EECE 574 - Adaptive Control

Laguerre-based Adaptive Control - Part II

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Bleach Plant pH Control

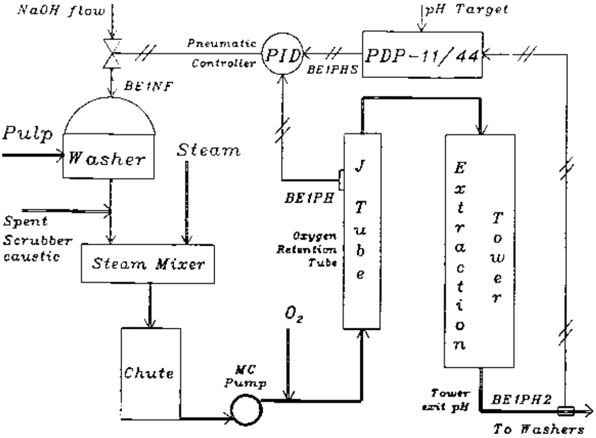
- First successfully tested on bleach plant extraction stage pH control in 1988 at Howe Sound Pulp
- Laguerre network with $N = 15$
- Choice of p can be guided by the fact that

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

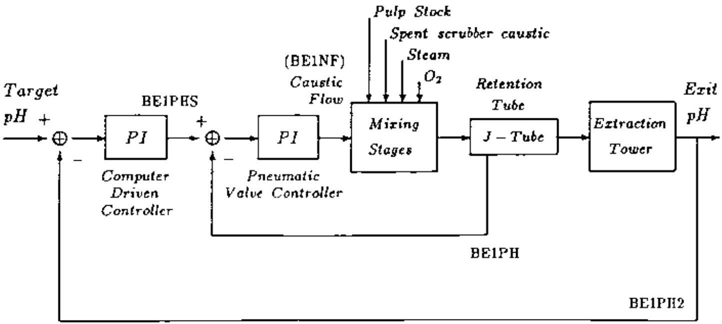
i.e. $p = 2N/T$ should provide an acceptable approximation of the time delay T

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

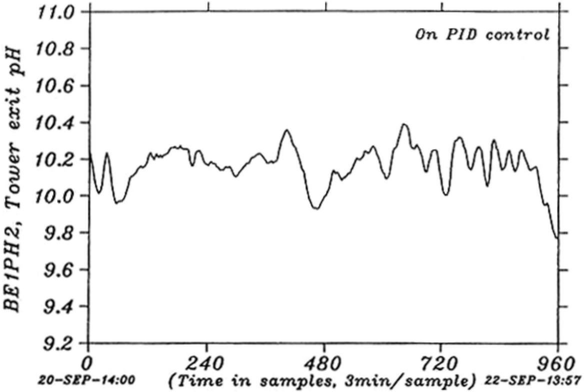
Bleach Plant pH Control



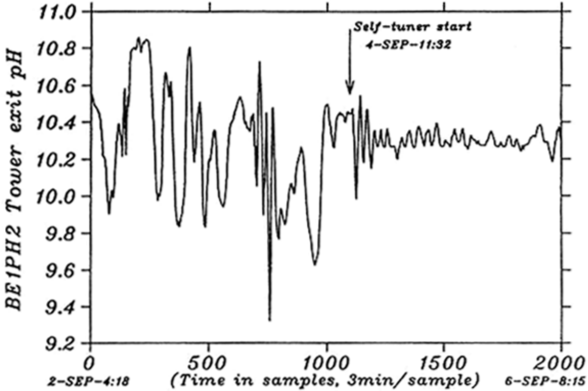
Bleach Plant pH Control



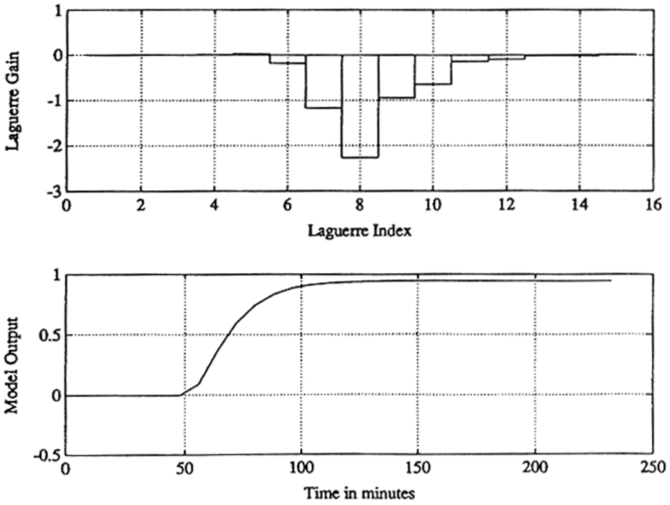
Bleach Plant pH Control



Bleach Plant pH Control



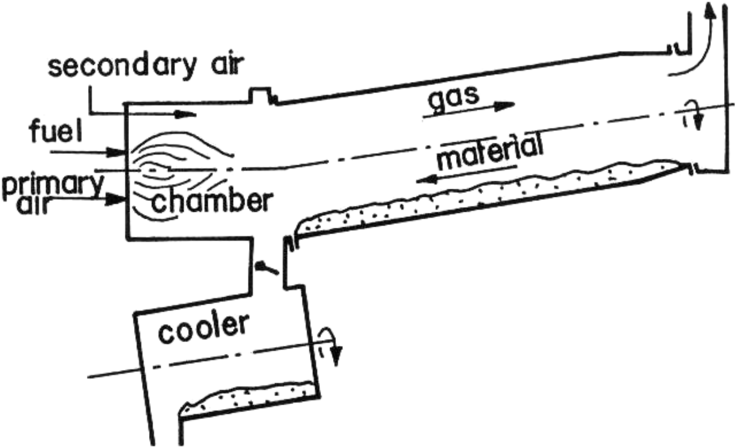
Bleach Plant pH Control



TiO_2 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 TiO_2 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

TiO_2 Kiln Control



TiO_2 Kiln Control

- The kiln dynamics can be represented by

$$
\begin{aligned}
l_1(t+1) &= Al_1(t) + bu_1(t) \\
l_2(t+1) &= Al_2(t) + bu_2(t) \\
y(t) &= c_1^T l_1(t) + c_2^T l_2(t)
\end{aligned}
$$

- 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

TiO_2 Kiln Control

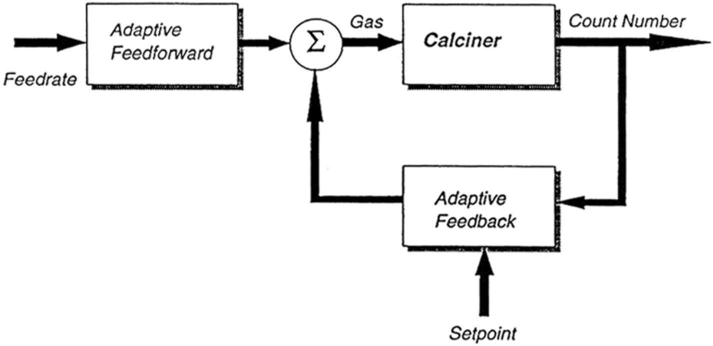
- Identification experiments showed that $N = 10$ for each network suffices to capture the essential dynamics
- Significant and frequent feedrate changes
- Rotational speed has to be changed as the feed rate changes
- Kile retention time approximately inversely proportional to rotational speed
- Easily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

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

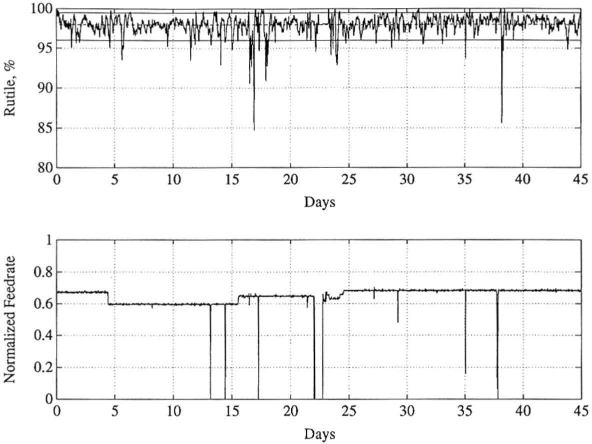
where p_0 and ω_0 are a reference point

TiO_2 Kiln Control

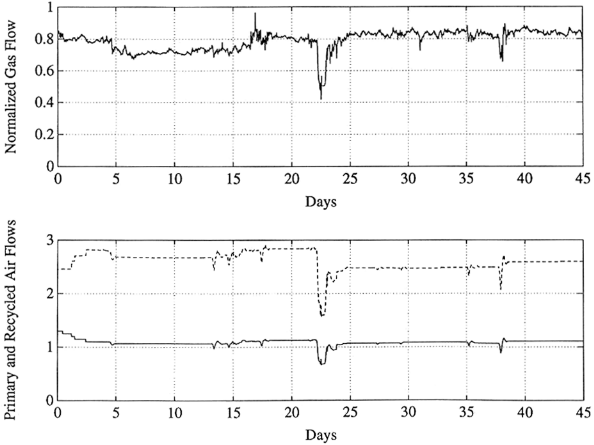
- Combined adaptive feedforward and adaptive feedback scheme



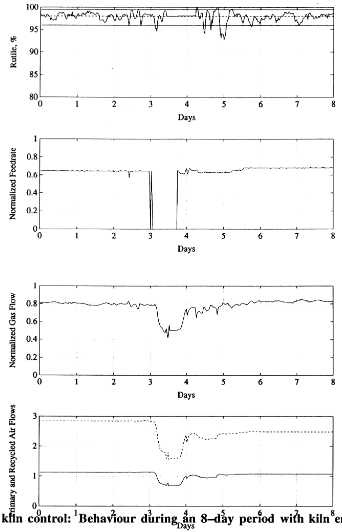
TiO_2 Kiln Control



TiO_2 Kiln Control



TiO_2 Kiln Control



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

TiO_2 Kiln Control

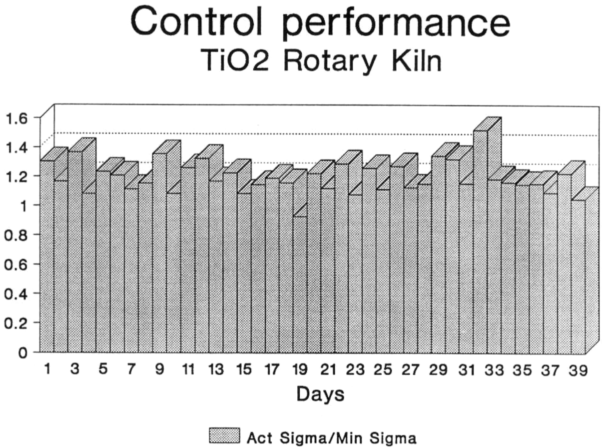


Figure 3: TiO2 kiln control: Performance for a 39–day campaign as measured by the ratio of the actual standard deviation to the estimated minimum one.

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

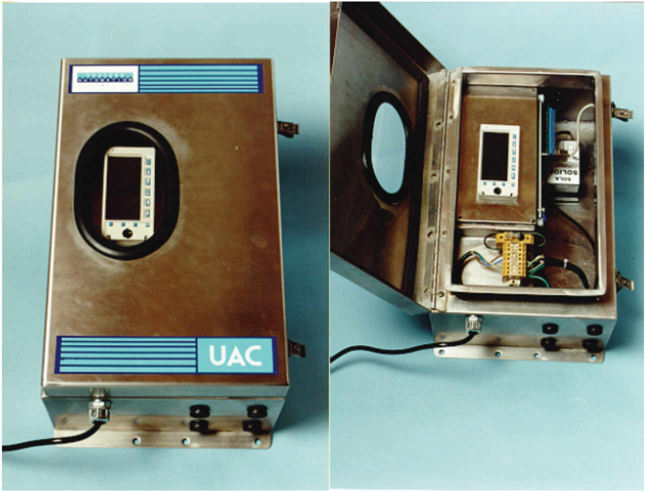
R & D NEWS

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

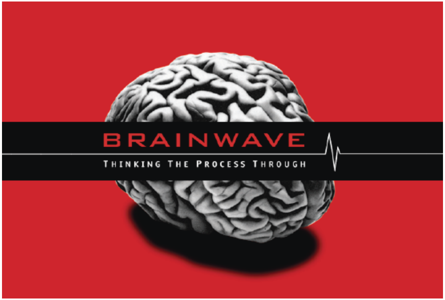
From LUST to BrainWave

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

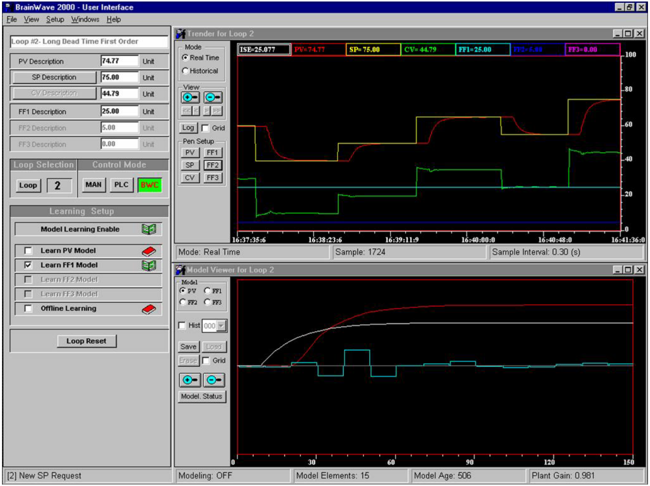


From LUST to BrainWave

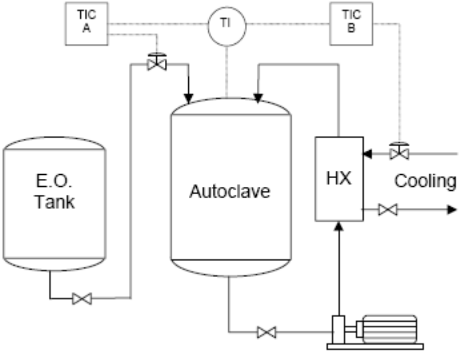
- Windows-based application developed in 1997
- Version for integrating plants in 2000
- BrainWave MultiMax, multivariable version in 2002



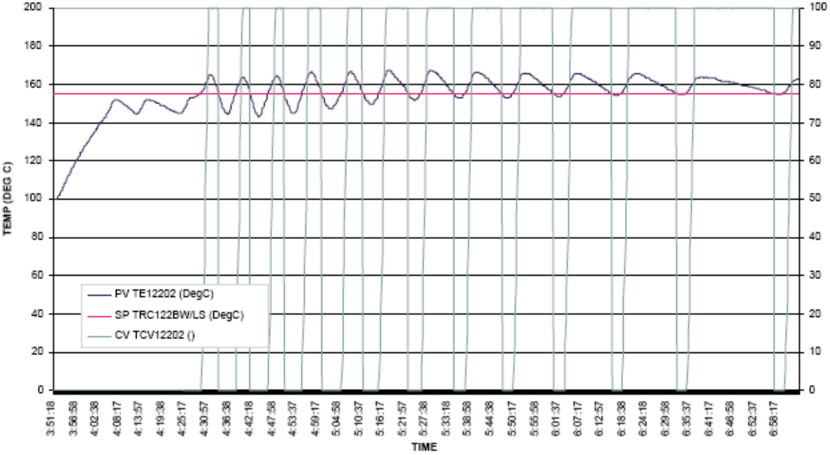
BrainWave


BrainWave 2000 - User Interface
File View Setup Windows Help
Loop #2- Long Dead Time First Order
PV Description 74.77 Unit
SP Description 75.00 Unit
CV Description 44.79 Unit
FF1 Description 25.00 Unit
FF2 Description 5.00 Unit
FF3 Description 0.00 Unit
Loop Selection
Control Mode
Loop 2
MAN PLC BWC
Learning Setup
Model Learning Enable
Learn PV Model
Learn FF1 Model
Learn FF2 Model
Learn FF3 Model
Offline Learning
Loop Reset
[2] New SP Request
Trender for Loop 2
Mode
Real Time
Historical
View
Log Grid
Pen Setup
PV FF1
SP FF2
CV FF3
ISE=25.077
PV=74.77
SP=75.00
CV=44.79
FF1=25.00
FF3=0.00
100
80
60
40
20
0
16:37:35:6
16:38:23:6
16:39:11:9
16:40:00:0
16:40:48:0
16:41:36:0
Mode: Real Time
Sample: 1724
Sample Interval: 0.30 (s)
Model Viewer for Loop 2
Model
PV FF1
FF2 FF3
Hist 000
Save Load
Erase Grid
Model. Status
0
30
60
90
120
150
Modeling: OFF
Model Elements: 15
Model Age: 506
Plant Gain: 0.981

Fatty Acid Reactor



Fatty Acid Reactor



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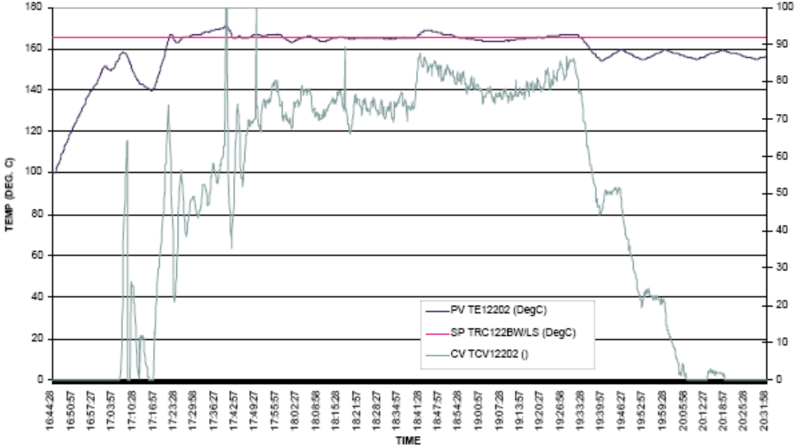

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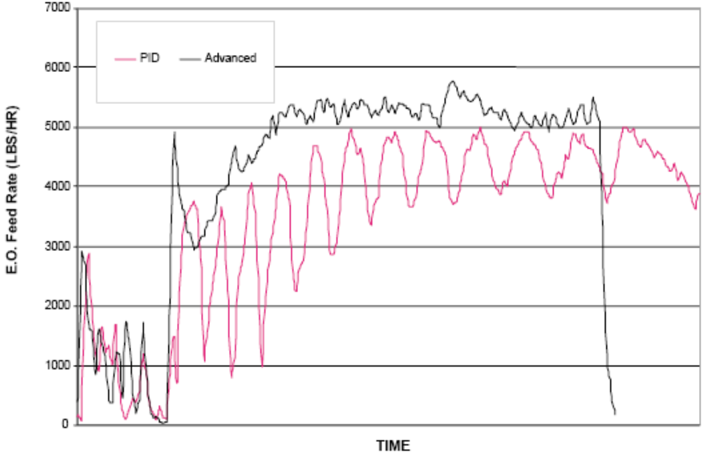
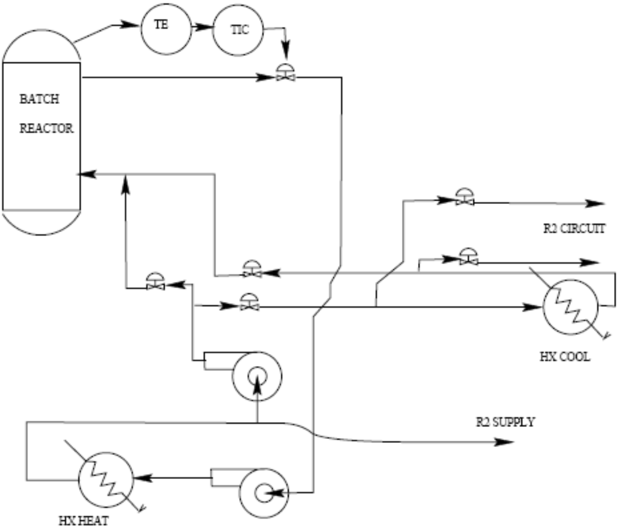
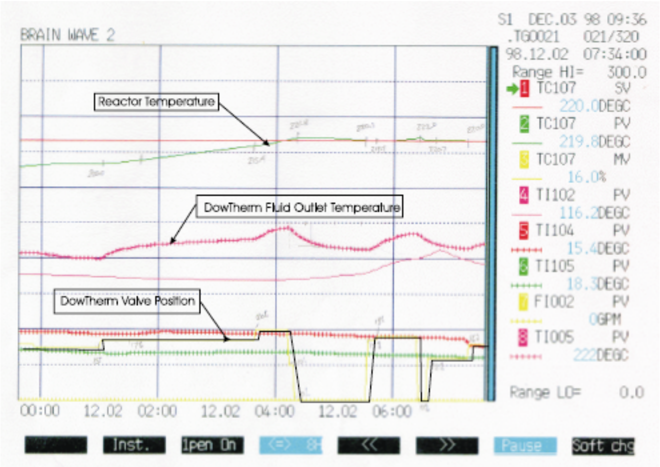


DowTherm Batch Reactor



DowTherm Batch Reactor



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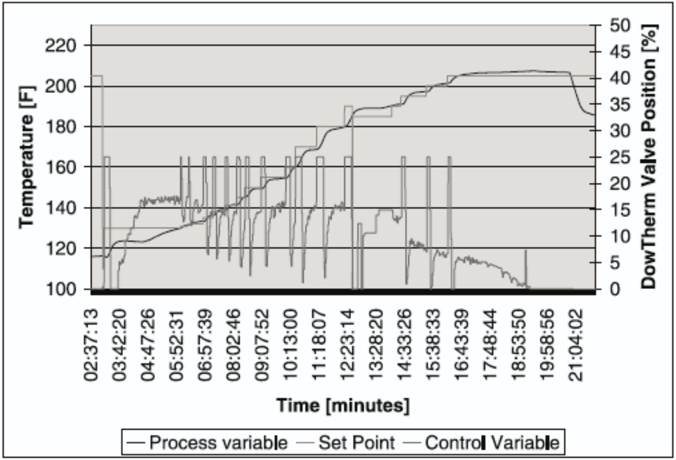
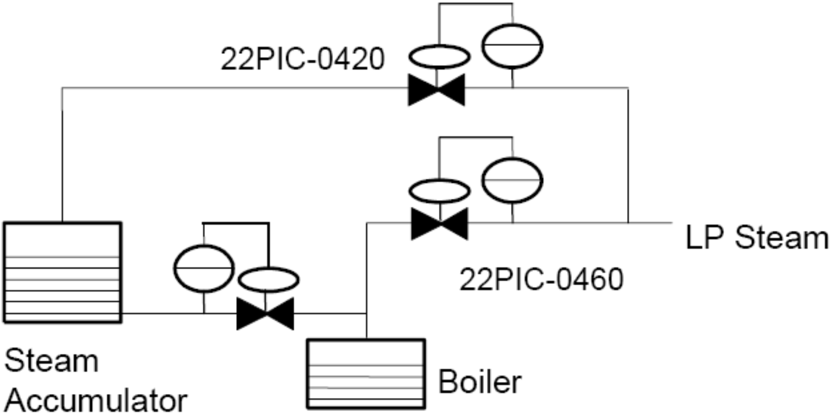
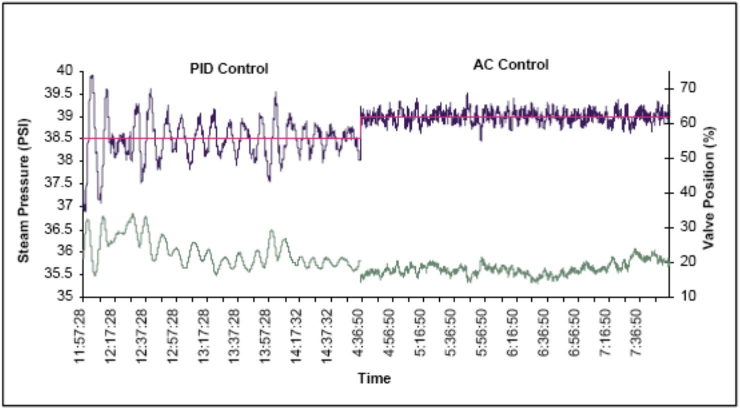


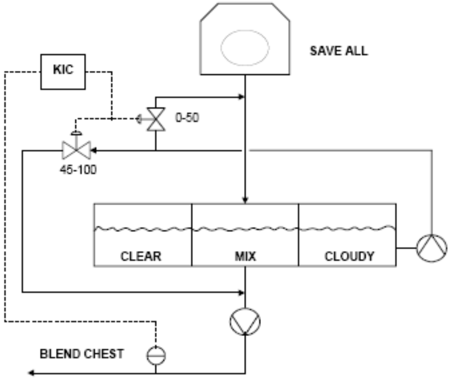
Steam Header Pressure



Steam Header Pressure



Saveall Consistency



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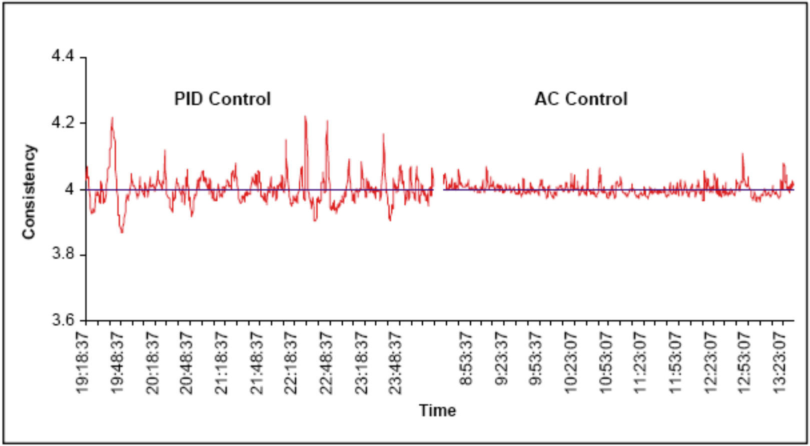
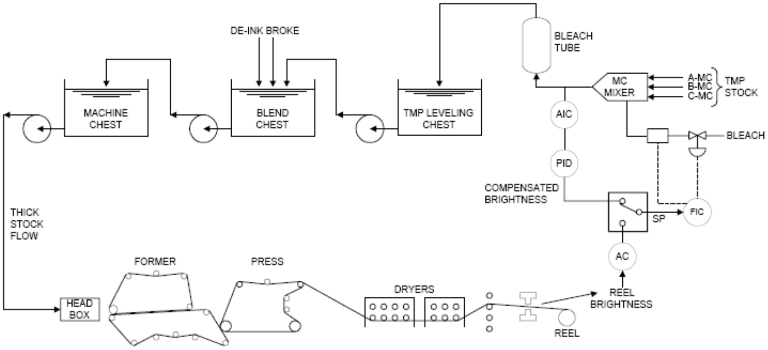


Paper Brightness



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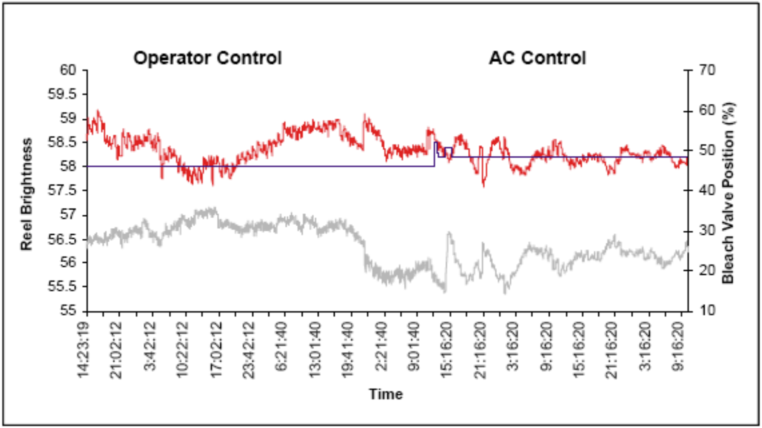
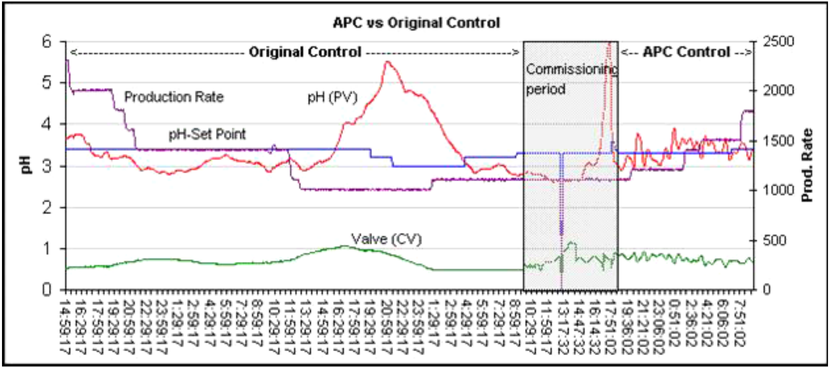
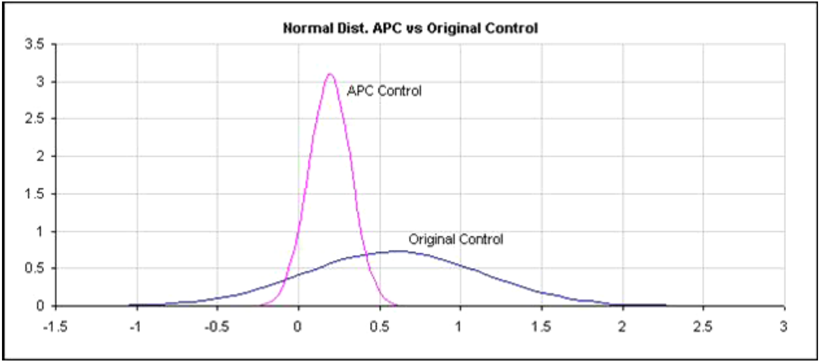


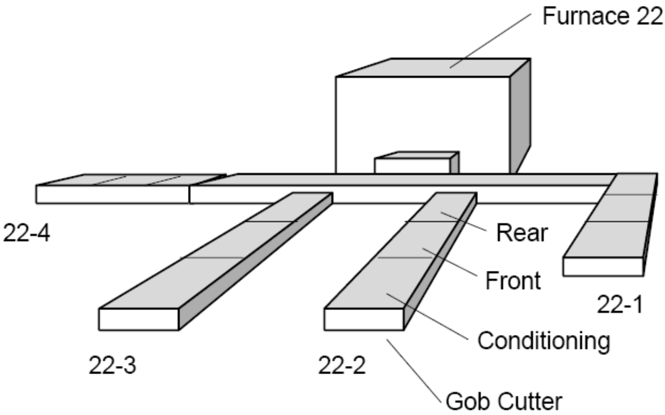
Bleach Plant Control



Bleach Plant Control



Glass Forehearth



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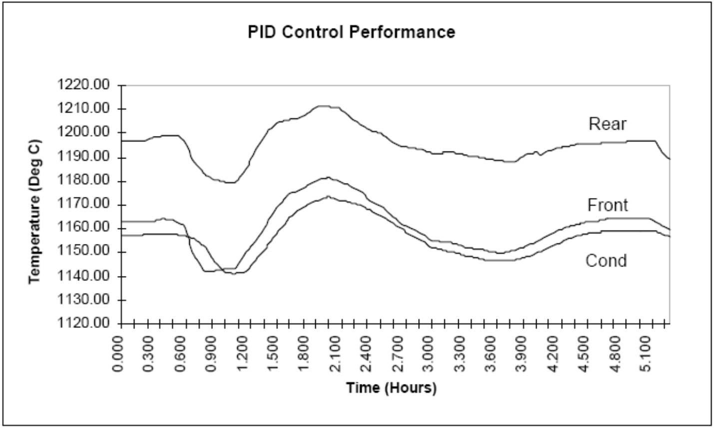

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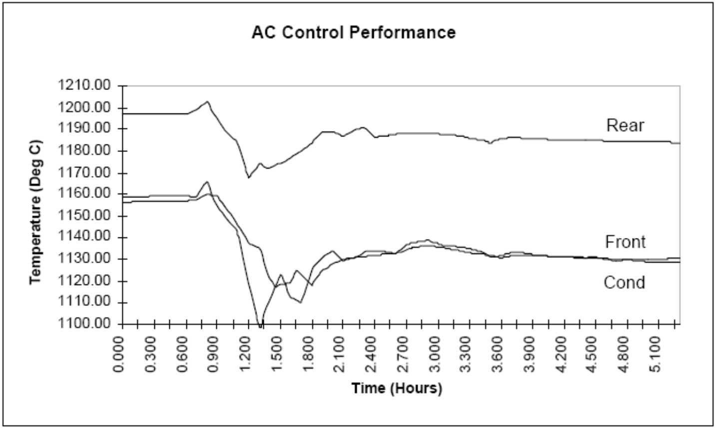

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