1. The figure shows a chemical stirred-tank reactor (CSTR), where a reaction $A \rightarrow B$ takes place. The heat of reaction is zero and the reaction rate depends on the reactor temperature $T$, the $A$ concentration $C_A$, and the inhibitor concentration $C_x$ (both in the reactor) according to $r_A = -k_0 e^{-E/RT} C_A(1 + kC_x)^{-1}$, where $k_0$, $k$, $E$ and $R$ are constants. This information is given for completeness — it may have no bearing on the solution.

The goal is to control the reactor concentration tightly by single-loop or cascade control, whichever is better. For each of the following disturbances, design the best control system, explain your design and illustrate it by a block diagram:

(a) the pressure $P_1$ of the heating medium;
(b) the temperature $T_s$ of the solvent feed before the preheater;
(c) the pressure $P_2$ of the reactant feed;
(d) the concentration $C_x$ of the inhibitor, which enters the reactor with the solvent.

The available measurements are the concentration of $A$ in the reactor, the reactor temperature, the flow rates of reactant and solvent, and the temperature of the solvent after the preheater. The flow rates of the streams indicated by valves can be used as control variables.

2. Given the process in the figure below, place them in order of how much each would benefit from feedforward control for a disturbance measured by the analyzer $A$. In the figure, $\theta$ denotes a time delay and $\tau$ denotes the time constant of a first-order system. Explain your ranking and illustrate the feedforward/feedback control by a block diagram.

3. A moist film is dried using two sources of heat as illustrated in the figure: an expensive electrical IR heater, which has a rapid effect on the moisture in the material, and a less costly steam heater, which has a slower effect. Design a control system to provide tight control of the moisture and to minimize energy costs. No controller tuning is required.