,t+\Delta t)}{\Delta t} \right) \right] \right| \qquad [1]$$

$$\underset{z}{\operatorname{argmax}} \left| \frac{\partial s(z,t)}{\partial t} \right| = \text{optimal analyzer position for time } t \qquad [2]$$

The optimal sensor location is at the place were the state s(z,t) is changing the fastest.

Example and results:

Illustration of the approach: The binary adsorption of benzene and toluene on charcoal in packed bed (PB) filter.
Predefined limiting value for both components at the outlet:
$1\cdot10^{-9}$ gmol/cm^3

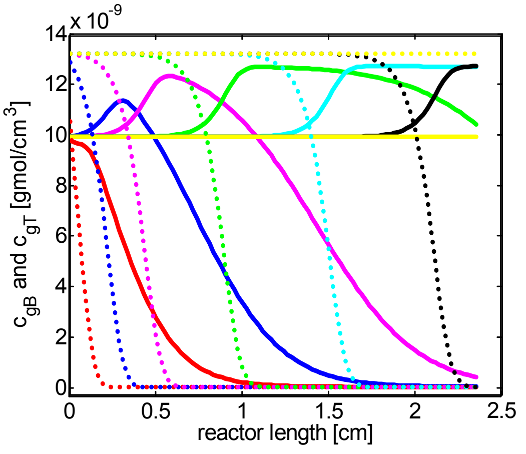

Figure 2. Benzene (solid line) and toluene (dotted line) profiles through reactor for different times.

Question: Where to measure in order to replace PB filter in time (outlet concentration above limiting value)?

Benzene elutes from PB first! – we are interested only in its profiles (Figure 2).
Eq. [2] solved for benzene concentration gives the optimal sensor position as a function of time (Figure 3).

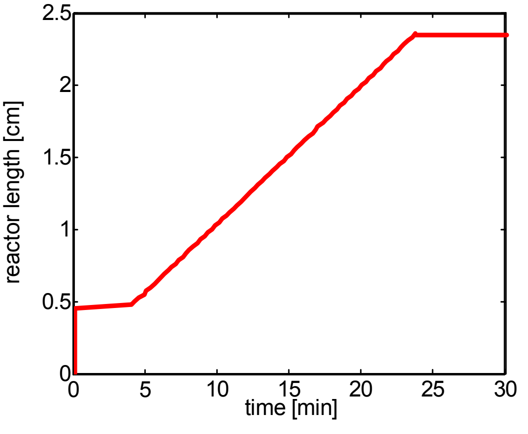

Figure 3. Optimal position for sensor placement in time.

From the process model: benzene reaches limited value after 17.3 min

⇓ Figure 3.

Optimal sensor position: 1.77 cm from the PB inlet

Conclusions

- Optimal sensor position for non-steady state processes is a function of time.
- The proposed approach is applicable for every linear or non-linear distributed parameter system if the model is known.
- Approach is mathematically simple.
- It has been applied to a packed bed filter and it yielded intuitively satisfying results.

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