Model Predictive Control Of Temperature Process In Pasteurization

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***Abstract- The* classical controllers like PI or PID controllers are widely used in process industries because of their structure and their tuning is well known among all industrial operators. But these controllers have so many limitations. These controllers provide better performance only at a particular operating range. The specific control problems associated with the plant operations severely limit the performance of conventional controllers. The increasing complexity of plant operations together with tougher environmental regulations, rigorous safety codes and rapidly changing economic situation demand the need for more sophisticated process controllers. Model predictive controller (MPC) is an important branch in automated control theory. MPC refers to a class of control algorithm in which a process model is used to predict and optimize the process performance. In this project temperature in pasteurization process is controlled using model predictive controller. It show a good performance in keeping both the milk and water temperatures at the desired set points without any oscillation and overshoot.**

***Index Terms-* model predictive control, proportional integral control, pasteurization**

I. INTRODUCTION

Milk pasteurization process, a nonlinear process and multivariable interacting system, is difficult to control by the conventional on–off controllers, since the on–off controller can handle the temperature profiles for milk and water oscillating over the plant requirements .The MPC technique for multi-input multi-output (MIMO) system is implemented in this project for application to the milk pasteurization process which is commonly found in the dairy industries. The highly nonlinear dynamic behaviour, multivariable in nature, and interaction between unit processes cause this process to be difficult to control by conventional controllers.

II. SYSTEM DESCRIPTION

Pasteurization is the reason for milk's extended shelf life. High-temperature, short-time (HTST) pasteurized milk typically has refrigerated shelf life of two to three weeks, whereas ultra-pasteurized milk can last much longer, sometimes two to three months. When ultra-heat treatment (UHT) is combined with sterile handling and container technology (such as aseptic packaging), it can even be stored unrefrigerated for up to 9 months.

The pasteurizer used is based on a clip 10-RM plate heat exchanger (PHE) and brazed heat exchanger (BHE). A PHE consists of a pack of stainless steel plates clamped in a frame .The plate are corrugated in a pattern designed to increase the flow turbulent of medium and the product.

The pasteurizer is divided into five sections, S1 to S5 section S1 and S5 are for regeneration, S1 and S3 for heating and S5 for cooling .The BHE are used to heat the water used as a heating medium in the PHE. The heating surface in a BHE consists of thin corrugated metal plates stacked on top of each other. Channels are formed between the plates and corner ports are arranged so that the flow media flows through alternate channels always in counter-current flow. The pasteurizer operates as follows, the raw milk at a concentration of 4.1% enters the section S4 of the PHE at a temperature of 2.0^{o} C. It is then preheated to a temperature of 60.5^{o}C by the outgoing pasteurized milk which as a result is reduced to a temperature of 11.5^{o}C.

Passing the section S3, the milk is now heated to temperature of 64.5^{o}C using the hot water as a medium. The milk, before reaching the next section, is first separated from the fat then standarised and homogenized to a concentration of 3.5% .It then enters section S2, where it is preheated to a temperature of 72°C using the already pasteurized milk as a medium. The milk is finally bought to the pasteurization temperature in section S1 (75.0°C) using the hot water at around 77.0°C as a medium.

After that the homogenized pasteurized milk is held at the temperature for 15s in the holding tube before being cooled using the incoming cold milk in section S4 and section S2. Finally, the pasteurized milk enters the cooling section (section S5) at the temperature of 11.5°C, where the milk is chilled to a temperature of 1.0°C using propylene glycol as a medium at a temperature of -0.5°C. The water for section S3 and S4 is bought to adequate temperature in steam/water heater. The steam temperature is constant and have a value of 110.0°C. Since milk is an excellent medium for microbial growth .and when stored at ambient temperature bacteria and other pathogens. Diseases which pasteurization can prevent are tuberculosis, brucellosis, diphtheria and scarlet fever. Pasteurization is the reason for the milk's long life, sometimes two to three weeks.

III. MATHEMATICAL MODELING

In this model, the effect of the plate is neglected and the exchange in every channel (between two plates) is described by the differential equation .This leads to an n by n system where n is the number of channels. Consider the differential equation describing heat exchange in every channel (i.e. between the plates) .This leads to a relatively large number of equations (i.e. equal the number of channels).

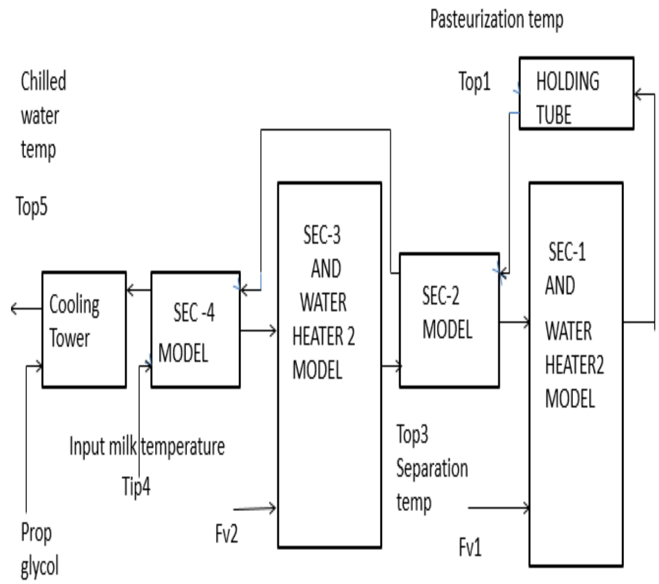

Figure 1 Pasteurization Process

The thermal evolution of the product (milk) and the medium (milk in preheating sections, or water in heating sections) is evaluated under the following assumptions:

Both medium and product flow in opposite directions (counter-current flow). A thin film of product and medium tends to create at each side along the wall. In the case of heating a product by a medium, the medium temperature decreases both spatially and over time, until reaching virtually the temperature of the medium's thin film. On the product side, the product temperature increases to reach the temperature of the products thin film.

The overall heat flow Q between product and the medium input temperature Tim (°C) and Tip (°C)respectively

Q=AU (Tip –Tim) (1)

where,

A is heat exchange area (m^2)

U is the total heat coefficient (W/m^2/K)

The heat flow between the product input Tip (°C) and the thin film's temperature on the product side Twp (°C)

Q=AUp (Tip-Twp) (2)

Where,

Up is the heat transfer coefficient plate at product (W/m^2/K)

Similarly,

$$Q = AUm\,(Twm - Tim) \qquad (3)$$

Where,

Um is heat coefficient plate/m (W/m^2/K)

Heat flow across the wall

$$Q = A\frac{Kpa}{Sw}(Twp - Twm) \qquad (4)$$

Where,

Kpa thermal conductivity of the wall (W/ (mk))

Twm is thin film's temperature on the medium side (°C)

Twp is the thin film's temperature on the product side(°C)

Sw is thickness of the wall(m)

To obtain the temperature of the films on both sides of the plate compare (1) and (2) as well as (3) and (4) Therefore the steady state temperature Twp and Twm can be written as

$$Twp = Tip - \frac{U}{Up}(Tip - Tim) \qquad (5)$$

$$Twm = Tim + \frac{U}{Um}(Tip - Tim) \qquad (6)$$

Considering each section of the PHE as a heat transfer problem between two fluids separated by a plate. The heat transfer evolution can be characterised by the energy balance equation (7) –(8)

Considering the product side

$$\backslash\ \rho_p CpVp\frac{dTop}{dt} = {}_{\varrho}pCpFp(Tip(t) - Top(t)) + UpA\,(Tpa(t) - Top(t)) \qquad (7)$$

Similarily at the medium side

$$\rho mCmVm\frac{dTom}{dt} = {}_{\varrho}mCmFm(Tim(t) - Tom(t)) + UmA(Tpa(t) - Tom(t)) \qquad (8)$$

Where,

ρ = density in (kg/m^3)

C= specific heat coefficient in (j/kg/K)

V = volume in (m^3)

F= flow rate (m^3/h)

Finally, the output temperature of the product T_{op} and the medium T_{om} are the found

$$\tau p\frac{dTop}{dt} + Tom(t) = \lambda pTip(t) + (1 - \lambda p)Tim(t) \qquad (9)$$

$$\tau m\frac{dTom}{dt} + Tom(t) = \lambda mTim(t) + (1 - \lambda m)Tip(t) \qquad (10)$$

Similarly, at BHE , the medium(water) used to heat the milk in section S1 and S3 has to be heated to an appropriate temperature before being routed into the BHE of type CB76 .The water becomes the product of heat using hot steam at 110.0 °C .Taking the above consideration ,the following energy balance equation is obtained:

$$\tau im\frac{dTim}{dt} + Tim(t) = \lambda imTom(t) + (1 - \lambda m)Tpa(t)$$

$$\tau pa\frac{dTpa}{dt} + Tpa(t) = Tim(t) + \lambda pa\,Fm$$

By combining equation (9)-(10) the pasteurization model can be then given as following state space equation

$$\begin{vmatrix} T\dot{o}p1 \\ T\dot{o}m1 \\ T\acute{i}m1 \\ T\grave{}pa1 \\ T\dot{o}m2 \\ T\dot{o}p2 \end{vmatrix} = \left\| \begin{matrix} \frac{-1}{\tau p1} & 0 & \frac{1-\lambda p1}{\tau p1} & 0 & 0 & \frac{\lambda p1 e^{ds}}{\tau p1} \\ 0 & \frac{-1}{\tau m1} & \frac{\lambda m1}{\tau m1} & 0 & 0 & \frac{1-\lambda m1}{\tau m1} \\ 0 & \frac{\lambda om1}{\tau im1} & -\frac{1}{\tau im1} & \frac{1-\lambda im1}{\lambda im1} & 0 & 0 \\ 0 & 0 & \frac{1}{\tau pa1} & \frac{-1}{\tau pa1} & 0 & 0 \\ \frac{\lambda m2}{\tau m2} & 0 & 0 & 0 & \frac{-1}{\tau m2} & 0 \\ \frac{1-\lambda p2}{\tau p2} & 0 & 0 & 0 & 0 & \frac{-1}{\tau p2} \end{matrix} \right\| \begin{bmatrix} Top1 \\ Tom1 \\ Tim1 \\ Tpa1 \\ Tom2 \\ Top2 \end{bmatrix} + \begin{vmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & \frac{\lambda pa1}{\tau pa1} \\ \frac{1-\lambda m2}{\tau m2} & 0 \\ \frac{\lambda ip2}{\tau ip2} & 0 \end{vmatrix} \begin{bmatrix} Top3 \\ Fv1 \end{bmatrix}$$

Where the system output y is the pasteurization temperature T_{op1}, given in

$$y = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} Top1 \\ Tom1 \\ Tim1 \\ Tpa1 \\ Tom2 \\ Top2 \end{bmatrix}$$

Table 1 The parameter values of process

λ's	λp1 =0.2 λim1=0.21 λp2 = 0.1 λp2 =0.45 λpa1=40

τ' s	τp1=30 τim1=30 τim1=30 τp2=15 τpa1=30

IV. CONTROLLER DESIGN

(A) .PI CONTROLLER

A PI controller calculates an error value as the difference between a measure process variable and a desired setpoint. The controller attempts to minimize the error by adjusting the process control inputs. A PI controller (proportional –integral controller) is a special case of the PID controller is a special case of the PID controller in which the derivative (D) of the error is not used. For designing a proportional integral control, the parameters to be calculated are proportional gain (Kc) and the integral gain (ki)

$$Kc = \frac{0.9}{td.Kp} = 13.0921$$

$$Ti = 3.33\, td = 2.9653\, sec$$

$$Ki = \frac{Kc}{Ti} = 4.415\, sec^{-1}$$

(B).MODEL PREDICTIVE CONTROLLER

Model predictive control toolbox in MATLAB provides tools systematically analyzing, designing and tuning model predictive controllers. To design and simulate model predictive controllers using the functions in MATLAB or blocks in Simulink. The predictive model, control and predictive horizons, input and output constraints, and weights can be set and modified.

V. SIMULATION RESULTS

(A). PI CONTROLR

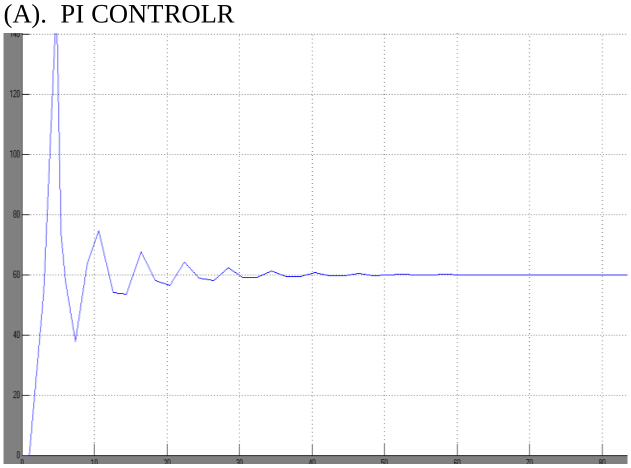

Figure 2 Response of PI controller in Simulink

From the response it is found that PI controller does not give a better performance for all operating region. Also the settling time and the overshoot of the PI controller is very large.

(B). MODEL PREDICTIVE CONTROL

From the response of MPC in Simulink. It shows that Model predictive control gives better performance. When compared to other conventional controller, MPC has less overshoot, oscillation and fast settling time.

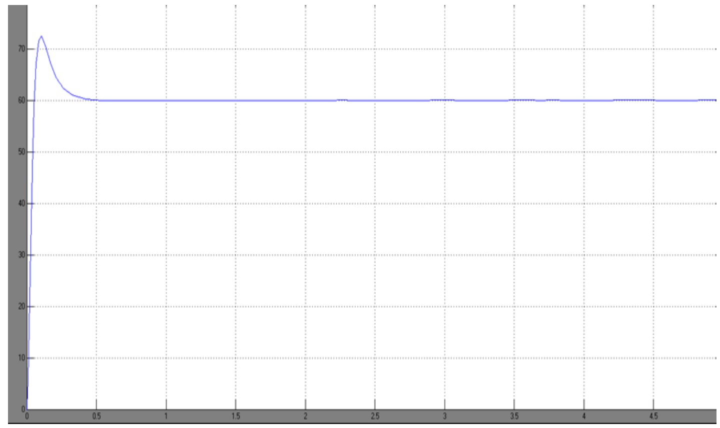

Figure 3 Response of MPC in Simulink

VI. PERFORMANCE ANALYSIS

A comparison between the performance of MPC and conventional controller was carried out and it was observed that model predictive controller has less overshoot, settling time and oscillation than the conventional PI controller. Thus, Model predictive control has better performance.

Table.2 Comparative Analysis

Controller	Setpoint (°C)	Settling time (sec)	Rise time (sec)	Overshoot (°C)
PI	60	60	2.5	153
MPC	60	0.42	2.5	21.05

VII. CONCLUSION

In this project, the milk pasteurization process is multi-variable interacting system, which make it difficult to control by the conventional control system. The Pasteurization process model was derived and analyzed by simulating with the conventional PI controller and MPC controller in MATLAB. MPC controller performed well in keeping the milk temperature and water temperature at the desired set points with less oscillation and overshoot. A comparison between the performance of MPC and conventional controller is carried out and it was observed that model predictive controller has got better performance with less overshoot and less oscillation than the conventional controller.

The accuracy of the Mathematical model is very important in implementation of MPC. Modeling of the system can be improved by using Non-linear methods. Future work of this project can be extended by using Internal Model Control and Nonlinear Model Predictive Control.

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