Exercises

Process monitoring

Plant-wide control

Problem 4 (4 points)

a) In dimension reduction based monitoring methods the dimension of the original measurement space is reduced. Give three examples of how the adequate number dimensions can be determined. (2 p)
b) Explain why many industrial systems are sufficiently described by only a few independent variables (e.g. principal components) although many more measurement variables are generally available. Give two reasons! (2 p)

PCA - no of components

- "Quick and dirty" for auto scaled data
  - Retain all components with singular value larger than 1
- Retain according to variability explained
  - Generally >80%
- Look for large jump in singular values
  - Scree plots
- Cross validation techniques

Solution:

a) The "quick and dirty" method, amount of variance explained (e.g. >80%), cross-validation techniques, scree plots (looking for a knee).
b) Redundant measurements for safety reasons, many variables are coupled (e.g. pressure in a pipe at different locations), the measured variables are often indirect measures of a few underlying main mechanisms driving the process.

Problem 6 (4 points)
Consider the process in Figure 1. It is an anaerobic digestion process used to produce biogas for heaters and vehicles. The overall goal of the process is to produce as much biogas as possible with the required quality (percentage of methane). One problem is the changing nature of the raw material composition made of organic solids in the slurry. The changes of the composition results in changes in the biological reactions (BR) in the process. The process consists of a reactor with a continuous input and output of organic slurry. The more slurry fed to the process the more gas produced as long as the biological process is not overloaded. The mean retention time (MRT) (*uppehållstid*) is about 12 days and corresponds to the average slurry feed rate to the reactor (all slurry must be used – no bypass possibilities). The gas produced raises to the surface of the slurry and is trapped in the gas filled head space (HS) above the slurry. The amount of slurry may change over time (input ? output) which implies that the HS changes in volume. The main mechanisms and the relations between important variables of the process are described below.

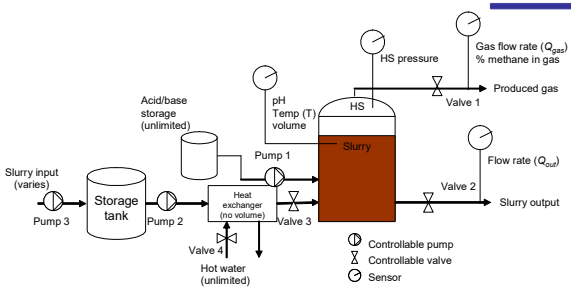

Figure 1. Biogas production process.

1 Biological reactions: *BR = f (MRT, T, pH, composition)*
2 Gas pressure HS: P_{HS} *= f (gas valve, BR)*
3 Gas flow rate: Q_{gas} *= f (BR,* P_{HS}*)*
4 pH in the reactor: *pH = f (addition of acid/base, BR)*
5 Temperature: *T = f (flow rate of heated water, ambient temperature, BR)*
6 Retention time: *MRT = f(added slurry, removed slurry)*

Most of the variables can be varied within reasonable ranges. Reactor temperature may vary between 30 and 38 °C, the MRT can range between 8 and 16 days without causing any process problems, the pH can be controlled between 6.5 to 8 and the pressure may range from atmospheric (1 bar) to 1 bar overpressure (2 bar). Liquid levels in the reactor and the storage tank are naturally limited by the tank geometry.

Based on the information above and using the definitions in Skogestad 2004:
a) What is the number of dynamic or control degrees of freedom (N_m)? Motivate! (1 p)
b) What is the number of the steady state degrees of freedom (N_{ss})? Motivate! (1 p)
c) What is the number of the unconstrained degrees of freedom (N_{opt})? Motivate! (2 p)

Solution
a) Nm=6. Pump 1, 2, 3 + valve 1 , 2 4. Note that valve 3 is obsolete if pump 2 is considered as manipulated variable. They are not independent.
b) N_{ss} = 4. In steady state, the liquid levels in both the storage tank and the reactor must be constant. This means that pump 2, 3 and valve 2, 3 are all dependent and must be balanced. The independent manipulated variables are: valve 4 + pump 1 + valve 1 + one of pump 2, 3 and valve 2, 3.
c) N_{opt} = 3. The active constraint of the process is that the feed of slurry is less than what the process can optimally handle. This means that the MRT is limited by the supply and cannot be considered independent since optimum will be at the minimum MRT. Left for optimization are: temperature, pH and gas pressure or expressed in manipulated variables: pump1, valve 1 and valve 4.