DEVELOPMENT OF IMPROVED PID CONTROLLER FOR SINGLE-EFFECT EVAPORATOR

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Abstract

Kraft pulping is the pulping process that is mostly used in paper mills. This is because the chemicals used in cooking are being recovered, and environmental pollution is minimized, as the chemicals are not discarded into the environment, but rather re-cycled. These chemicals are recovered by burning the black liquor that leaves the digester in a reactor called a recovery boiler. Feeding the black liquor directly from the digester to the recovery boiler will cause a water/smelt explosion. This explosion happens if the percentage of water in the liquor is high, the solid content of the black liquor leaving the digester is usually between 13-18%. To avoid such disaster the concentration of the black liquor has to be increased, which should in the range of 60-70%, this is done in a single or multiple effect evaporator.

In this paper, a single effect evaporator control has been designed using a Proportional Integral Derivative (PID) controller. During the first design a simple PID controller with a feedback control was used. Then taking into consideration the load disturbance in the process, a feed forward control has then been introduced into the controller design. Subsequently the concept of boiling point rise (BPR) to measure concentration has then been used in the controller design of a single effect evaporator.

Key Words: *Boiling Point Rise, Concentration, Evaporators, feed forward control, Paper mill, PID controller, Pulping process, Single-effect evaporator*

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1. INTRODUCTION

The paper making process as a whole consist of various sub sections, wood is a raw material used in paper making. Trees from the field are cut down into wood logs, then transporting the wood logs to the paper mill industry. The wood logs undergo what is known as wood preparation, upon reaching the paper mill. This wood preparation includes de-barking, wood chipping and then chip selection. The selected chip with appropriate size is then sent to a digester for cooking. The cooking is done under a predetermined temperature and pressure for a certain period of time. The cooked pulp then undergoes washing, which the pulp is then separated from the black liquor. The black liquor undergoes chemical recovery in order to recover the used chemicals [4]. The washed pulp then goes to a bleaching if required. The bleached pulp is then conveyed to the paper making machine. It is at the paper making machine were the pulp is transformed into a giant paper web, and water is squeezed out of it, leaving behind a delicate paper which need to be dried, and later cut into required sizes.

The black liquor enters the chemical recovery cycle at the evaporation section. This is crucial as the black liquor leaving the digester has low solid content usually 13-18%, and for the black liquor to be fired into the recovery boiler it must have at least 58% of solid content [5], otherwise a water/smelt explosion may occur. For that purpose the concentration of black liquor has to be increased, and this is done by evaporation process. The evaporation process is done in vessels called evaporators.

Evaporators are heat exchangers. This heat exchangers are bodies in which the evaporation takes place. This evaporators are also called as effects. The principle operation of the evaporators is to increase the concentration of the black liquor in it. Superheated steam or hot air is fed to the evaporator effect, in which contains the black liquor. As the steam enters into the wall tubing, it exchanges it is heat energy with the liquor inside the evaporator. This rises the temperature of the black liquor to a point whereby it starts to boil [6]. Upon boiling, the water present in the liquor is converted to a gaseous form and leave the salt [2]. The steam that gives away it is energy to the liquor changes to liquid state, and is collected as condensate at one end. In pulp and paper mills, there are different types of evaporators used, for the purpose of increasing it is concentration, some of them are. Rising film, falling film, direct contact and forced circulation [4].

This work focuses on the design of a Proportional Integral Derivative (PID) Controller for single effect evaporator, for the purpose of increasing the solid concentration of black liquor leaving the digester, before it is fed to the recovery boiler for combustion.

2. CONTROLLER FOR SINGLE EFFECT EVAPORATOR

2.1 Control Requirements

To achieve the target concentration in the end product, the rate at which the steam is fed to the heat exchanger has to be controlled. The rate at which the steam is to be supplied will be determined based on the solid content concentration of the black liquor, and to what percentage the concentration is required to be increased to. For operation and control of the single effect evaporator, a PID controller is used to control the degree of opening or closing of a motorized control valve.

2.2 Simple PID Controller

For a simple PID controller in a single effect evaporator process, the controller can either be a Micro-process based [1] or PLC based. The desired set point of the concentration is inputted into the PID which will be in digital form. A concentration sensor is placed inside the outlet of the evaporator so as to measure the concentration of liquor leaving the evaporator. The sensor measures the concentration and feds the analog reading to and ADC, the digital data now is fed to the PID controller. The PID controller generates an error signal based on the difference between the measured concentration and set point [3], and feds it to a DAC. The digital signal is fed to the motorized control valve, which determines the degree of opening or closing of the valve based on the error signal fed to it. This in turns control the amount of steam to be fed to the process. Fig 1 is a block diagram that illustrates the control strategy employed here and fig 2 shows the simple PID controller for a single-effect evaporator.

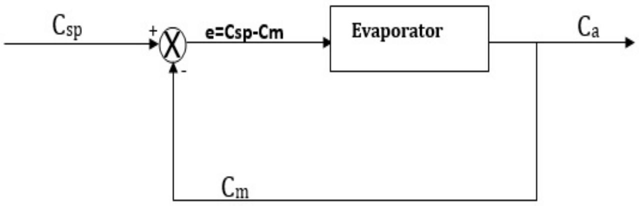

Fig -1 Block diagram of control strategy of single effect evaporator

(Csp: Concentration set point, Cm: Measured concentration, Ca: Actual concentration).

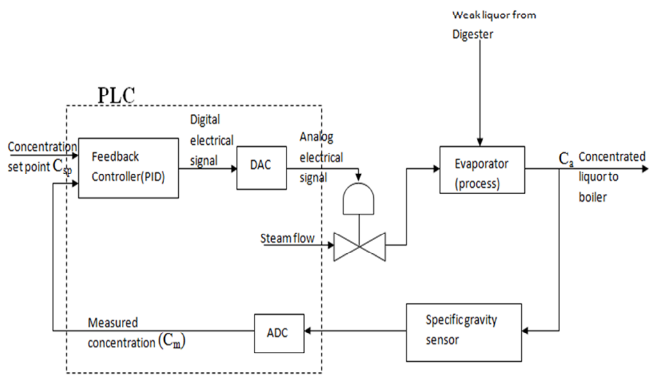

Fig -2: Block diagram of PID controller for a single effect evaporator

3. PID CONTROLLER WITH FEED FORWARD CONTROL FOR SINGLE-EFFECT EVAPORATOR

3.1 Necessity of Feed Forward Control

In the previous control, the controller regulates the amount of steam flow into the evaporator based on the concentration measured at the output by the sensor. The rate at which the process respond is slow, as the rate of steam flow is only altered if changes has been measured at the output, this does not take care of disturbance that may occur on the process. In evaporators there are two major disturbance that can affect the process, this are, the rate at which the weak liquor is fed to the process, and the change in concentration of black liquor entering the process. If the rate at which the weak liquor is fed to the evaporator is increased, then the rate of which steam is fed to the process has to be increased, and vice versa. If the concentration of solid content in the weak liquor is decreased then more steam will be required to evaporate. If the concentration of the weak liquor is increased then less amount of steam will be required inside the process in order to concentrate it to its required concentration.

To overcome the effect of this disturbance on the process a feed forward control is used. This feed forward controller sends a correcting signal before the disturbance affects the process [3].

3.2 PID Controller with Feed Forward Control

In this PID controller configuration a feed forward control is introduced. In the previous control configuration the control signal sent to the motorized control valve is from an error generated after measuring the output and comparing with the preferred set point. This will take a certain time delay before correcting if there is a disturbance on the process. To overcome this delay a feed forward controller is used. The feed forward controller is used to overcome and neutralize the effect of disturbance on the system, before it even effects the overall system. Fig 3 shows PID controller scheme.

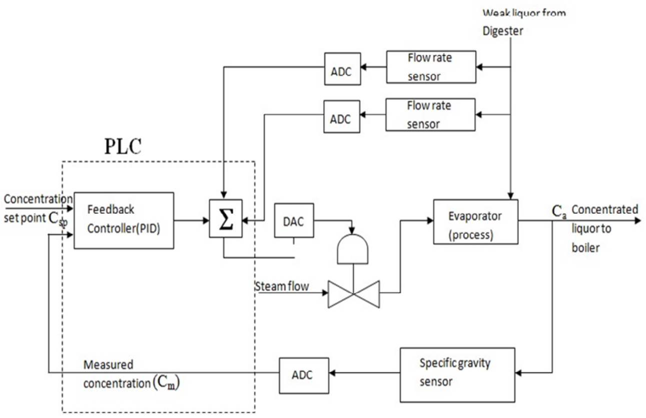

Fig-3 Block diagram PID controller with feed forward control

4. FURTHER IMPROVEMENT IN PID CONTROLLER

4.1 Boiling Point Rise (BPR) as Measure of Concentration

Boiling point rise is the difference between the temperature of a boiling solution and the temperature of boiling water (pure) at the same pressure. A dhuring chart can be used to determine the BPR. The BPR is usually expressed in degree Fahrenheit (^oF) but can also be in degree Celsius (^oC) [8].
Dhuring chart states that, there exist a linear relationship between the temperature of boiling water and that of a solution at the same pressure [9]. Since the boiling temperature of the solution can be measured and the temperature of steam i.e. the temperature of boiling water. At the same time measuring the pressure inside the vessel. Values of these three parameters can be used to compute the concentration using Eqn 1 or 2.

$$BPR= (a1+b1Pr)[x/(1-x)] \text{ for } x<0.65 \ldots\ldots\ldots\ldots \quad (1)$$

$$BPR= [(a2+b2Pr) + (a3+b3Pr)][x/1-x] \text{ for } x>=0.65. \quad (2)$$

Where a1, a2, a3, b1, b2 and b3 are experimentally determined constants and Pr is the pressure in the evaporator. The concentration is first computed for the first equation that is x<0.56, if x is found to be grater then 0.65 then the second equation will be used. Therefore if the temperature of the boiling solution can be measured as well as the temperature of boiling water and pressure at which this takes place, then the concentration of that solution can be calculated. This can be seen in fig 4

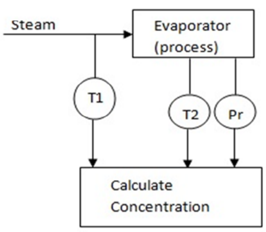

Fig -4 Schematic for measuring concentration through BPR

(T1: Temperature sensor that measure the temperature of steam, T2: Temperature sensor that measures the temperature of boiling solution, Pr: Pressure sensor that measure the pressure inside the evaporator).

4.1 PID Controller of a Single Effect Evaporator Using BPR

In section 3.2 a concentration sensor has been used to measure the solid content concentration of the liquor. This concentration sensors are not that efficient in reading the exact concentration of the liquor, as there are not designed initially for a particular salt. A Refractometer is used for measuring concentration, measurement of concentration using a refractometer is not accurate for higher solid concentration, but rather works on prediction. Also the cost of purchasing such sensors is very costly, such as the specific gravity sensor. In order to overcome such problems of concentration measurement sensors.
The sensors are replaced with something that will eliminate those disadvantages. To achieve that, the concept of BPR fully known as Boiling Point Rise is used. In evaporators, to measure the boiling temperature of the solution, a temperature sensor is placed just below the surface of the boiling solution, another temperature sensor is to be placed in the vapor region inside the evaporator so as to measure the boiling point of the steam. A pressure sensor is then placed in the head of the evaporator so as to measure accurately the pressure at which the boiling takes place. The measured parameters are sent to a multiplexer and then to an ADC so as to convert the analog signal to digital form, which will be suitable for the computer (controller) to interpret and manipulate. The ADC output if fed to the controller that calculates the concentration based on either equation 1 or 2. Then sends the reading of measured concentration to the feedback controller. The feedback controller will generate an error signal based on the difference between the set point and the measured concentration. This signal will be sent to DAC, which converts the digital signal back to an analog signal. The analog signal is fed to a motorized control valve, this valve controls the amount of steam to be fed to the evaporator. Fig 5 shows a PID controller block diagram using the concept of BPR.

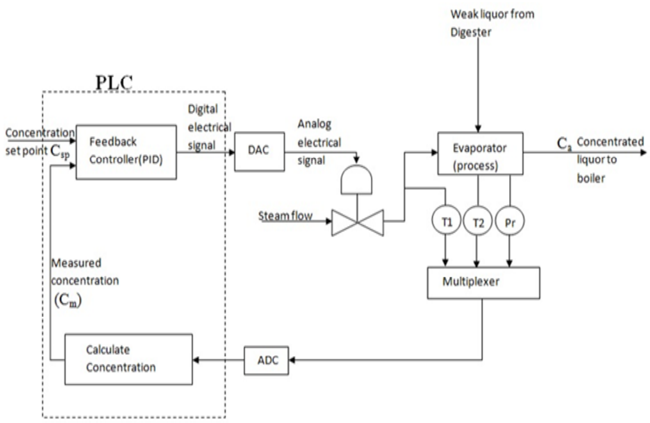

Fig-5 Control scheme of single effect evaporator using BPR

4.3 Improved PID Controller of Single Effect Evaporator using BPR with Feed Forward

Using the concept of BPR to determine the concentration of liquor, as well as using a feed forward control to overcome any effect due to disturbance will be the fore more best control design for a single effect evaporator. This can be seen in fig 6.

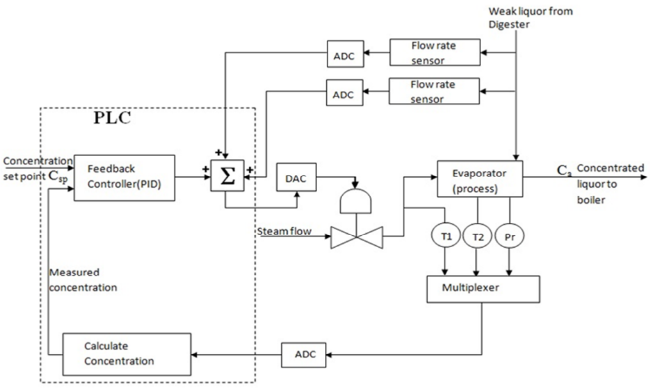

Fig-6 PID controller using BPR with feed forward control

5 CONCLUSION

In this paper, single effect evaporation process was discussed with four different control configurations, in order to achieve the end target of attaining the value of concentration accurately.

A simple PID controller was first designed with a feedback control, then taking into consideration of disturbances on the process, a feed forward control was then employed to overcome that effect. Later using a concept of BPR to determine the concentration was used, which is more accurate than using conventional concentration measuring sensors and less cost of their purchase. Combining all this together gives an improved PID controller for single effect evaporator.

A single effect evaporator is not commonly used anymore these days since it is not economical, as the output vapor is not re-used in the process.

For that purpose a multi-effect evaporation process has replaced it these days. Authors are working on the development of a PID controller for multi-effect evaporators.

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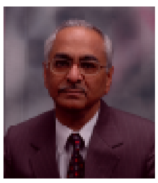
BIOGRAPHIES

Aminu Tijjani graduated in Electrical Engineering in 2012 from Kano University of Science and Technology wudil, Kano state Nigeria in 2012, Then offering his Master of Technology in Sharda University in Electrical and Electronics with specialization in Instrumentation and Control.



H. K. Verma graduated in Electrical Engineering in 1967 from the University of Jodhpur and obtained Master of Engineering and Ph.D. degrees in 1969 and 1977, respectively, from the erstwhile University of Roorkee (now Indian Institute of Technology Roorkee). Prof. Verma has published over 200 research papers, and guided 15 Ph.D. theses and 130 M.E./M.Tech. dissertations. He was honoured twice, first in 2004 and again in 2009, by the Indian Institute of Technology Roorkee as a Distinguished Teacher.

Chhaya Sharma (chayafpt@iitr.ernet.in) received Ph.D. (Pulp and Paper Engineering) in 1994 from IIT Roorkee (erstwhile University of Roorkee). She started her career as Research Fellow (JRF, SRF and RA) 1988 then joined as faculty in July 2000 at IIT-Roorkee and continuing till date. She has published more than 45 research papers