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Real time Implementation of multimodel based PID and Fuzzy controller for Injection molding machine

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Abstract: Good control of plastic melt temperature for injection molding is very important in reducing operator setup time, ensuring product quality. Motivated by the practical temperature control of injection molding proposes a variety of controllers such as PID controllers, FLC and ANFIS based controllers in a multi model fashion .The injection molding process consists of three zones and the mathematical model for each zone is different. The control output for each zone controller is assigned a weight based on the computed probability of each model and the resulting action is the weighted average of the control moves of the individual zone controllers. The performance criteria of the different controllers are compared, and the advantages, limitations of different implementation methods are also discussed. The proposed real-time Fuzzy control for the injection molding process mainly contributes the barrel temperature control.. time.

Keywords: Injection-molding, multimodel PID control, temperature control, Fuzzy Logic control,Real time.

1. INTRODUCTION

Injection molding is one of the most widely used techniques in the plastic industry, in which zone temperature control is important approaches to improve the quality of the molded parts. Temperature control is an important issue in many industrial processes. These processes usually show an integrating response characteristic during the heating up, and after rising to the set point temperature, it tends to behave in a stable manner given a certain heating range, due to air-convection losses. The challenges in these process are to avoid overheating (to reduce over shoots in temperature) in the heating up stage and to tightly maintain the set point temperature against load disturbance and process ambient temperatures.

An Injection molding machine, also known as an injection press, is a machine used for manufacturing plastic products by the injection molding process. Injection molding is a manufacturing process for producing parts from both thermoplastic and thermosetting plastic materials. It consists of two main parts, an injection unit and a clamping unit. There are four major elements that influence the process. They are molder, material, injection molding machine, and mold. Of these four, the injection machine and the mold are the most varied and mechanically diverse. Most injection machines have three platens and may be electrically operated. Most function horizontally, but there are some vertical models in use. The injection system mechanism may be of the reciprocating screw type or, less frequently, the two-stage screw type. Also included is a hopper, a heated injection barrel encasing the screw, a hydraulic motor, and an injection cylinder. The system function is to heat the thermoplastic to the proper viscosity and inject it into the mold. As the resin enters the injection barrel, it is moved forward by the rotation of the screw. As this movement occurs, the resin is melted by frictional heat and supplementary heating of the barrel encasing the screw. The screw has three distinct zones which further processes the resin prior to actual injection. [3].

Injection is accomplished through an arrangement of valves and a nozzle, all acted upon by the screw and the hydraulic pump that pushes the resin into the mold. This so-called “packing action” occurs at pressures from 20,000 to 30,000 psi and higher. The clamping system’s function is to keep the plastic from leaking out or “flashing” at the mold’s parting line. The clamping system consists of main hydraulic pressure acting on the mold platens and a secondary toggle action to maximize the total clamping pressure.

The platens are heavy steel blocks that actually hold the mold tightly closed during the injection phase. Most injection machines have three platens. The “stationary” platen has a center hole that receives the injection nozzle and holds the cavity half of the mold. This platen also anchors the machine’s four horizontal tie bars. The “movable” platen holds the core half of the mold. This platen moves back and forth on the tie bars and as the mold opens, the mold's ejection system of pins and posts expel the finished part. The "rear stationary" platen holds the opposite ends of the tie bars and anchors the whole clamping system. Injection molding is a cyclic and dynamic process, in which polymer melt temperature is a critical variable to be controlled. Melt temperature affects several other important process variables such as injection velocity, cavity pressure and part cooling time. These process variables have profound effects on the overall product quality, which include factors such as shrinkage, warpage, and surface finish.

Tao Liu, Ke Yao and Furong Gao have used relay feedback test for online identification of the 3 zones of the barrel in an injection molding machine. The local PID controllers are designed based on first principle models and are used to control the non-linear process. Chris Diduch and Wan Gui Li have developed a first principle model for the injection molding process based on certain assumptions. Rickey dubay,Adam C.Bell , have used MIMO and SISO models and Chris Diduch and Rickey dubay has designed the control for 1st principle model. Ke Yao,Furong Gao discusses the controlling of the temperature of the IMM , during the initial start up when it is prone to heavy transients.Dequn Li,Huamin Zhou,peng Zhao,Yang Li has discussed the real time optimization for online defects. G.K.Lowe.M.A.Zohdy provide a method for approximating a non linear system, using multiple linear models.Mingzhong Li,Yi Yang,furong Gao and Fuli wang has developed an Adaptive predictive control strategy for injection molding machine using multiple linear models.Nicolae Constantin discussed the predictive control for non linear applications using multimodel approach as well as multi model estimation.Musa R.Kamal,Avrram I.Isayev,Shihjung Liu,explained the IMM process and multimodel fuzzy temperature control .Mechanical details of the machine were obtained from the technical specification Messrs.Larsen&Toubro. The heating barrel of an injection molding machine is as shown in Fig.1

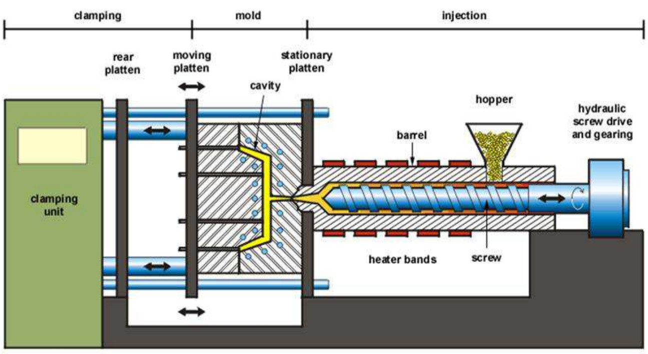

Fig. 1. Schematic diagram of an injection molding machine

2. REAL TIME IMPLEMENTATION

The proposed multimodel based PID &multi model based Fuzzy logic controller are designed and are validated in the Injection molding machine available at Larsen & Toubro ltd, Chennai.

2.1 Real Time Data Collection

To achieve better product quality and control of the many process parameters, there is a requirement for improved temperature control that reduces temperature fluctuations and transients during startup and molding. The dynamics of the IMM that relate heater inputs and barrel or melt temperature are distributed and nonlinear, and depend on a variety of factors that include the type of plastic, the backpressure and screw speed.Although the temperature is distributed over the Injection molding machine, the temperature-control system uses a fixed number of strategically placed heaters and thermocouples, each associated with a particular zone.

Real time data was collected from a fully automatic Injection Molding Machine Larsen &Toubro De Tech with iCon controller Fig.2. The programming was done in LASAL and downloaded to the controller through Ethernet cable.

Fig. 2. Injection molding machine-Real time setup

2.2 Multi Model PID and Fuzzy Logic Controllers – Real Time Implementation

For Multi-model based PID and Multimodel based Fuzzy logic controller, the Injection molding machine is assumed to have an operating temperature range of 308.15 K to 443.15 K. In order to compensate for the non- linearity, the entire non-linear region is divided into the following linear regions: Region1 is 308.15 to 423.15 K, Region 2 is 423.15 < T < 433.15 K and Region 3 is 433.15 < T < 443.15 K.

Individual multi models are developed for each of these above regions. Accordingly, three individual PID controllers are designed one for each of three regions. For mutimodel based fuzzy logic controller four fuzzy controllers are designed one for each of three regions and the fourth one for choosing the weights for the three controllers. If the temperature is in the range 308.15 to 423.15 K, the effect of the first controller alone will be felt. If the temperature is in the range 423.15 to 433.15 K, a combination of the effects of the first and second controller will be felt. If the temperature is in the region 433.15 to 443.15 K a combination of the second and third controller will act. The contribution of each controller will be decided by the weights that are generated based on the current temperature values.

2.2.1 Multi Model PID Controller – Real Time Implementation

To design the controller based on multiple model concept, the nonlinear process has been linearized at different operating points and the linear PI controllers are designed based on the selected linear models. The operating points are chosen, so that the fused linear model should track the rigorous nonlinear model without steady state error. The three operating points are chosen at the temperature of 423.15 K, 433.15K and 443.15K and their corresponding transfer function models are reported in Table 1. The steady state profile of the IMM temperature process is shown in Figure 3.

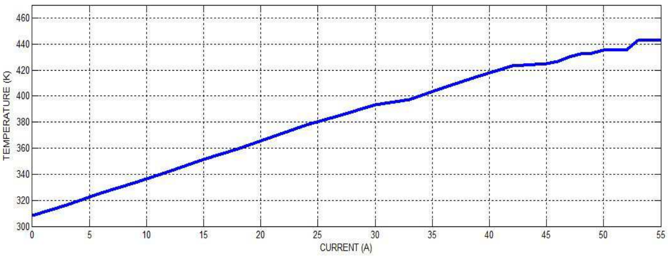

Fig. 3. Steady State Profile of the IMM Process.

Table 1. Process Model at Different Operating Points for IMM

ZONE NUMBER	HEATER CURRENT (A)	TEMP (K)	TRANSFER FUNCTION MODEL
Zone 1, i=1	45	423.15	$\frac{62.6212e^{-29.4s}}{(153s+1)^2}$
Zone 2, i=2	49	433.15	$\frac{62.7337e^{-27.8s}}{(145s+1)}$
Zone 3, i=3	55	443.15	$\frac{31.4213e^{-23.4s}}{(113s+1)^2}$

The tuning parameters for the 3 PID controllers are calculated using Zeigler-Nichols method. Since temperature T is the scheduling variable, the controller parameters K_C (a) and T_I(a) are calculated by substituting n=3 and a=T, in the following equations.

$$K_C (a) = \sum_{i=1}^{n} w_i (a) k_{c,i} \qquad (1)$$

$$T_I (a) = \sum_{i=1}^{n} w_i (a) T_{I,i} \qquad (2)$$

$$T_D(a) = \sum_{i=1}^{n} w_i (a) T_{d,i} \qquad (3)$$

Using K_C (T) and T_I (T), the global PID controller output is calculated. In equations (1), (2) and (3), w_i (T) is a weighing factor and weights are estimated based on the scheduling variable T.

The weights are calculated according to the algorithm as given below.

If $T \le T1$, then
$w_3 = 0$; $w_2 = 0$; $w_1 = 1$
If $T1 \le T \le T2$, then
$w_3 = 0$; $w_2 = (T - T1) / (T2 - T1)$; $w_1 = 1 - w_2$
If $T2 \le T \le T3$, then
$w_3 = (T - T2) / (T3 - T2)$; $w_2 = 1 - w_3$; $w_1 = 0$
If $T \ge T3$, then
$w_3 = 1$; $w_2 = 0$; $w_1 = 0$

The PID controller accepts the scheduling variable (temperature) as input and computes the controller parameters namely controller gain Kc and Integral time Ti and Derivative time Td at each and every sampling instant. The block diagram of Multi model based PID controller is shown in Figure 4.The screenshot of the controller's monitor available at L&T, Injection molding machine during running condition is shown in Figure 5. Based on the weights w_3 ,w_2 ,w_1 are obtained and the controller output is decided.

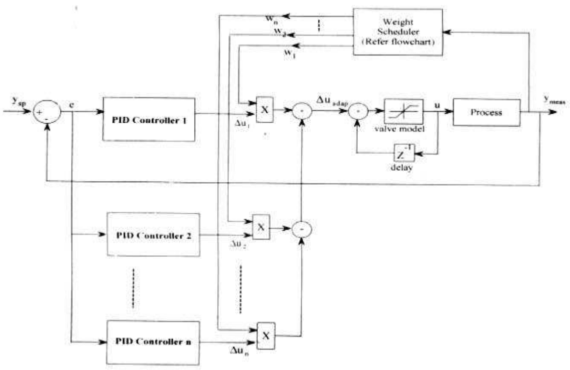

Fig .4. Block diagram of Multi model based PID controller

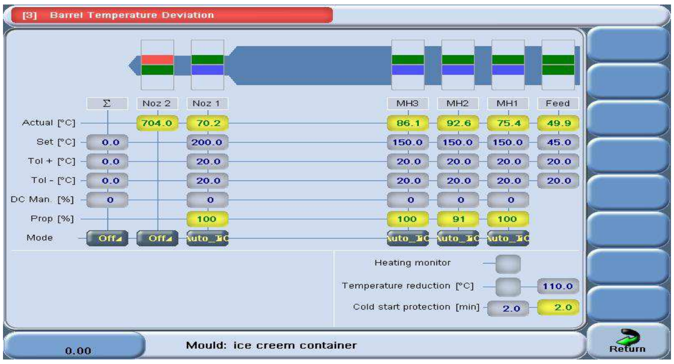

Fig .5. Screen shot of Multi model based PID controller

2.2.2 Multi Model Based Fuzzy Logic Controller – Real Time Implementation

The feature that differentiates Fuzzy Logic controller from other type of controllers is the use of linguistic variables rather than numerical variables. Linguistic variables, defined as variables whose values are sentences in natural language (such as small and large) may be represented by fuzzy sets.

A fuzzy logic controller is based on a collection of control rules. The execution of these rules is governed by the compositional rule of inference.

The general structure of a Fuzzy logic controller comprises four principle components:
1) A fuzzification inference converts input data into suitable linguistic values;
2) A knowledge base consists of a data base with the necessary linguistic definitions and control rule set;
3) A decision making logic infers the fuzzy control action from the knowledge of the control rules and the linguistic variable definitions;
4) A defuzzification inference yields a non-fuzzy control action from an inferred fuzzy controlled action.
Four fuzzy controllers have been designed, one for each of the three zones and another for choosing the weights for the controllers. Each controller uses two input variables: error : e and integral of error : eint. The output of these controllers are combined using weights to give net output = (w1*out1) + (w2*out2) + (w3*out3).

For weight selection controller, similar membership functions are defined for the universe of discourse. Design of the rules are based on heuristic knowledge of the behavior and based on the theoretical criteria. Twenty five rules are defined for each controller. The rule base matrix for the IMM controller is shown in Table 2. Same rule base is taken for the weight selection system.

Table 2. Rule Base Matrixes for FL Controller

ie / e	VS	S	M	B	VB
VS	VS	VS	S	S	M
S	VS	S	S	M	B
M	S	S	M	M	B
B	S	M	B	B	VB
VB	M	B	B	VB	VB

The proposed fuzzy logic controllers control the Injection molding machine zone temperatures using conventional triangular membership functions. Furthermore, the fuzzy inference engine implements a set of IF-AND-THEN rules on the error e, integral of eint and output 'out'. All three universe of discourse are divided into five overlapping fuzzy regions labeled VS (Very Small), S (Small), M (Medium), L (Large) and VL (Very Large).

3. SIMULATION RESULTS

3.1 PID Controllers for IMM without Multimodel Approach – Real Time Implementation

The process is run with the conventional PID controller and the results are presented for different set points. We have collected the readings in real time from Larsen &Toubro DeTech Injection Molding Machine with iCon controller. The closed loop responses of PID controller without multimodel approach in real time for the zone1, Zone 2 and Zone 3 are shown in Figures 6, 7 & 8. The performance criteria of the PID controller without multi-model in real time are given in Table 3.

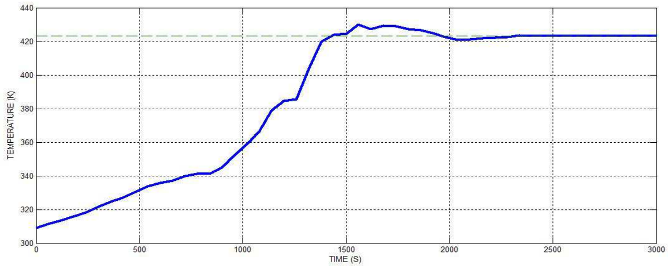

Fig. 6. Closed loop response for a set point of 423.15 K without multimodel PID (Zone 1)

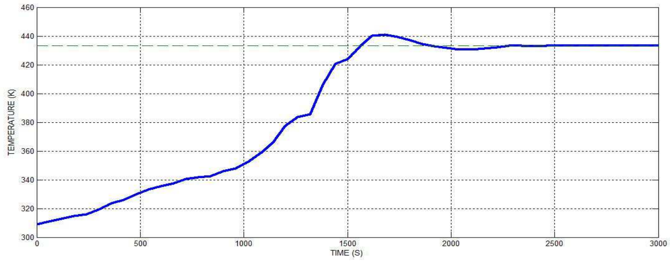

Fig. 7. Closed loop response for a set point of 433.15 K without multimodel PID (Zone 2)

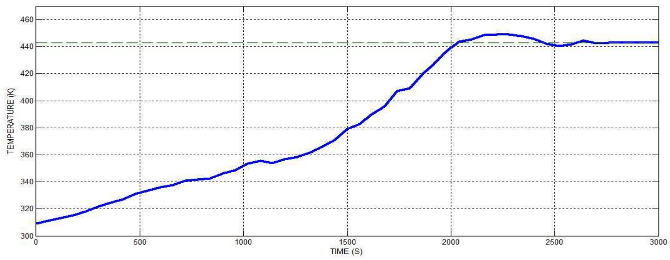

Fig .8 .Closed loop response for a set point of 443.15 K without multimodel PID (Zone 3)

Table 3. Performance Criteria for PID Controller without MM in Real Time

ZONE	IAE	ISE	SETTLING TIME (s)
Zone 1 (423.15 K)	1.8317x 10^3	3.3551x 10^6	2345
Zone 2 (433.15 K)	2.1834x 10^3	4.7675x 10^6	2430
Zone 3 (443.15 K)	2.9199x 10^3	8.5261x 10^6	2810

3.2 PID controllers for IMM With Multimodel Approach – Real Time Implementation

The process is run with the Multi model based PID controller and the results are obtained. The closed loop responses of PID controller with multimodel approach in real time are shown in Figures 9, 10 & 11 for different set points. The performance criteria of the Multi model based PID controller in real time is given in Table 4.

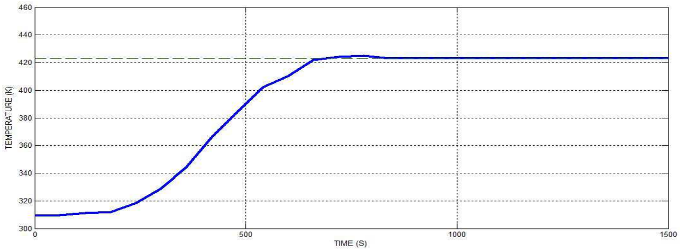

Fig 9 Closed loop response for a set point of 423.15 K with multimodel PID (Zone 1)

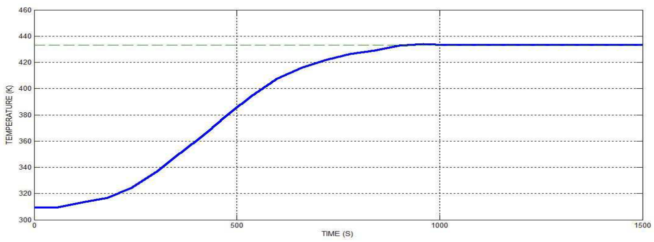

Fig 10 Closed loop response for a set point of 433.15 K with multimodel PID (Zone 2)

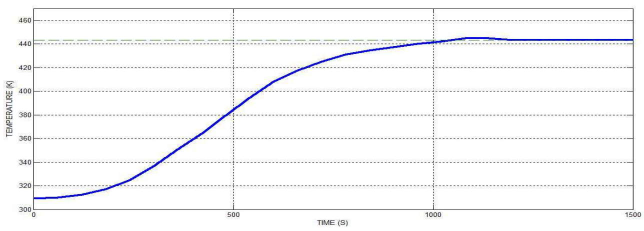

Fig 11 Closed loop response for a set point of 443.15 K with multimodel PID (Zone 3)

Table 4. performance criteria for multi model PID controller in real time

ZONE	IAE	ISE	SETTLING TIME (s)
Zone 1 (423.15 K)	855.95	7.3265x 10^5	850
Zone 2 (433.15 K)	994.3	9.8863x 10^5	1015
Zone 3 (443.15 K)	1.1389x 10^3	1.2971x 10^6	1150

3.3 *Fuzzy Logic Controllers for IMM Without Multimodel Approach – Real Time Implementation*

The process is run with Fuzzy Logic controller without multimodel and the results are presented. The readings are collected in real time from Larsen &Toubro DeTech Injection Molding Machine with iCon controller and the closed loop response of Fuzzy controller without multimodel approach in real time is obtained and shown in Figures 12, 13 & 14 for a different set points. The performance criterion of the Fuzzy Logic controller without multi-model in real time is given in Table 5.

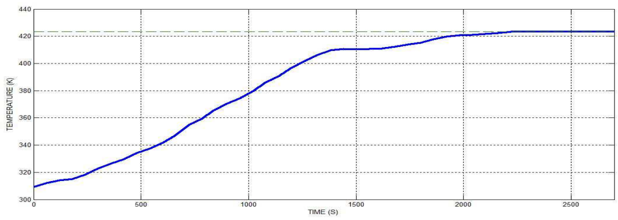

Fig 12 Closed loop response for a set point of 423.15 K fuzzy without multimodel (Zone 1)

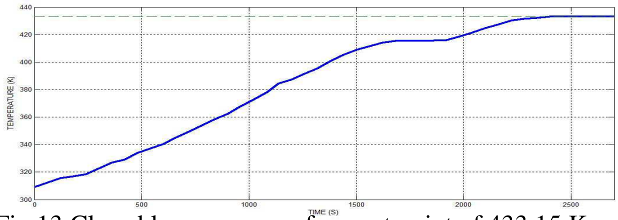

Fig 13 Closed loop response for a set point of 433.15 K fuzzy without multimodel (Zone 2)

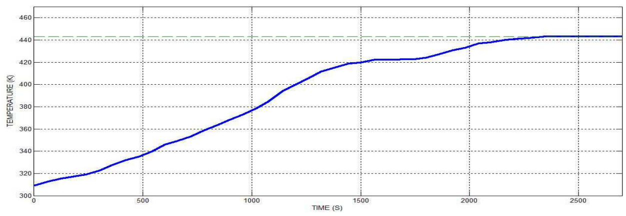

Fig 14 Closed loop response for a set point of 443.15 K fuzzy without multimodel (Zone 3)

Table 5. Performance Criteria for Fuzzy Logic Controller Without MM in Real Time

ZONE	IAE	ISE	SETTLING TIME (s)
Zone 1 (423.15 K)	904.85	8.1875x 10^5	835
Zone 2 (433.15 K)	968.3	9.3760x 10^5	950
Zone 3 (443.15 K)	1.1076x 10^3	1.2269x 10^6	1005

3.4 *Fuzzy Logic Controllers for IMM With Multimodel Approach – Real Time Implementation*

The process is run with the Multi model based Fuzzy Logic controller and the results are obtained. The real time readings collected from L&T DeTech Injection Molding Machine with iCon controller. The closed loop response of Fuzzy controller with multimodel approach in real time is obtained for different set points and shown in Figures 15, 16 & 17. The performance criteria of the Multi model based Fuzzy Logic controller in real time is given in Table 6.

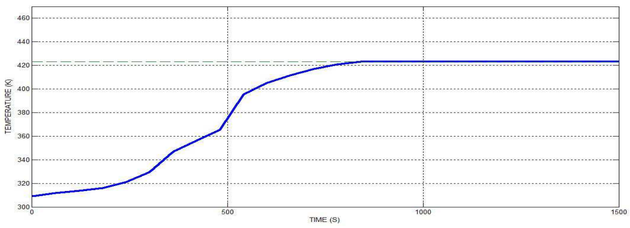

Fig 15 Closed loop response for a set point of 423.15 K fuzzy with multimodel (Zone 1)

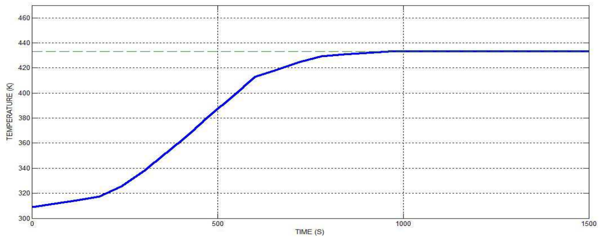

Fig 16 Closed loop response for a set point of 433.15 K fuzzy with multimodel (Zone 2)

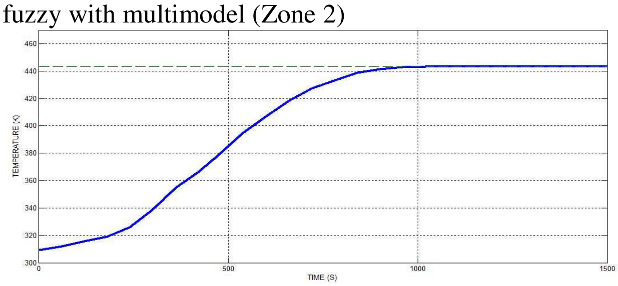

Fig 17 Closed loop response for a set point of 443.15 K fuzzy with multimodel (Zone 3)

In order to access the tracking capability of designed controllers, set point variations have been given. From the response it can be inferred that, all the controllers designed for the injection molding barrel are able to maintain the desired barrel temperature.

Table 6. Performance Criteria for Fuzzy Logic Controller With MM in Real Time

ZONE	IAE	ISE	SETTLING TIME (s)
Zone 1 (423.15 K)	1.7450x 10^3	3.0452x 10^6	2200
Zone 2 (433.15 K)	2.2119x 10^3	4.8925x 10^6	2445
Zone 3 (443.15 K)	2.3096x 10^3	5.3343x 10^6	2365

4. CONCLUSIONS

In this work the real time results are obtained by collecting data from the L&T DeTech Injection Molding Machine with iCon controller. The injection molding process consists of three zones for which temperature control is required and the model for each of the zone is different. Multimodel based PID control and multimodel based Fuzzy is used to control the barrel temperature to achieve better performance. Three different controllers have been designed for controlling the injection molding process. The conventional PID controller for three zones performance is analyzed.

The multimodel based fuzzy logic controller is implemented in real time, and it has a better IAE and ISE when compared to PID controller. The settling time is also slightly improved. The PID and Fuzzy logic controllers without multimodel gives a higher IAE and ISE, compared to their multimodel controllers.

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