

EECE 574 - Adaptive Control

Laguerre-based Adaptive Control - Part II

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Bleach Plant pH Control

- First successfully tested on bleach plant extraction stage pH control in 1988 at Howe Sound Pulp
- Laguerre network with $N = 15$
- Choice of p can be guided by the fact that

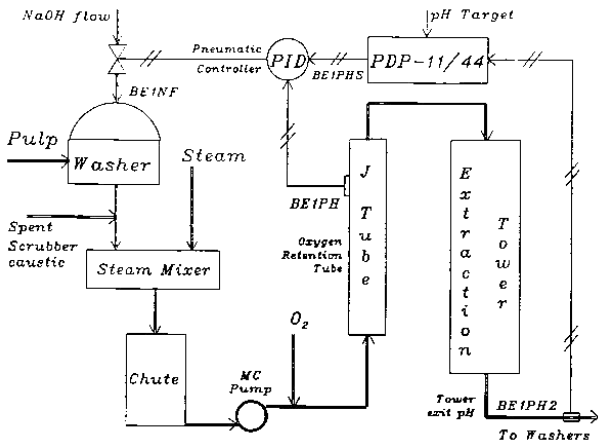
$$e^{-sT} = \lim_{N \rightarrow \infty} \frac{(1 - sT/2N)^N}{1 + sT/2N)^N}$$

i.e. $p = 2N/T$ should provide an acceptable approximation of the time delay T

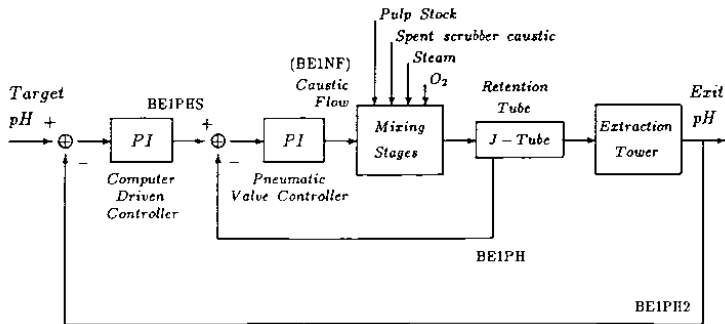
- here, $N = 15$ and $p = 0.25$



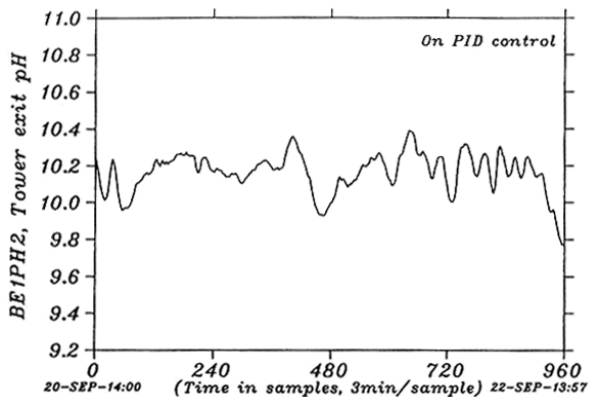
Bleach Plant pH Control



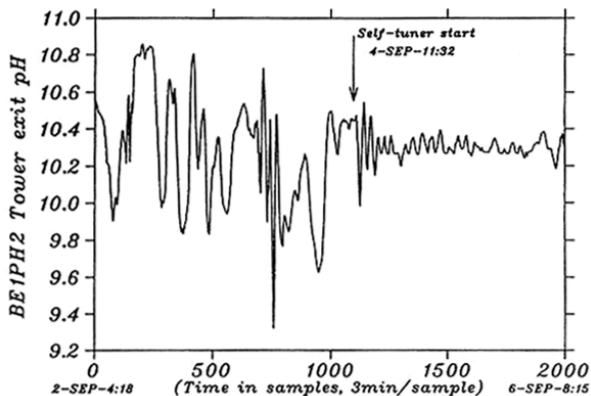
Bleach Plant pH Control



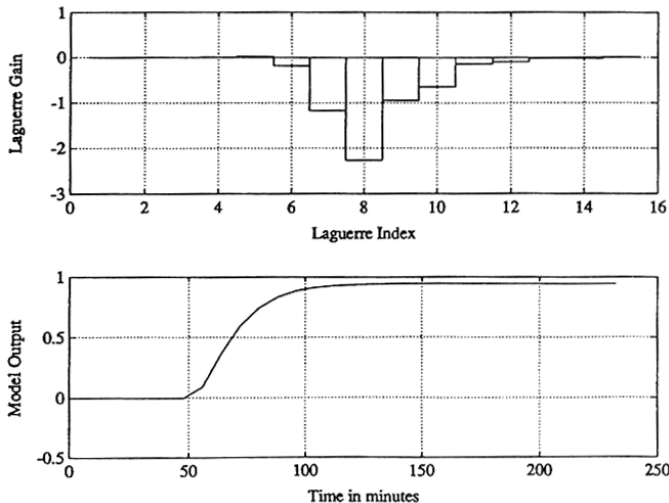
Bleach Plant pH Control



Bleach Plant pH Control



Bleach Plant pH Control

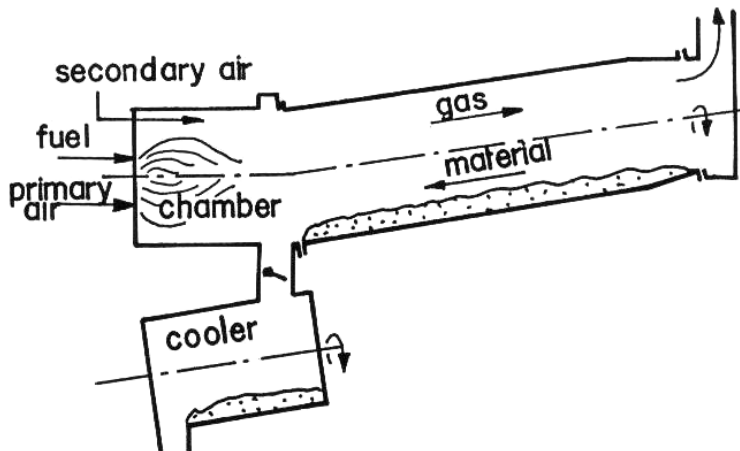


TiO₂ Kiln Control

- Titanium dioxide is a substance used as a pigment in paints, textiles, plastics, cosmetics and other materials
- Raw material mostly available in a crystalline form known as anatase, while another form **rutile** has the most interesting pigmentary properties
- In the sulphate route to produce TiO₂ pigment, the most critical step is the calcination in a rotary kiln of a hydrous precipitate of titanium dioxide, during which transformation from anatase to rutile occurs, accompanied by crystal growth
- Good control of the rutile content is essential as it affects most pigmentary properties, in particular paint durability, plastics undertone and lightfastness of laminated papers



TiO₂ Kiln Control



TiO₂ Kiln Control

- The kiln dynamics can be represented by

$$l_1(t+1) = Al_1(t) + bu_1(t)$$

$$l_2(t+1) = Al_2(t) + bu_2(t)$$

$$y(t) = c_1^T l_1(t) + c_2^T l_2(t)$$

- where u_1 is the main control variable, i.e. the fuel rate and u_2 is the main measured disturbance, i.e. the pulp feedrate



TiO₂ Kiln Control

- Identification experiments showed that $N = 10$ for each network suffices to capture the essential dynamics
- Significant and frequent feedrate changes
- Rotational speed has to be changed as the feed rate changes
- Kile retention time approximately **inversely** proportional to rotational speed
- Easily accounted for by Laguerre network by making Laguerre pole p proportional to rotational speed ω

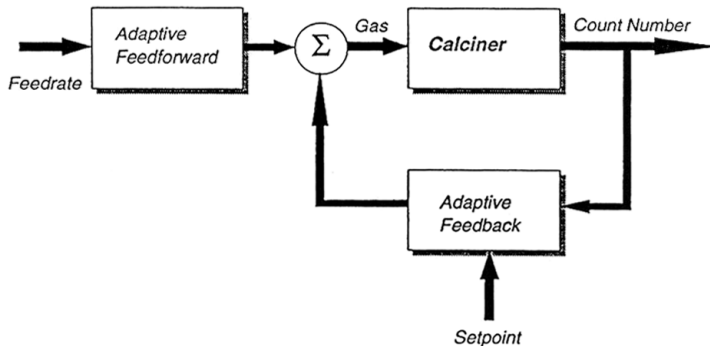
$$p = p_0 \frac{\omega}{\omega_0}$$

where p_0 and ω_0 are a reference point

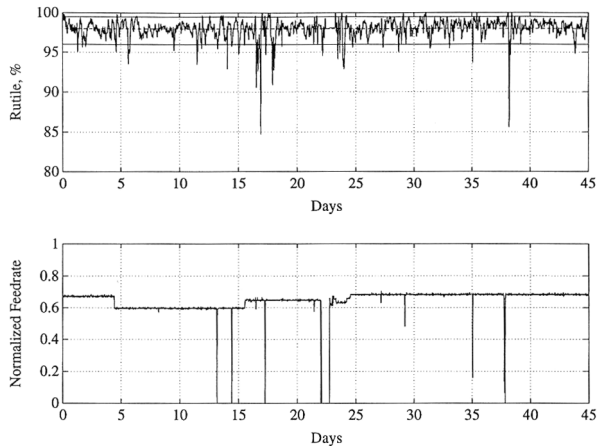


TiO₂ Kiln Control

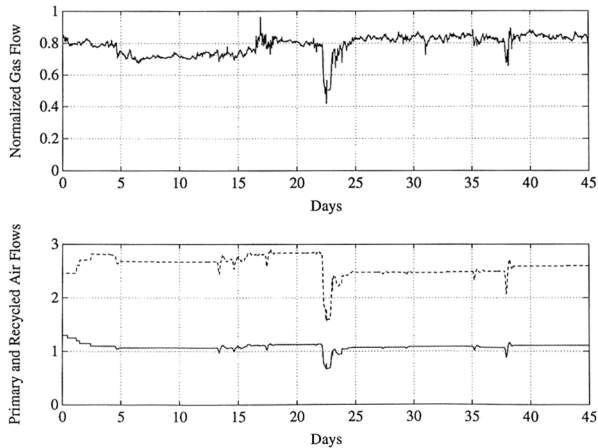
- Combined adaptive feedforward and adaptive feedback scheme



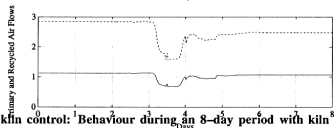
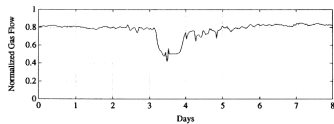
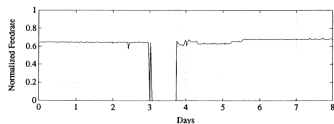
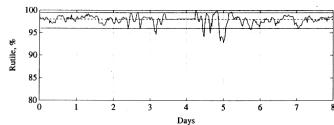
TiO₂ Kiln Control



TiO₂ Kiln Control



TiO₂ Kiln Control



TiO₂ kiln control: Behaviour during an 8-day period with kiln emptying.

TiO₂ Kiln Control

Control performance TiO₂ Rotary Kiln

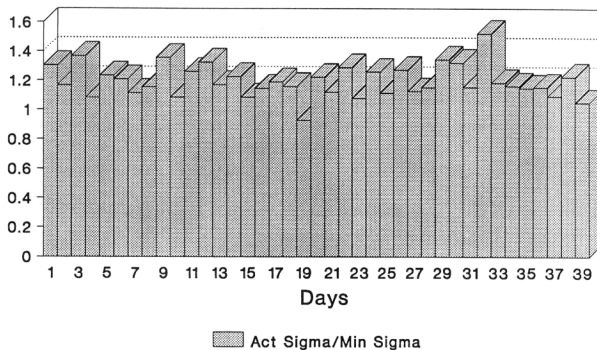


Figure 3: TiO₂ kiln control: Performance for a 39-day campaign as measured by the ratio of the actual standard deviation to the estimated minimum one.

Ensuring Successful Identification

- Proper choice of Laguerre pole and sampling interval
- Closed-loop identification
 - Switching between different linear controllers. A technique to improve identifiability in predictive control is e.g. to implement the first two control actions before computing the next set of two, in a pseudo-multirate fashion. In this case, the control law switches continuously between $u(t) = f(r(t), y(t))$ and $u(t) = f(r(t), \hat{y}(t|t-1)) = g(r(t), y(t-1))$. As shown by Kammer and Dumont this improves identifiability at minimal cost.
 - Use of a known, external excitation to the plant. This is usually realized by way of setpoint changes. A safe procedure is then to only estimate parameters of the plant model following a setpoint change. This can be termed event-triggered identification.



Choosing Feedforward Variables

- The use of feedforward variables does not come for free because models must be built and estimated
- The feedforward variable must contribute unique information about disturbances on the process.
- Using more than one variable that is correlated to the same process disturbance will not only complicate the control strategy with no benefit, it will also make the identification of unique feedforward models impossible.



Choosing Feedforward Variables

- Combining the variables into a single calculated feedforward can simplify the control strategy and reduce the process modelling effort required to commission the controller.
- An example of this situation would be combining a density measurement with a flow rate measurement to produce a single mass flow signal.
- This approach also makes sense from a process point of view because often such combined variables are more representative of the fundamental cause of the process disturbance and the direct relationship to the process can be better observed.



From LUST to BrainWave

- After successful bleach plant application

R & D NEWS

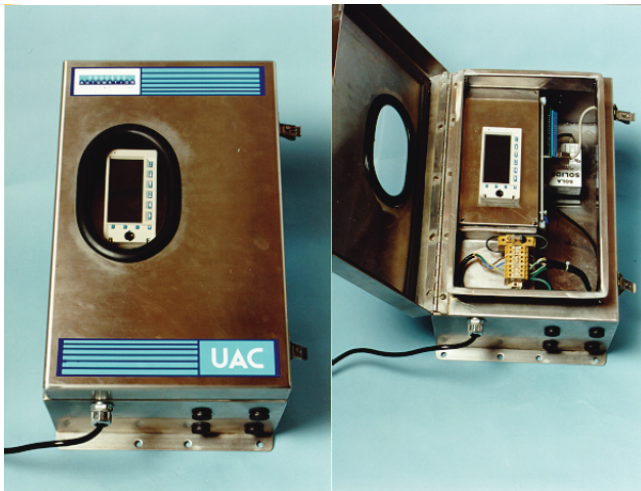
LUST in Canadian mills

VANCOUVER, B.C. — A new approach in computer control of industrial processes has been developed at the University of British Columbia's Pulp and Paper Centre. The method has been successfully implemented in the Howe Sound Pulp and Paper mill where it significantly lowered the pH variability after the first extraction stage in the bleach plant. The more-uniform operation that results leads to better product quality. The new method, Laguerre unstructured self tuner (LUST), was developed by G.A. Dumont and C. Zervos. LUST is a software package that is introduced into the existing process control computer to represent the process dynamics by a network of Laguerre functions. According to Dumont, this allows "the parameters characterizing the process dynamics to



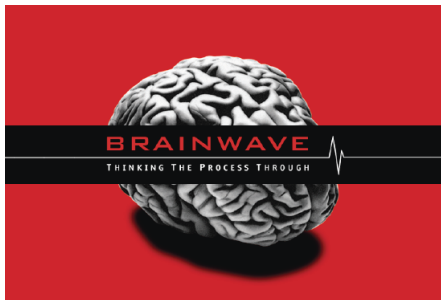
From LUST to BrainWave

- Standalone adaptive controller first developed in 1992 to control lime kilns

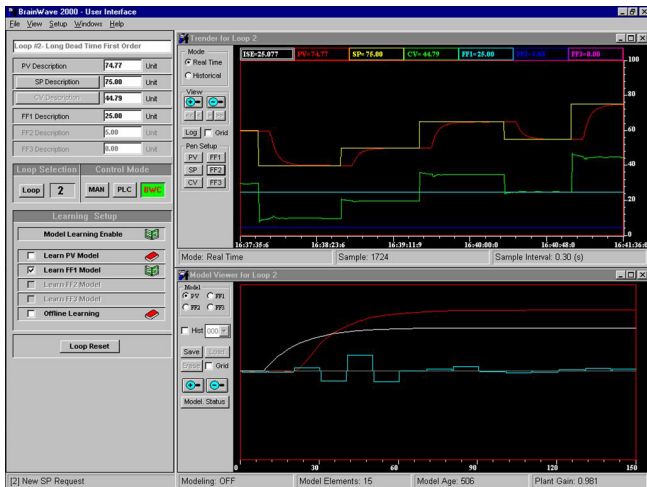


From LUST to BrainWave

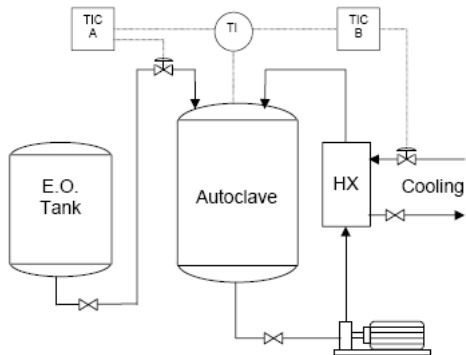
- Windows-based application developed in 1997
- Version for integrating plants in 2000
- BrainWave MultiMax, multivariable version in 2002



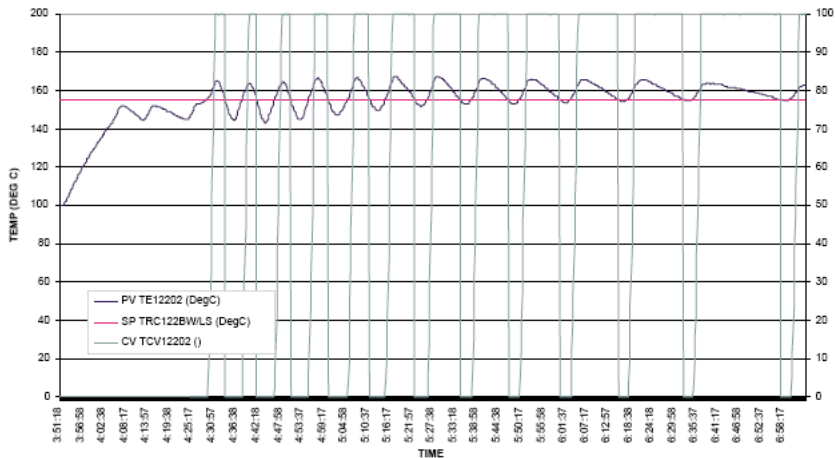
BrainWave



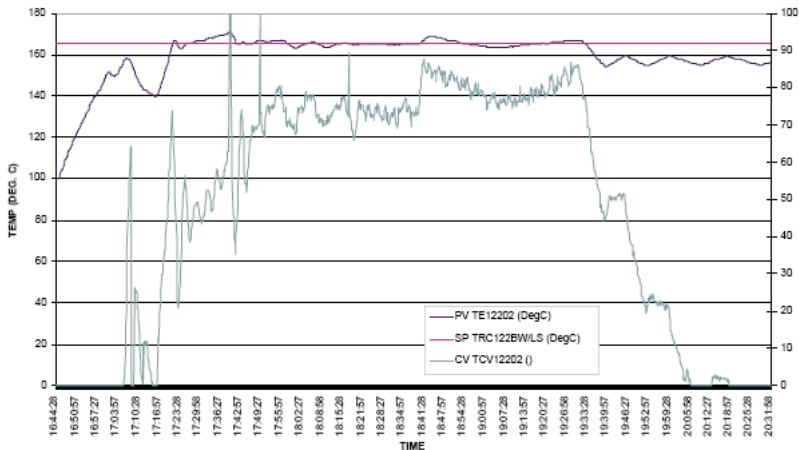
Fatty Acid Reactor



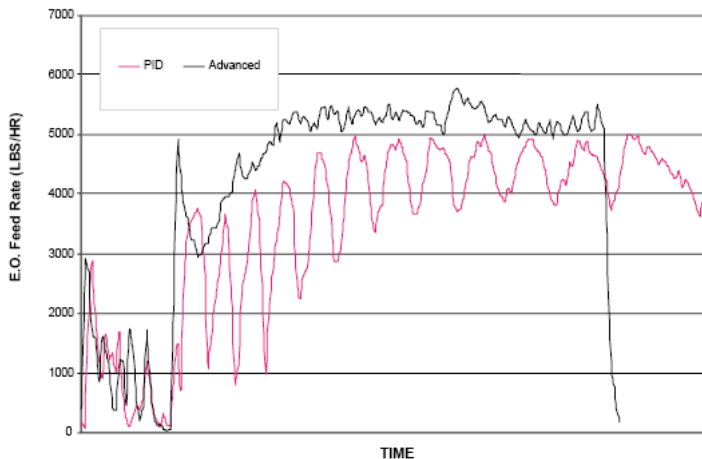
Fatty Acid Reactor



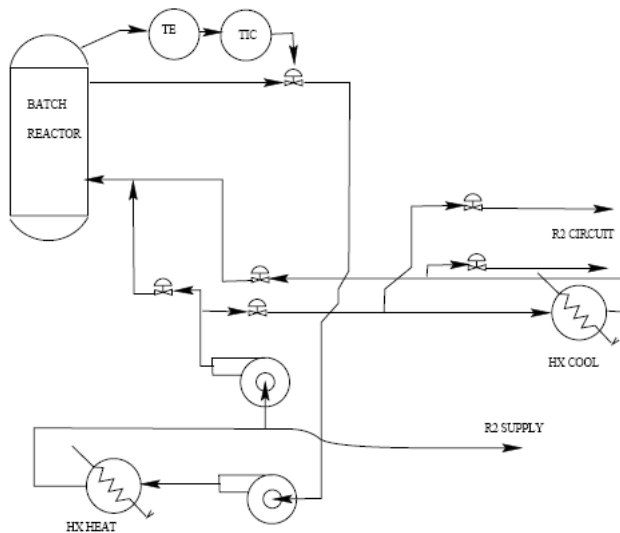
Fatty Acid Reactor



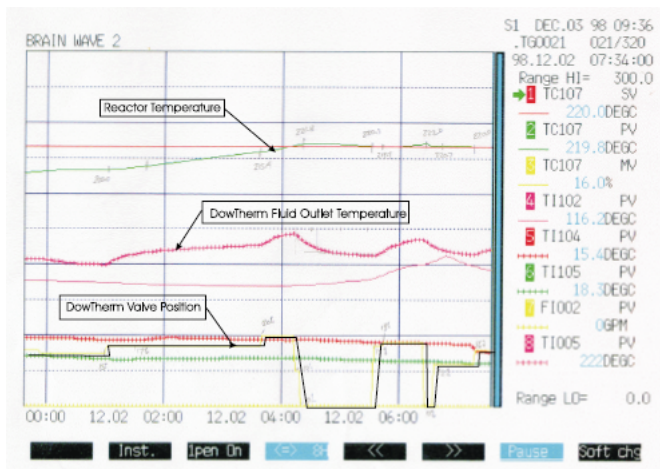
Fatty Acid Reactor



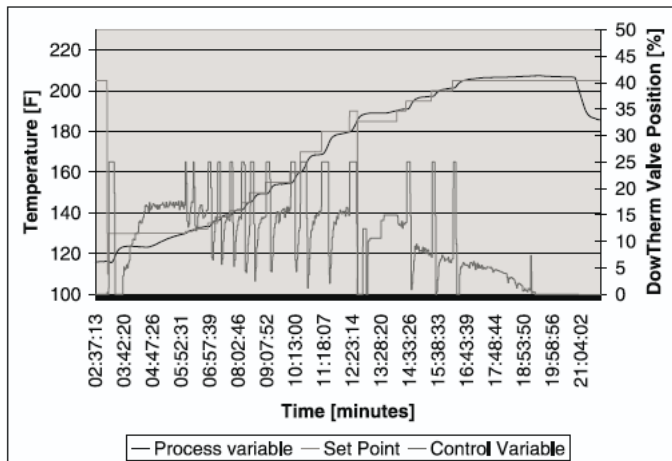
DowTherm Batch Reactor



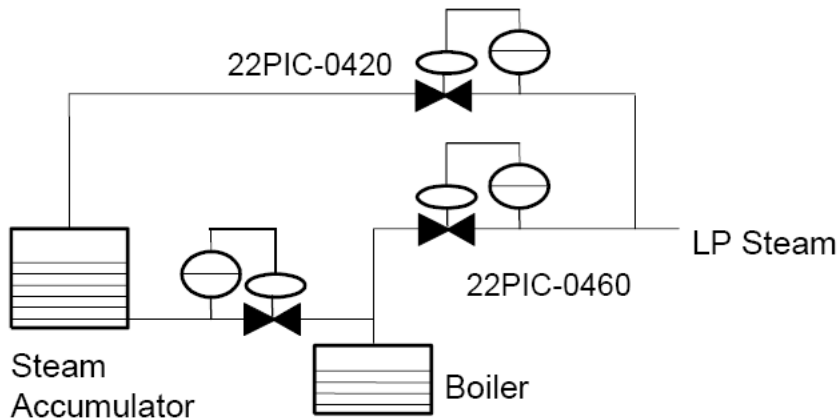
DowTherm Batch Reactor



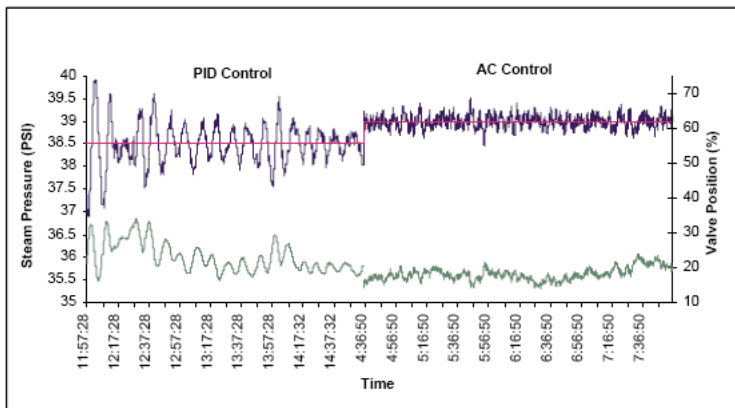
DowTherm Batch Reactor



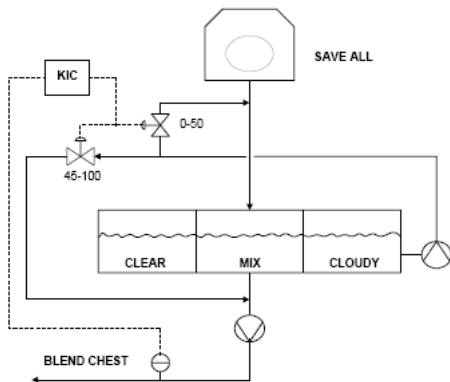
Steam Header Pressure



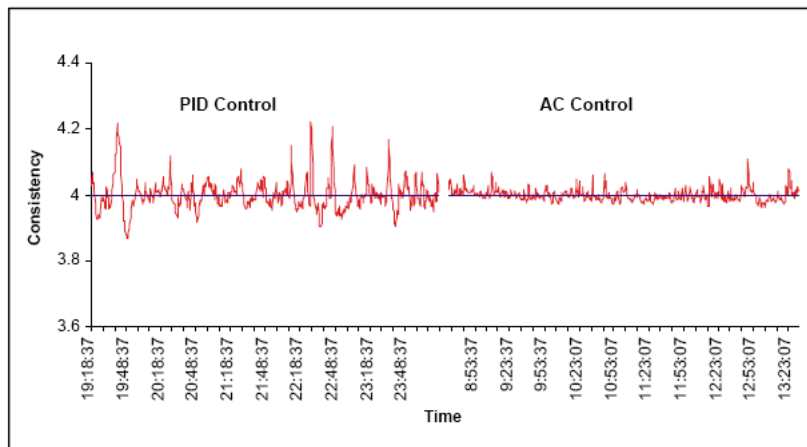
Steam Header Pressure



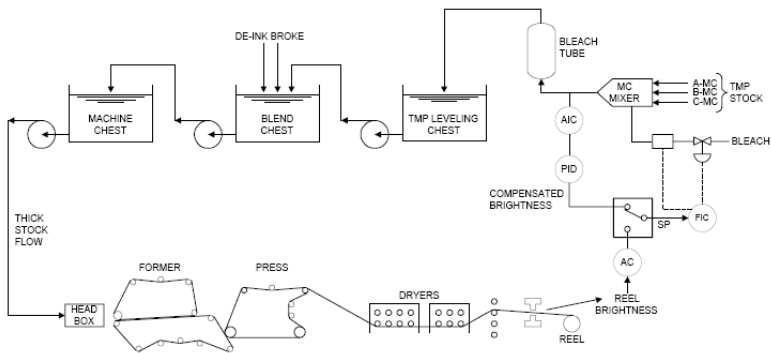
Saveall Consistency



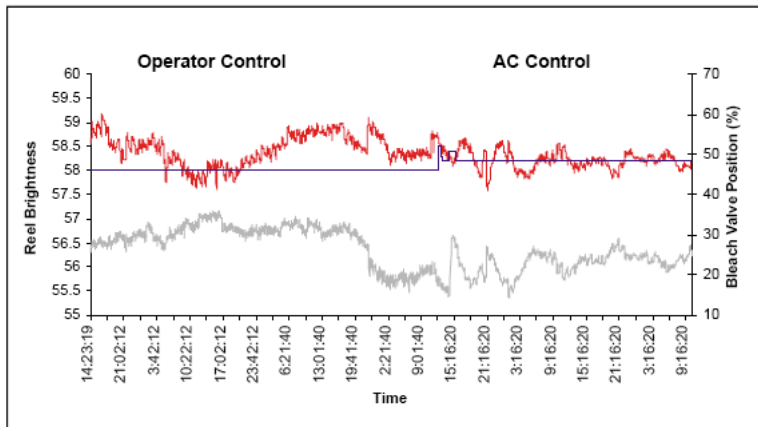
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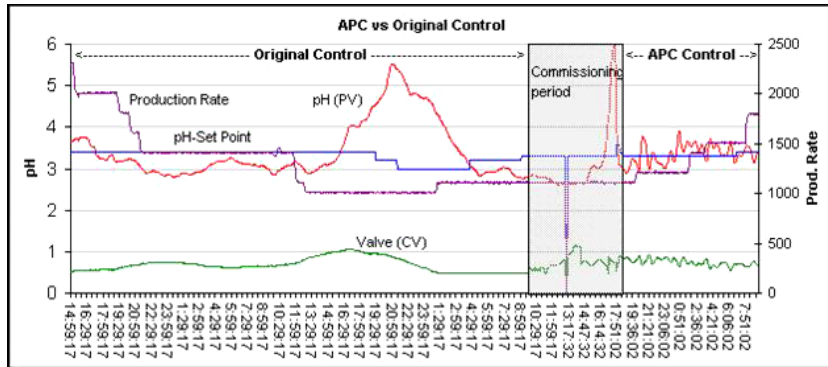
Paper Brightness



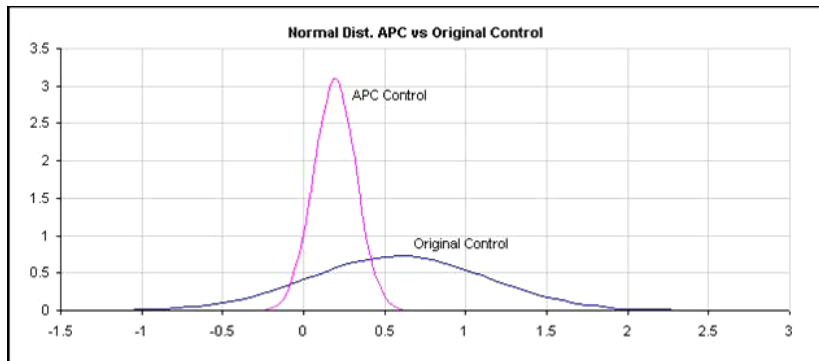
Paper Brightness



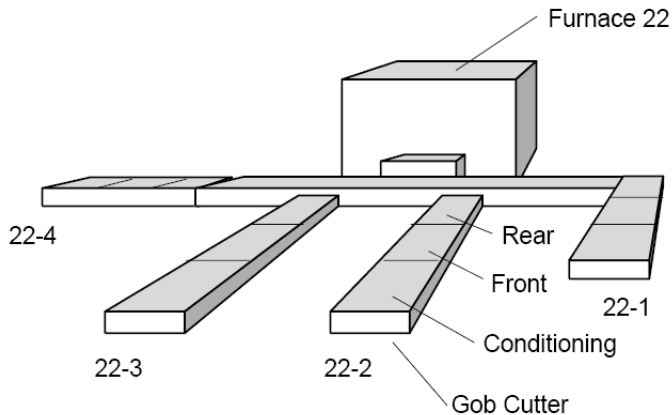
Bleach Plant Control



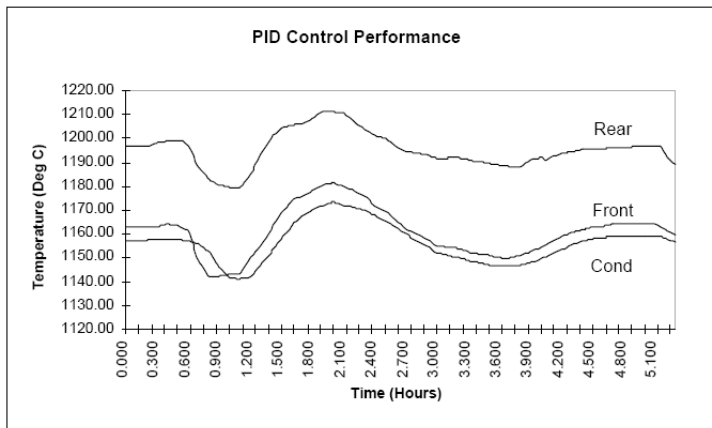
Bleach Plant Control



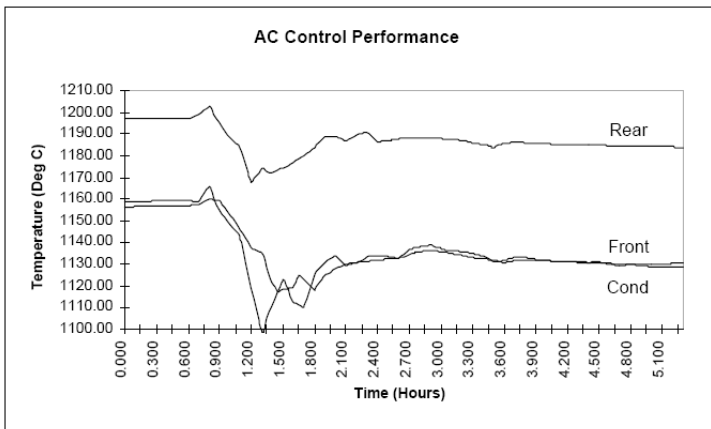
Glass Forehearth



Glass Forehearth



Glass Forehearth



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