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Advanced Control of Pans in Sugar Plant

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Abstract: Operation of pan involves evaporation and crystallization, which in effect means concentration of material of different purities and growth of sugar crystals to the desired size. The process at the initial stage of the pan is similar to the process of evaporator section. If the required temperature at a particular height is obtained, then the desired concentration can also be achieved. So the dependence of temperature of the syrup on the level is of considerable importance. Hence the level and temperature at the initial stage of pan is controlled here. Comparison between conventional controller and advance controller is done to control the level of the pan at the initial stage and the results are verified.

Keywords: PID controller, MPC controller, modelling, juice.

I. INTRODUCTION

Food processing plays an increasingly vital role in modern day society. The sugar industry is one of the largest sectors of the Indian economy and India is now among the largest producers and consumers of sugar in the world. Sugar production from cane is nominally a continuous operation. Manufacturing of sugar consists of different stages such as milling, clarification, evaporation, crystallisation, centrifugaling. The milling process occurs in two steps: breaking the hard structure of the cane and grinding the cane. The screened raw juice received from mill house is collected in a tank. It is heated using the vapours from the evaporator bodies in the raw juice heater. The purpose of raw juice heating is to destroy or stop the development of microbial activity in the raw juice. The sulphated clear juice is again heated and fed to the clarifier tank. Flocculants are added to the clear juice in the clarifier. Clarified juice goes to the evaporators without additional treatment. The mud is filtered and the filter cake is washed with water. The clear juice contains about 83 to 85% water, the remaining portion being represented by the sugar and impurities known as non-sugar components.

The evaporator station which performs the function of concentrating the clear juice to syrup. is performed in two stages: initially in an evaporator station to concentrate the juice and then in vacuum pans to crystallize the sugar. Crystallization of the sugar starts in the vacuum pans, whose function is to produce sugar crystals from the syrup. A centrifuge machine used in the sugar industry is a mechanical device for separating a solid from a liquid. The centrifugal section has a metal basket with perforations used to separate the sugar crystals from liquid (massecuite). The centrifugals get a batch of massecuite and are rotated at programmed speeds to the get the sugar crystals.

Sugar boiling is one of the most important stage in producing sugar. It is mainly carried out at evaporator section and pan station. At evaporator section juice is converted to sub- saturated syrup, while at the pan station syrup is converted to the supersaturated syrup. Pan(shown in fig1) has heating chamber surrounds a set of vertical tubes that containing boiling juice. A flow of steam enters this chamber and transfers heat to juice providing energy needed for boiling. The steam condenses around the tube and leaves the evaporator as the condensate. A sugar solution of low concentration flow into the base of the pan and starts boiling consequently we get a solution of higher concentration. When the syrup become supersaturated small grains of sugar are added to the pan thus small sugar crystals were formed.

In this paper, only consider the initial stage of the pan.

Pan operation classified into two stage: juice from the evaporator station converted to supersaturated syrup and next stage is the crystallization. Good quality sugar production can be achieved by running the pan operation in a controlled manner.. For controlling the pan in a good manner, developing a model is an important task. Operation of a pan can be studied via mathematical modelling. Mathematical modelling of chemical process generally have mass balance and energy balance.

Combination of Proportional, Integrator ,derivative controller and Model predictive Control is used in this paper to control the level and temperature at the intial stage of pan. The classical MPC strategy uses a discrete model obtained from general model consists of mass and energy balance.

The remainder of this paper is organized as follows. Section II provides a system description. Section III presents the mathematical modelling of the system, and Section IV its performance evaluation by means of simulation.

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II. SYSTEM DESCRIPTION

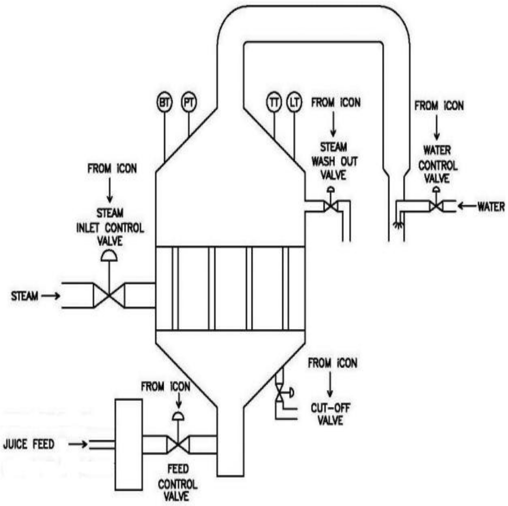

Fig 1: vacuum pan

Pan boiling involves evaporation and crystallization which in effect means concentration of material of different purities and growth of sugar crystals to the desired size .At the initial stage inlet feed flow should be open until the level of the juice reaches above the calandria after that inlet feed flow closed while inlet steam flow open. The process is characterised by strongly non-linear and non-stationary dynamics and can be divided into several sequential phases.

Charging: During the first phase the pan is partially filled with a juice containing dissolved sucrose (termed liquor).
Concentration: The next phase is the concentration. The liquor is concentrated b evaporation, under vacuum, until the supersaturation reaches a predefined value. At this stage seed crystals are introduced into the pan to induce the production of crystals. This is the beginning of the third (crystallisation) phase.
Crystallisation (main phase): In this phase as evaporation takes place further liquor or water is added to the pan in order to guarantee crystal growth at a controlled supersaturation level and to increase total contents of sugar in the pan. In most cases, due to economical reasons, the liquor is replaced by other juice of lower purity (termed syrup).

Tightening: The fourth phase consists of tightening which is principally controlled by the evaporation capacity. The pan is filled with a suspension of sugar crystals in heavy syrup, which is dropped into a storage mixer. At the end of the batch, the final massecuite undergoes centrifugation, where final refined sugar is separated from the (mother) liquor.

III.PROBLEM FORMULATION

Pan level and temperature at the initial stage are controlled here by using PID and MPC controller.

IV. PROCESS MODELLING

The traditional way of process modelling for many years has been by mathematical equations. Non-linear mathematical model of the plant is obtained by using simple physical laws. Mathematical Modeling of a pan is usually developed from the principles of conservation of mass and energy.

The principles of conservation of mass (without any chemical reaction) can be written, mathematically

Rate of accumulation of mate material within a system . = Rate of material into the system _ Rate of material out of the system (1)

For the pan being considered, subject to the principles stated in Equation (1):

$$\rho A_c \frac{dh}{dt} = F_{in} - F_{out} \tag{2}$$

Since,

$$F_{out} = c_v \sqrt{p - p_{out}} \tag{3}$$

According to liquid properties the pressure difference is given by,

$$p - p_{out} = \rho g h \tag{4}$$

Substituting equation (3) and (4) in equation (2) ,

$$\frac{dh}{dt} = \frac{F_{in} - c_v \sqrt{\rho g h}}{\rho A_c} \tag{5}$$

The principles of conservation of energy can be written, mathematically,

Rate of accumulation within a system = Rate of energy into the system - Rate of energy out of the system (6)

For the pan being considered, subject to the principles stated in Equation (6),

$$\rho c_p A_c \frac{d(h[T - T_{ref}])}{dt} = F_{in} H_{in} - F_{out} H_{out} + Q_{steam} - Q \tag{7}$$

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The enthalpy of juice feed into the system is,

$$H_{in} = c_p (T_{in} - T_{ref}) \qquad (8)$$

Since T_{ref} is constant,

$$\rho c_p A_c h \frac{dT}{dt} = F_{in} c_p (T_{in} - T_{ref}) - F_{out} c_p (T - T_{ref}) + Q_{steam} - Q - c_p T (F_{in} - c_v \sqrt{\rho g h}) \qquad (9)$$

The heat transferred from steam to liquid Q_{steam}

$$Q_{steam} = (UA)_{coil} \frac{h}{h_{max}} (T_{steam} - T) \qquad (10)$$

The heat lost as a result of vaporization Q

$$Q = (F_{in})\,\Delta H_{vap} \qquad (11)$$

Substituting equation (10) and (11),

$$\frac{dT}{dt} = \frac{F_{in} c_p (T_{in} - T_{ref} - T) + c_p c_v T_{ref} \sqrt{\rho g h} + (UA)_{coil} \frac{h}{h_{max}} (T_{steam} - T) - F_{in} \Delta H_{vap}}{\rho c_p A_c h} \qquad (12)$$

The state-space form is,

$$\dot{x} = Ax + Bu$$
$$y = cx \qquad (13)$$

Where A,B,C are,

$$A = \begin{bmatrix} -4.77 * 10^{-3} & 0 \\ -2.7807 & -8.81 * 10^{-3} \end{bmatrix}$$

$$B = \begin{bmatrix} 4.166 * 10^{-3} & 0 \\ -3.959 & 8.75 * 10^{-3} \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \qquad (14)$$

V. MODEL DEVELOPMENT AND SIMULATION USING MATLAB

The differential equation (5)and (12) are solved and simulation studies are carried out with the help of nominal values of the pan parameters collected from the sugar plant during the study.

The data pertaining the pan parameters are represented in table 1.Openloop step response tests are conducted on the model in order to determine its suitability to control application.

Table 1: Nominal values of pan variables

DESCRIPTION	SYMBOL	UNITS	VALUE
Inlet feed flow rate	F_{in}	Kg/sec	.00833
Valve constant	c_v	Kg/(sec $bar)^{.5}$	.0183
Liquid density	ρ	Kg/ m^3	800
Acceleration due to gravity	g	m/ s^2	9.81
Cross sectional area	A_c	m^2	.3
Inlet temperature	T_{in}	K	150
Specific heat	c_p	K j/(kg K)	6
Steam temperature	T_{steam}	K	600
Heat of vaporization	ΔH_{vap}	Kj/kg	463
Reference temperature	T_{ref}	K	268
Maximum level	h_{max}	m	1
Heat transfer coefficient and heat transfer area	$(UA)_{coil}$	K j/(sec K)	.21

Input and Output of the pan is represented in Figure 2

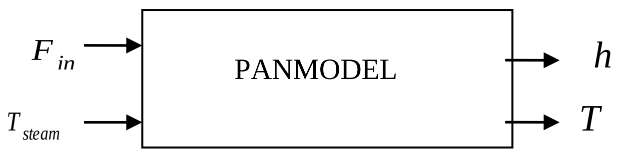

FIG 2: PAN MODEL

VI.SIMULATION RESULT

The pan, level and temperature control at the initial stage is model led in this paper and is simulated with conventional PID controller and an advanced control technique such as MPC using matlab. The simulations are carried out with nominal values. In both cases syrup and steam temperature given to the pan are taken as the input and corresponding variation in level of syrup and temperature of syrup are analysed.

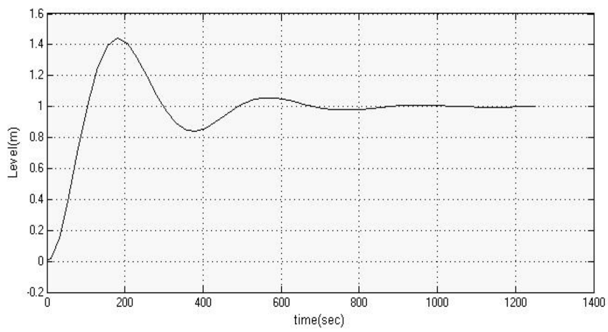

Fig 3: Regulation of pan level using PID controller

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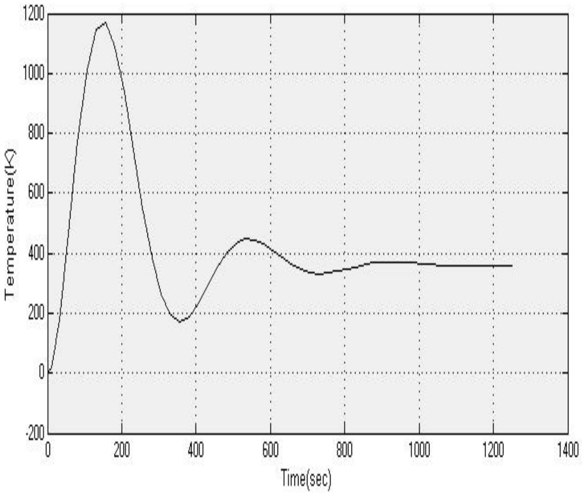

Fig4: Regulation of temperature by using PID controller

Experiments were carried out by using PID controller and the simulations are shown in figure 3 and 4.From the simulation response ,the PID controller took longer time to settle. To improve the response of PID controller here we use an advance controller MPC.

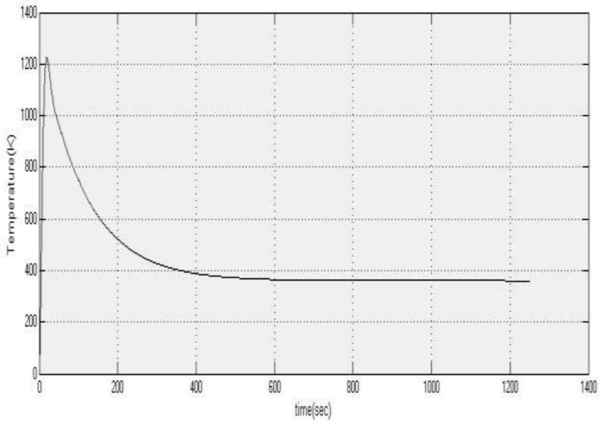

Fig 5: Regulation of temperature by using MPC controller

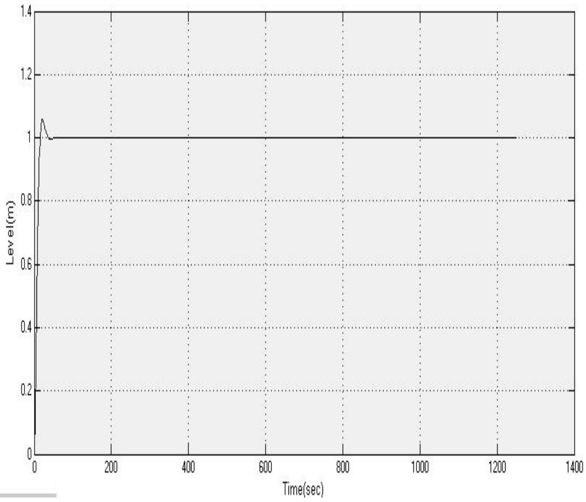

Fig 6: Regulation of pan level using MPC controller

Experiments were carried out by using MPC controller and the simulation is shown in figure 5 and 6.It is found that the level and temperature are track in a very short time.

VII.CONCLUSION

In this paper, the regulation of pan level at particular temperature is done by using PID and MPC controller. The performance of PID and MPC controller are evaluated and comparison between both the control strategies are studied by using this work .From the simulation response the performance of MPC is more accurate and better than PID controller.

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