Control of Brown Stock Washing Process in a Paper Mill using ANN Strategy

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ABSTRACT

Brown Stock Washing (BSW) is a complex multi-variable continuous process where there is a need to control variables that are not directly or instantaneously controllable. Most of the conventional control systems for BSW process utilize individual PID loops to control several process variables. The set points for each loop are determined by process experts.

Artificial Neural Networks provide a powerful tool for the process control and overcomes the problems of the prior art, including manual control and statistical control.

In the present work, Artificial Neural Network model was developed using Single Perceptron Algorithm and Back Propagation Algorithm. The process variables were identified and their values were generated using known mathematical relationships for supervised learning and for unsupervised learning for which the range of values were taken from M/s Star Paper Mills Ltd, Saharanpur, India. Then the neural network was trained from the set of values generated through random reference.

Introduction

Brown stock washing is one of the subsystems of a pulp mill to separate clean unbleached pulp from black liquor obtained from a digester through a multi stage counter-current washing. The objectives of Brown Stock Washing are

To clean the outgoing pulp produced from digester operation as practicable as possible through cleaner water so that it does not carry any black liquor solids (sodium based and lignin based) to bleach plant and minimize environmental load.

- To extract all the solutes (organic and inorganic) present in pulp and put in to the black liquor stream, thereby maximizing black liquor concentration.
- To maximize pulp consistency and recycling of liquor

Process Description

Figure 1 illustrates a typical single pulp washer. A pulp slurry stream (22) enters an inlet mixer (10) where it is admixed with a process water flow (9) to form an admixture of pulp and contaminated water solution. One or more agitators are located in the mixer to thoroughly mix the admixture which then flows over a weir (13) into the washer vat (2).The washer drum (1) is covered by a filter media (12) generally a mesh cloth of plastic or metal called the face, rotating in the direction shown by arrow (3) where part of the drum is submerged in a pulp slurry contained in the vat (2). A lower pressure inside the drum (1), due to barometric leg or vacuum source, extracts the contaminated water solution from the pulp slurry with the pulp forming a mat (4), interchangeably called a sheet or cake, on the face of filter media (12) in the sheet forming zone (14).

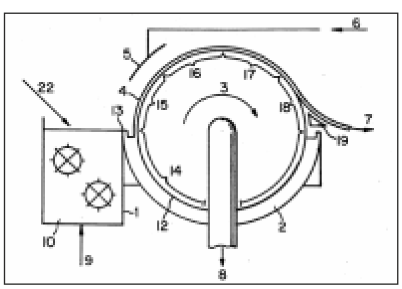

Fig 1. Typical single pulp washer

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As the sheet (4) emerges from the slurry, it enters a drying zone (15) where additional water solution is removed from the mat. As the drum rotates, the mat passes into the displacement zone (16). A stream of fresh water (6)(shower flow), or reused process water, is sprayed onto the mat by shower (5) and displaces the more contaminated liquor from the mat. The mat then passes another drying zone (17) and finally a discharge zone (18) where a mat is removed from the by a removal device (19).

In some cases, a washer will operate singly (for example a bleach pulp washer or a pulp thickener), however in many cases a plurality of washers are combined to form a complete washing system as shown in the Fig-2. Referring to this figure, three washers are operating together to form a washing system where the pulp slurry passes from washer to washer and reused filtrate is passed from washer to washer in the opposite direction, called countercurrent washing.

A pulp slurry stream (22) is introduced into the mixer and is admixed with dilution stream (23). The balance of the system is made up of washers 1, 1', 1” rotating in the directions indicated by the arrows 3, 3', 3” inside vats 2, 2', 2” discharging mats 7, 7', 7”. Water streams 6, 9', 21' are introduced via showers 5, 5', 5” with the final pulp mat being discharged from the system as pulp slurry stream (24).

Typically the only fresh water is in stream (6). The filtrate removed from the mats on washers 8, 8', 8” passes into filtrate tanks 20, 20', 20”.The filtrate from tanks 20 and 20' become dilution streams 9 and 21 into mixers 10 and 10'respectively. Side streams 9' and 21'spilt off the main dilution stream and pass to showers 5 and 5'. The filtrate from storage tank 20” becomes dilution stream (23) to mixer 10” with a side stream 23' that passes out of the system to a chemical recovery process.

Brown Stock Washing Control

Carryover of black liquor solids from the washers increases the cost of pulping, chemical make-up, effluent treatment. On the other hand, the use of too much wash water from the showers increases the cost of its evaporation from the recovered liquor. Consequently the primary aspect of washer control strategy is to lower operating costs by using shower water more efficiently. Therefore the core objectives for Brown Stock Washer control are:

- Reduce process variations and better stability.
- Optimize the shower flow to reduce carryover of black liquor solids.
- Optimize washer load distribution.
- More stable and higher solids liquor, steam savings in evaporation.

In a single or multiple pulp washing systems described with reference to Figs.1 and 2, there are actually two process cycles that must be considered and controlled. Referring to Figure 2, one process cycle is the actual pulp mass moving through the pulp washing system with the time cycle of typically less than ten minutes from the time the pulp mass enters the first washer, as

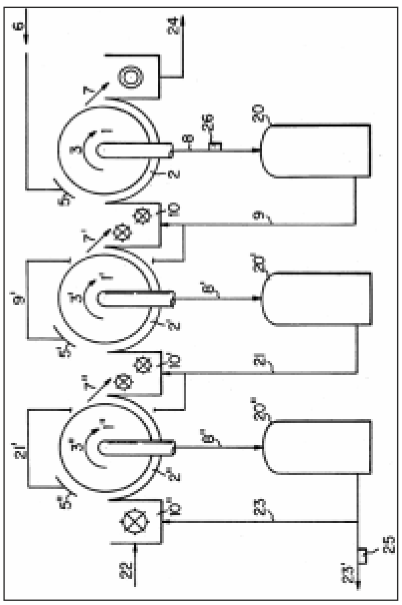

Fig 2. Plurality of washers combined to form a complete washing system

pulp slurry (22), until it leaves the last washer, as the pulp slurry (24). The second process cycle is the reused wash liquor cycle made up of fresh water and other reused process water, streams 6, 9', 21', which have a time cycle in the range of two to four hours from the time

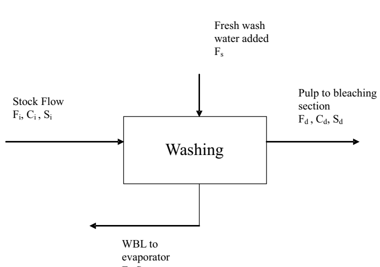

Fig 3. Mass balance for BSW

fresh water stream 6 is added on the last shower until the filtrate leaves the first storage tank 20" as dilution stream (23) and wash liquor stream 23' going to the chemical recovery.

Attempts to control wash water flow (6) by measuring the solids content of the wash liquor stream (23'), going to the recovery system, by a measurement means (25), either manually done or by continuous sensor means, is difficult due to tremendous lag times (typically 2-4 hours) between the time a change is made and the results are measured. The actual controls that take place must relate to the control of the shower water applied during the short time of the pulp flow cycle represented by the passing of the pulp slurry from entering pulp slurry stream (22) to exiting pulp slurry stream (24).

Ideally, the pulp slurry stream 24 carries the minimum amount of soluble organic and inorganic materials because these must be reacted with chemicals in a later process stage and replaced when the liquor stream 23'is processed by a spent chemical recovery system. The fewer the soluble materials in the washed pulp stream, the less the expense for the chemicals used and chemical make-up in the recovery cycle. The wash liquor stream 23' cannot simply sewered due to its potentially adverse effect upon the environment. By evaporation, the solubles are separated and water is reused. Therefore, the less water in the wash liquor stream the better. The soluble and insoluble materials in the wash liquor stream are combustible and can be used as a source of energy.

ANN Model Development

Input and Output variables

The washing process is characterized by

i) measured and controlled process variables
ii) measured and uncontrolled process variables
iii) at least one predictable process variable

The variables identified for the development of neural network model are presented in Table 1.

After identifying the input and output variables the next step is deciding the Neural Network algorithm. For this purpose the following two algorithms are utilized:

1. Single Perceptron Layer Algorithm
2. Back-Propagation Algorithm

Both these algorithm works on almost

Parameter	Description	Tag name	Variable type
A	Stock flow to washer	FI002	Measurement
B	Stock consistency to washer	CI009	Measurement
C	WBL flow	FI131	Measurement
D	WBL solids concentration	SOLIDS	Lab test
E	Drum speed	SI015	Measurement
F	Liquor Conductivity	COND	Lab test
G	Vat level	LI015	Measurement
H	Mat thickness	AI100	Measurement
1	Discharge consistency	CI200	Network output
2	Soda loss	AI201	Network output
3	Dilution factor	DF202	Network output

Table 1. Variables identified for development of neural network model

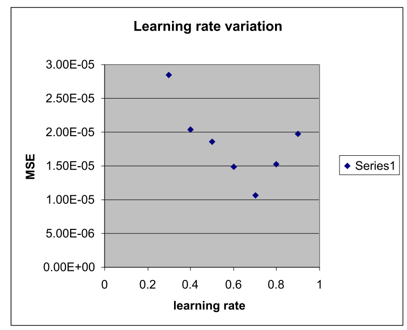

Fig. 4. MSE Vs Learning Rate

the same principle i.e. to minimize Mean Square Error (MSE) between the actual output and network output by adjusting the weights of inter connected neurons.

Training of ANN model

The neural network controller is trained so that when production rates are changed from one level to another, historical experience is used to adjust the low rates in a manner that obtains optimum operating condition at various fractions of time constant for each particular pulp washing system. Consequently, when operators make changes to the pulp stock input to pulp washing system, they need no longer merely wait for changes to occur in the liquor stream some hours later to respond manually, but they can allow the system to dynamically adjust for the change as in a feed forward manner eliminating the problems associated with the long lag in response time.

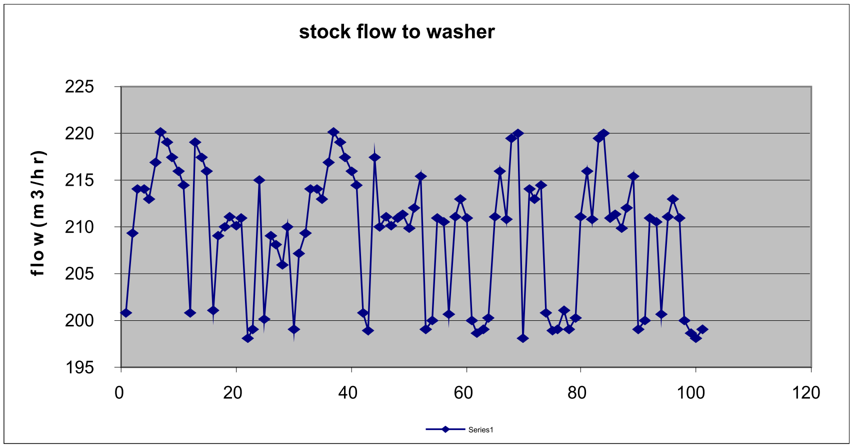

Fig. 5. Random data for network training for Stock flow rate to washer

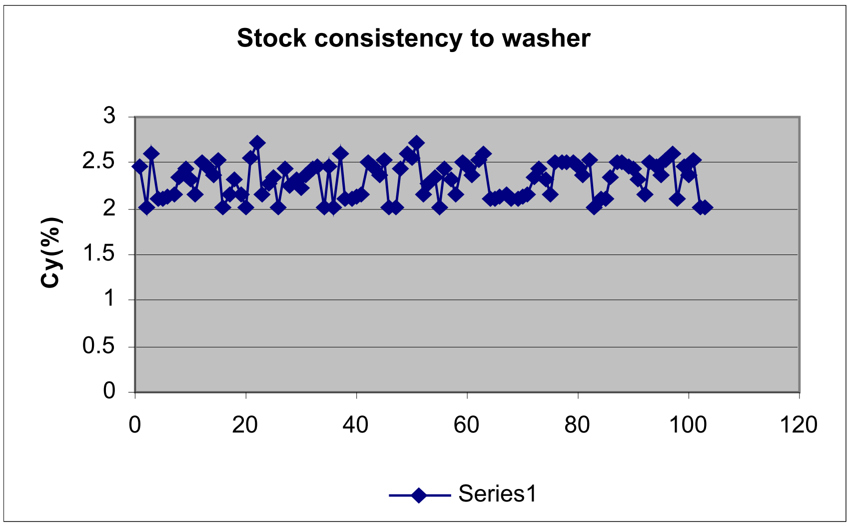

Fig. 6. Random data for network training for Stock consistency to washer

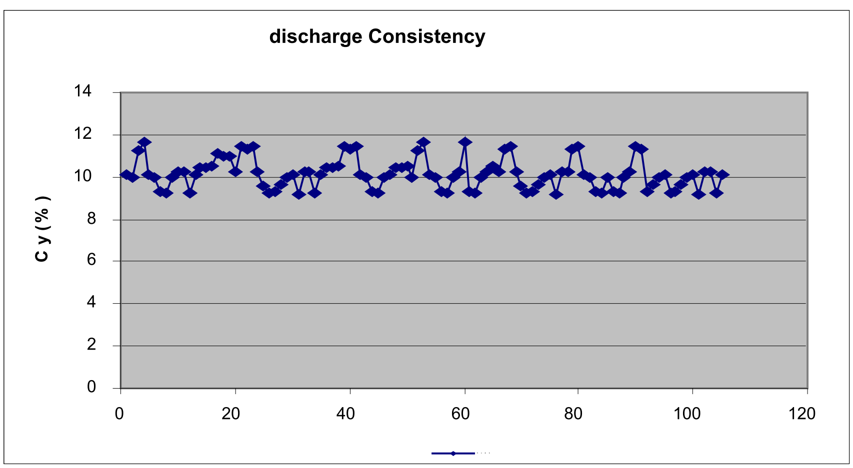

Fig. 7. Random data for network training for discharge consistency

Supervised Learning:

Usually, supervised learning is performed off- line, with the aim to identify the set of weights for minimum error. Also Single layer perceptron supports the supervised learning. The general rule for supervised training is to get the permissible range of input variables feed into the network for training. Calculate the MSE then change the network parameters see the change in MSE and optimize the network parameters.

ANN Model for supervised learning (Single Perceptron Layer)

Input and output values generation

As discussed earlier supervised training utilizes the mathematical model for generation of data. As washing is a simple mass balance equation we can develop the equation for DF depending on process parameters.

The DF concept is used to improve the variability in the solids removed from the pulp passing through the washing system in an effort to minimize the fresh and/or reused water which ultimately must be evaporated by the recovery

Dilution factor is the liquor in the shower minus that in the discharge:

$$DF = L_S - L_D$$

where:

L = mass liquor / mass fiber in the discharge

S refers to shower, D refers to discharge Also C_d and S_d are consistency of pulp discharge and BLS concentration.

Hence we can arrive at final equation as:

$$DF = [Fs-\{Fd(1-Sd)*(100-Cd)/100\}]/(Fd*Cd/100) \qquad [I]$$

Similarly other equation can be developed as:

$$DF = [(F_i(1-S_i)(100-C_i)/100] - F_l(1-S_l) \qquad [II]$$

With the help of above two equations we develop the range of data for DF with varying $F_i C_i$ and Cd.

Hence for training we get:
Inputs: varying F_i, C_i and Cd.
Output: DF

The system is designed considering a 200 TPD mill using brown stock washer, and the ranges for these data have been taken from the literature and through mass balance calculations and is represented in Table 2.

Step II:

After generating the data, the network is required to be trained ,so the first step is to keep the number hidden

Table 2 : Range of data

Input	Range
F_i	180-230 m3/hr
C_i	1-3%
C_d	9-11%

Table 3 : MSE calculated for first 200 epochs

Learning rate	MSE
0.3	$2.85*10^{-5}$
0.4	$2.04*10^{-5}$
0.5	$1.86*10^{-5}$
0.6	$1.49*10^{-5}$
0.7	$1.06*10^{-5}$
0.8	$1.52*10^{-5}$
0.9	$1.92*10^{-5}$

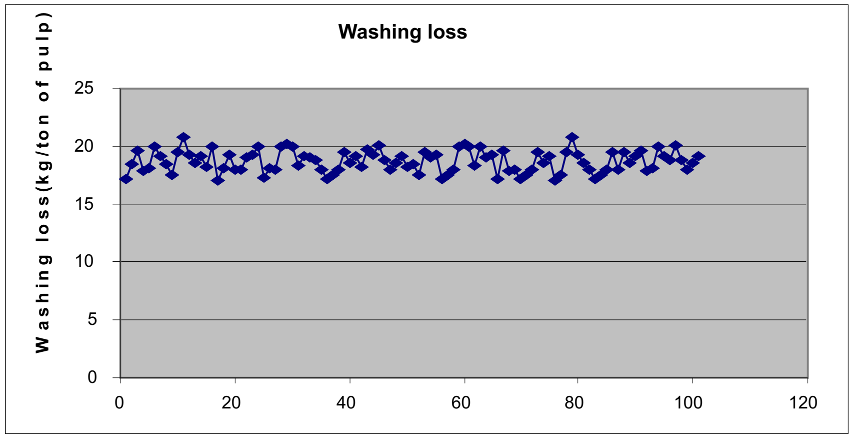

Fig. 8. Network output

Production rate: 200 TPD (OD)

Pulping: Conventional Kraft pulping

Table 4: Range of data received from M/s Star Paper Mill, Saharanpur, India :

Parameter	Description	Tag name	Range
A	Stock flow to washer	FI001	200-220 m3/hr
B	Stock consistency to washer	CI001	2-3%
C	WBL flow	FI003	58-62 m^3/hr
D	WBL solids concentration	SOLIDS	15-16 %
E	Drum speed	SI001	2.01 rpm
F	Liquor Conductivity	COND	2 µmho/cm
G	Vat level	LI001	0.34
H	Mat thickness	AI100	2.5 cm
1	Discharge consistency	CI002	9-11%
2	Soda loss	AI201	17-22 Kg Na_2SO_4/T
3	Dilution factor	DF202	$3m^3$/T

neurons constant and vary the learning rate.

Data is trained for various learning rates η = 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9; MSE is calculated for first 200 epochs and the average value is noted and presented in Table 3. From the graph in figure 4 it can be deduced that value of MSE is least for 0.7, hence the value of learning rate is optimized.

Unsupervised Training

The back-propagation algorithm can be utilized best for the predictive control. As stated earlier the training in this case will be done with actual mill data, i.e. unsupervised learning.

Input and Output Data

For this purpose we have taken the range of data for which the brown stock washers operate from M/s Star Paper Mills.

A brief description of star paper mill is:

Bleaching sequence: CEpHH

Brown Stock washing: 4 rotary drum washers and Washing control through DCS

Hence for training we have generated the random reference within the mill range, while some of the data value has taken as it is. Some of the values are calculated by the equations.

Network Parameters:

Learning rate η: 0.7

Momentum Rate α: 0.9

Number of hidden neurons: 7

Thresh value: MSE = $1*10^{-5}$

So training is accomplished by inputting the mill data and the weights are adjusted to minimize the MSE.

Conclusions

A control system for Brown Stock Washer is designed based on Artificial Neural Network. An ANN model is developed which is trained for plurality of variables involved in Brown Stock Washing. The trained network predicts the values of some indirectly controlled variables to give a set point to shower flow for an optimum dilution factor.

The said model is multivariable, non-linear and dynamic. This model follows the dynamics of the process without any assumption. The system thus designed has the following advantages:

- **Response time is reduced**

The neural Network controller is trained so that when production rates are changed from one level to another, historical experience is used to adjust the flow rates in order to obtain optimum operating conditions at various fractions of time constant. Consequently when operators make changes to pulp stock input to the pulp washing system, they need no longer merely wait for changes to occur in the liquor stream some hours later to respond manually, but they can allow the system to dynamically adjust for the change as in a feed forward manner eliminating the problems associated with the long lag in response time.

- **Removing the need of the operator involvement for balancing the soda loss and wash water requirement.**

The invention overcomes the problem of large lag times existing between the controlled parameter (dilution factor) and the variable that is being controlled (shower flow), by looking at the plurality of variables involved and adjusting the set points of controlled variables.

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