Effect of recycle on control of a purely integrating process

Mohammed Adlouni, Perstorp AB

2016-06-15

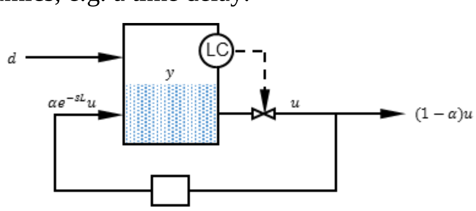
Aiming for higher plant efficiency, recycling heat and material seems to be on the rise. The numerous interconnections between units can result in plantwide effects of underperforming control loops. Some of these are due to recycle.

Introduction

Chemical plant designs with heat or material recycle are becoming more common due to economic and environmental reasons. Underperforming control loops in chemical plants may in some cases be attributed to the presence of recycle streams. This is because recycle alters the dynamics of neighboring processes. During commissioning work, when control engineers are tuning control loops, they are often under time pressure and it is therefore not unusual to try to perform as short step response experiments as possible. Recycle dynamics could then be missed altogether. Recycle could depend on a controlled variable, an uncontrolled variable or a manipulated variable. This paper will shed some light on how control of a purely integrating process is affected by the addition of a recycle stream that is a function of the manipulated variable.

Analysis

Consider a tank with an inflow and outflow in which the level is controlled by manipulating the outflow. The level is modeled as a purely integrating process. This simple system is very common in industry and there are many well-known methods for tuning it. Further, consider adding a recycle stream back into the tank that is a fraction of the outflow with some given dynamics, e.g. a time delay.



The relevance of such a configuration lies the fact that similar systems can be found throughout chemical plants, e.g. when heat integrating distillation columns. Below, an analysis will be presented regarding how the process is changed as well as the consequences that the recycle has on the tuning procedure and control performance.

Let the process from u to y without recycle be

$$P(s) = \frac{k_v}{s} \tag{1}$$

where k_v is the speed gain. Further let $H(s)$ be the recycle dynamics. If

$$H(s) = \alpha e^{-sL} \tag{2}$$

where α is the fraction of tank outflow that is recycled and L is a time delay, the process from u to y with recycle is

$$P_r(s) = P(1-H) = \frac{k_v}{s}(1-\alpha e^{-sL}) \tag{3}$$

With the PI controller

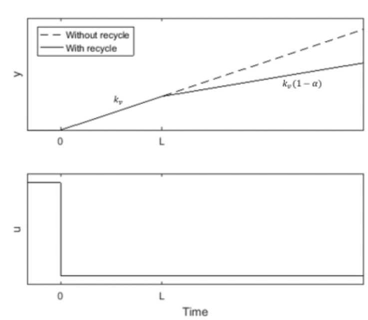
$$C(s) = K_c\left(\frac{1+sT_i}{sT_i}\right) \tag{4}$$

the closed loop transfer function for the system becomes

$$G_{yr}(s) = \frac{P_r(s)C(s)}{1+P_r(s)C(s)} = \frac{k_v K_c(1+sT_i)(1-\alpha e^{-sL})}{k_v K_c(1+sT_i)(1-\alpha e^{-sL})+s^2 T_i} \tag{5}$$

which is clearly irrational.

When performing a step response experiment on the process P_r, the speed gain for $t < L$ is k_v while it is $k_v(1-\alpha)$ for $t > L$.



The implication of this is that the length of the step response experiment has become much more important than for the process without recycle. One common tuning method for PI-controlled integrating processes is the arrest time tuning method (also called double-pole placement or lambda-tuning) which explicitly uses the speed gain of the process.

When arrest time tuning a purely integrating process, the stability is guaranteed (not considering limitations in equipment dimensioning) and there is no limit on how fast the controller can be made. Furthermore, certain properties exist for the resulting control, e.g. maximum control deviation when subjected to a load disturbance with given magnitude. The arrest time tuning method gives the following controller parameters for a purely integrating process

$$K_c = \frac{2}{k_v T_a} \quad (6)$$

$$Ti = 2T_a \quad (7)$$

where T_a is the arrest time, i.e. the time needed before the control error starts to decrease after a step disturbance. It is also the time that passes before the controlled variable reaches its reference for the first time after a step change in the reference. However, if there is recycle present, these properties no longer hold and the actual control performance is hard to predict during the design stage and robustness is deteriorated. One obvious question is: which speed gain should be used when applying the arrest time tuning method on the process with recycle? If the initial speed gain k_v is used, i.e. the one observed before the recycle effect has come in, closed loop system instability occurs for small choices of T_a. If the steady-state speed gain $k_v(1-\alpha)$ is used instead, the closed loop system will be stable for all choices of T_a in the tuning formula, however T_a has no meaning!

One conclusion to be drawn from these insights is that knowledge about the existence of recycle in the plant is very important. When recycle streams exist, the control engineer must consider these during the data collection phase to reveal all the needed dynamics. Another conclusion is that continuing to model a process as integrating after recycle streams are added and using the arrest time tuning method is not a good choice.

Suggested modeling and tuning

When a simple process no-longer behaves like it should, i.e. extra dynamics is present, the obvious remedy is to look for a model structure that betted describes the process. For the purely integrating process with recycle from the manipulated variable, the new process resembles and may be approximated as

$$\widehat{P}_r(s) = \frac{k}{s}\left(\frac{1+sT_1}{1+sT_2}\right) \quad (8)$$

with $T_1 > T_2$. Using the recycle parameters this model becomes

$$\widehat{P}_r(s) = \frac{k_v(1-\alpha)}{s}\left(\frac{1+s\frac{L}{1-\alpha}}{1+sL}\right) \quad (9)$$

This is the same as approximating $H(s) = \alpha e^{-sL}$ with

$$\widehat{H}(s) = \frac{\alpha}{1+sL} \quad (10)$$

Recommended PI tuning method for the new process is to use $T_i = L$ and chose K_c to achieve a desired maximum control deviation when subjected to a step disturbance. Choosing $T_i = L$ means cancelling the process pole with the controller zero. To relate the control deviation and value of parameter K_c, one can assume a P-controller structure. For a disturbance with magnitude Δd, the minimum K_c needed to keep the control deviation less than e_{max} is

$$|K_c| > |K_{c,min}| = \frac{|\Delta d|}{|e_{max}|} \quad (11)$$

Simulations have shown that this rule is slightly conservative, i.e. the actual control deviation will be smaller than designed for.

Acknowledgements

Johan Rönnberg and Krister Forsman at Perstorp AB have provided valuable input and comments to this paper. Preceding this paper is a master thesis [1] performed at Perstrop AB.

References

[1] Castro. S (2016), *Control and properties of processes with recycle dynamics*, Department of Automatic Control, Lund University