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Model Identification and Agitator Speed Optimization for Bioreactor Process Using Soft Computing Techniques

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Abstract

In biochemical industry process variables such as pH, temperature, dissolved oxygen and speed are the main parameters that need to be controlled for optimal cellular activity. These control implementations are achieved via regulation of flow rate of acid/base, flow rate of fluid through the cooling coil, and agitation respectively. This paper presents a fuzzy logic controller to optimize the speed of an agitator in a bioreactor system. An open loop test was conducted and model parameters were determined. The identified process was represented by first order plus dead time model (FOPDT). From the model parameters, PI and fuzzy tuned PI controllers were Designed using MATLAB. The closed loop performance was studied for both servo and regulator problems. Based on overshoot, rise time, settling time, and ISE, it was found that the fuzzy tuned PI controller is best suited for this process.

Keywords: FOPDT, ISE, Speed, PI Controller, Sacchromyce, Invertase

1 Introduction

Recent time's fuzzy controllers that combine intelligent and conventional technique are commonly used for control of complex dynamic systems for their ability to handle uncertainty. In biochemical industry growth rate plays vital role, hence the control of growth rate over a short period of time for a biochemical process is highly significant. Edward katende et al [1] have developed non-linear generalized predictive control algorithm for batch reactor system. Stigter et al [2] have designed optimal parametric sensitivity controller for a fed batch reactor to estimate the growth rate. Valenica et al [3] have designed the controller using simulation technique for fed batch reactors. Choi et al [4] have designed non linear model-based control for batch polymerization reactor which generates the polymer molecular weight distribution. Soni et al [5] have used a multi scale model to describe the dynamic behavior of aerobic fed batch cultures of sacchromyces cursive. Shen [6] has identified the model using the dynamic data for semi-batch reactor.

Sachin et al [7] have monitored the process variables in the bioreactor to incorporate multi rate estimation. Srinivas [8] has designed pH neutralization process using fuzzy logic controller. Gao et al [9] have designed stable fuzzy logic controller for industrial process. Rovatti et al [10] has developed fuzzy system for identification of a structure by means of parameter optimization. Martin et al [11] have developed fuzzy logic controller to control the dissolved oxygen in the fermentation process. Madhavasarma et al [12-19] have identified the process model and designed fuzzy logic controller for nonlinear processes. The present work aims at identification of bioreactor model using SK technique and design of PI based fuzzy control algorithm to optimize the agitator speed using MATLAB software.

2 Experimental Setup

FIGURE 1. The photographic view of the Experimental setup of Bioreactor

The reactor with provisions for setting temperature, agitator speed, and pH and air flow was shown in figure1. The reactor was filled with the growing medium– yeast maltose, yeast extract – 3gm/l, malt extract – 3gm/l, dextrose – 10 gm/l, peptone – 5gm/l. The agitator was used for the proper mixing of nutrients and for equal distribution of oxygen within the medium to make it a homogenous mixture. In order to study the effect of agitation speed on cell and mixture two different experiments were carried out at bioreactor at 200 rpm and 350 rpm for 18 hours. For the measurement of dry cell weight 5ml of culture was centrifuged for 10 min at 10,000 rpm, washed twice with distilled water and dried at 105 c to constant weight. The agitator speed was monitored using an online Honeywell analyzer. A computer with Analog-to-Digital (A/D) and Digital-to-Analog (D/A) converters is employed for data acquisition and the control of the system.

3 Model Identification

A step-wise change of agitator speed ranging from0 to 200 rpm and 200 to 350 rpm was introduced and the concentrations of mixture were studied. The results for two concentrations are presented and discussed below. The data in Figure 2 was fitted to a first order plus dead time model using SK technique discussed briefly in [15, 20] given by equation 1. Where K_p is the process gain, τ_d the time delay and τ is the process time constant. The model parameters are given in Table 1.

TABLE 1 Model parameters for the bioreactor process

SNo	Process Gain	Time constant (τ Minute)	Delay time (τ_d Minute)
1	295	0.035	0.33

$$G_p(s) = \frac{K_p e^{(-\tau_d s)}}{\tau s + 1} \qquad (1)$$

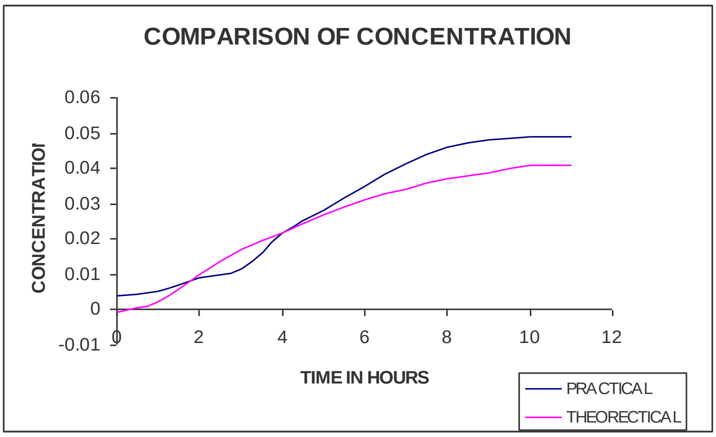


FIGURE 2 Comparison of experimental values for FOPDT model.

4 Effect Of pH, Temperature and Do Due To Agitator Speed

Aeration is an important design parameter in the bioreactor and by its efficient control the overall productivity of the process can be increased. Product’s requirements of oxygen depend on the energetic of the pathway leading to the product. Because the oxygen uptake is linked to the cellular metabolism, the oxygen dynamics reflect the changes in the environmental conditions. Oxygen is poorly soluble in water -and even less in fermentation broths- and is relatively scarce in air (20.8%). Oxygen transfer is usually helped by agitation that is also needed to mix nutrients and to keep the fermentation homogeneous. The impact in production yield was achieved by varying the above parameter with change in aeration, agitation system and stirrer speed. In order to obtain the best possible growing conditions the speed, pH and temperature levels are maintained at constant rate. To investigate the relationship between speed and concentration the effects of the other parameters with respect to the agitator speed were studied. The agitator speed was changed manually from 0 to 200 rpm and 200 to 350 rpm respectively. The response for dissolved oxygen, pH and temperature was shown in Figures3to5. From the Figure 3 it was observed that due to change in speed the variables such as dissolved oxygen, temperature, and pH also varies which affects the model parameters and growth rate of Sacchromyces cursive, In order to avoid the variation in the agitator speed during process operation optimal tuning values were selected using the fuzzy logic based PI control system.

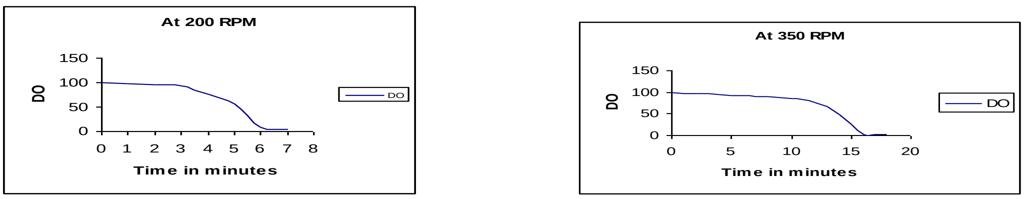


FIGURE 3 Response for Do for step change in speed of Magnitude 150 rpm

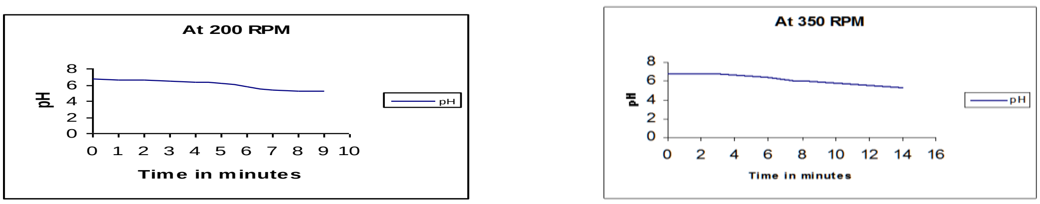


FIGURE4 Response for pH for step change in speed of Magnitude 150 rpm

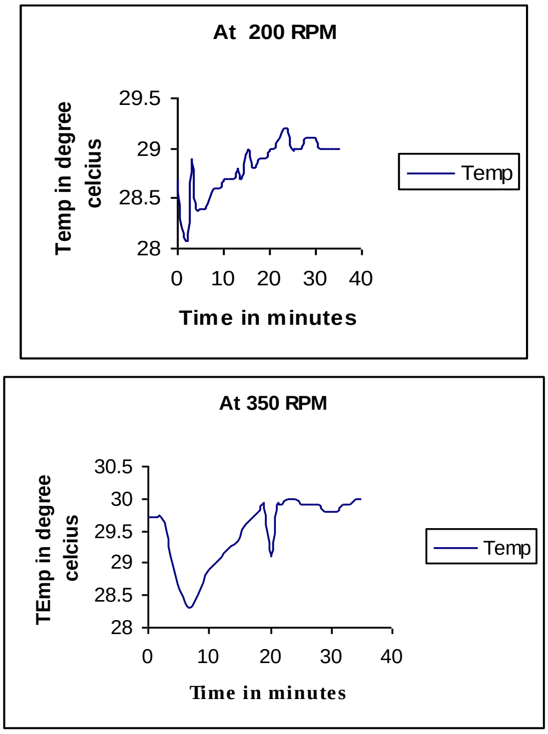


FIGURE 5 Response for Temperature for step change in speed of Magnitude 150 rpm

5 PI Controllers for the Bioreactor Process

A system consisting of a plant and a controller with unity feedback is shown in Figure 6. The controller output was given to bioreactor process. The PI controller optimum settings such as the critical gain (Ku) =14.33, critical period (Pu) =24, Proportional gain (Kc) = 0.645 and integral gain (Ki) = 20 were obtained by Ziegler Nichols tuning method. The designed PI controller was run for the both servo and regulator problem for 200 rpm. The variation in the speed was recorded in both the cases.

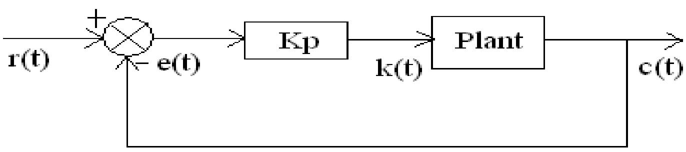


FIGURE 6 Schematic diagrams for PI controller

6 Design of Fuzzy Logic Controller

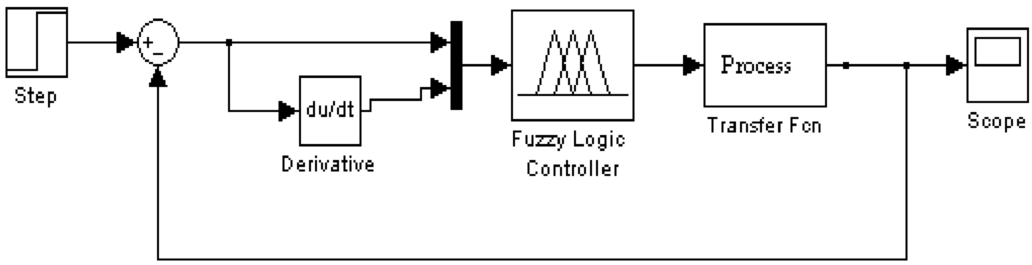
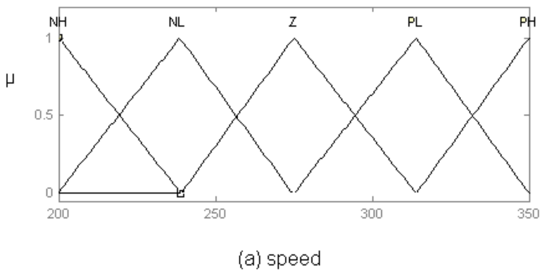


FIGURE7 Block diagram of Mamdani type fuzzy control system

The block diagram of mamdani type fuzzy control is shown in Figure 7. The fuzzy logic controller was developed here using two input variables E (Error) and CE (Change of error) and one controller output. The inputs E and CE are directly fed to the mamdani type fuzzy controller. Each of these variables have seven membership functions which are labeled as NB-negative big NH-negative high, NS-negative small, ZE-zero, PS-positive small, PH-positive high, PB-positive big. Figure 7.1 (a) to 7.1 (c) shows error, change in error and controller output as a function of membership function respectively. The surface generated by the inputs is shown in Figure 8 and Table.2 depicts the 49 control rules developed for this process using E and CE as input. This set was defuzzified in the final step of the cycle, into a single value. The defuzzified values represent action taken by the fuzzy controller in individual control cycle.

TABLE.2 Rule base of the Fuzzy controller

E/CE	NB	NH	NS	ZE	PS	PH	PB
NB	NB	NB	NB	NB	NH	NS	ZE
NH	NB	NB	NB	NH	NS	ZE	PS
NS	NB	NB	NH	NS	NE	PS	PH
ZE	NB	NH	NS	ZE	PS	PH	PH
PS	NH	NS	ZE	PS	PH	PH	PH
PH	NS	ZE	PS	PH	PH	PH	PH
PB	ZE	PS	PH	PB	PH	PH	PH



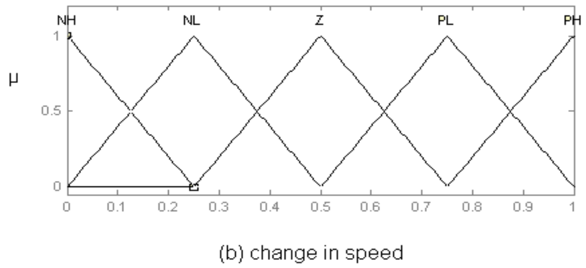


FIGURE 7.1 (a) Error (E)

FIGURE 7.1 (b) Change of error (CE)

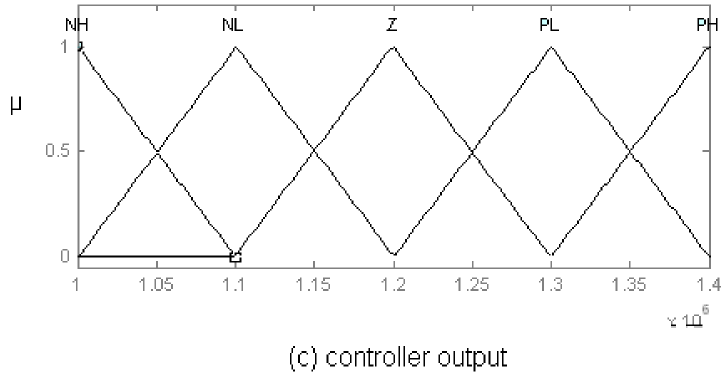


FIGURE7.1(c) Controller output (CO)

FIGURES 7.1(a)-7.1(c) Membership functions for error, change of error, controller output**.**

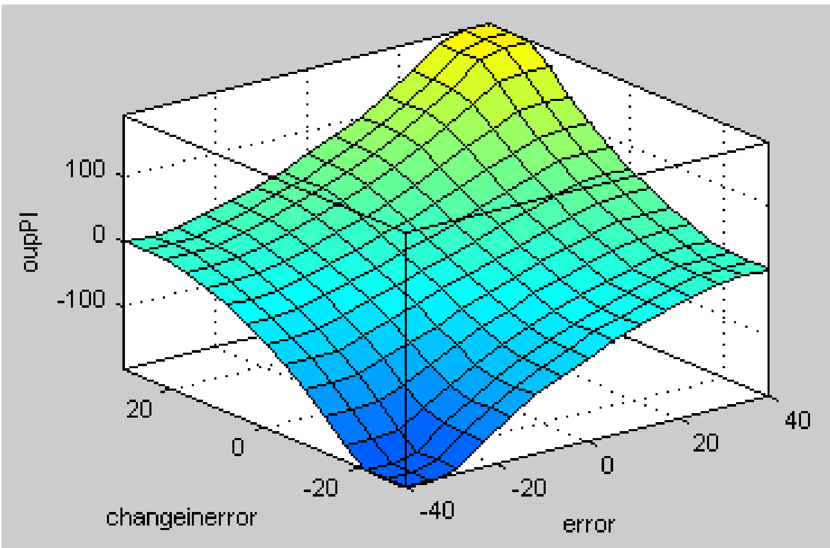


FIGURE 8 Bumpy Surface generated by the Input families E and CE

7 Results and Discussions

To evaluate closed loop performance of the PI controller for the process step change in the set point was introduced. Servo response to set point change of 200 units' rpm for the process and the output response were shown in Figure 9. The +10 % changes in set point response are shown in Figure10. Load disturbance of magnitude of 50 units at time 2000 seconds was given to process and there response was shown in Figure11.The Uncertainty analysis of PI controller was shown in Figure 12. To evaluate the closed loop performance of the fuzzy PI controllers for the process, step change in set point and disturbance are introduced. Servo response to set point change for a step input of magnitude 150 units for the process response was shown in Figures 13 to 14 the comparison of controller performance was given in Table 3.

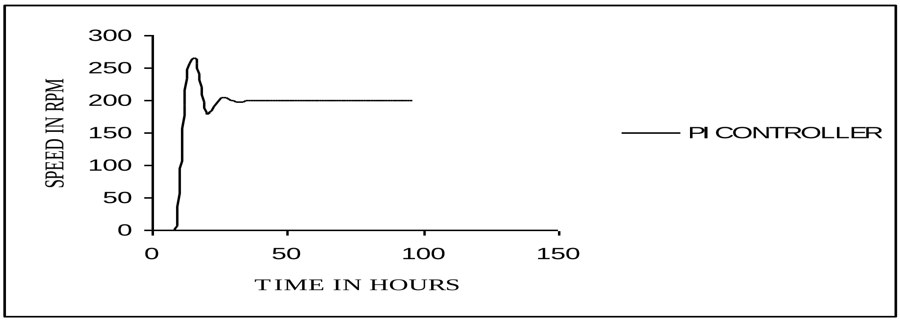


FIGURE 9 PI controller output response for Bioreactor process

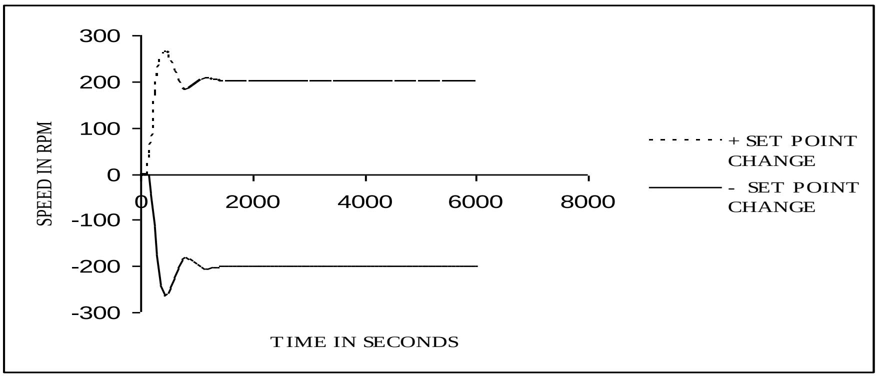


FIGURE 10 PI controllers output response for Set point Change of Bioreactor process

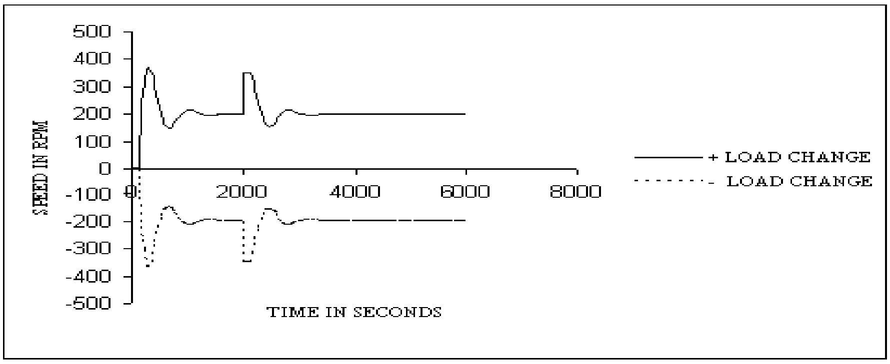


FIGURE 11 Regulator responses for bioreactor process

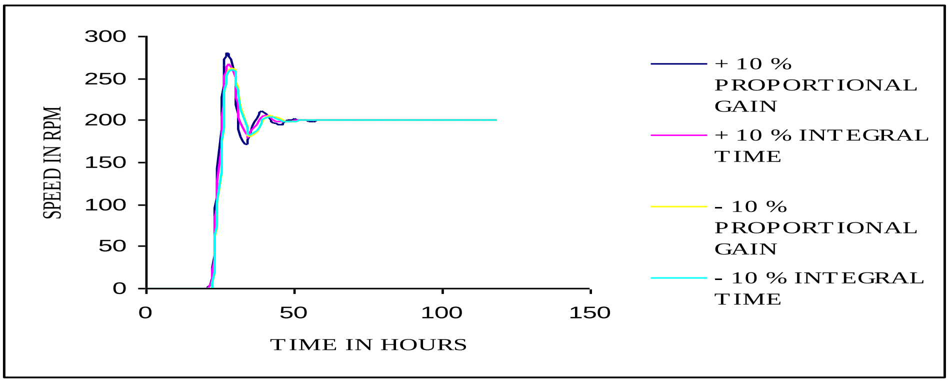


FIGURE 12 Uncertainty analysis of a PI controller

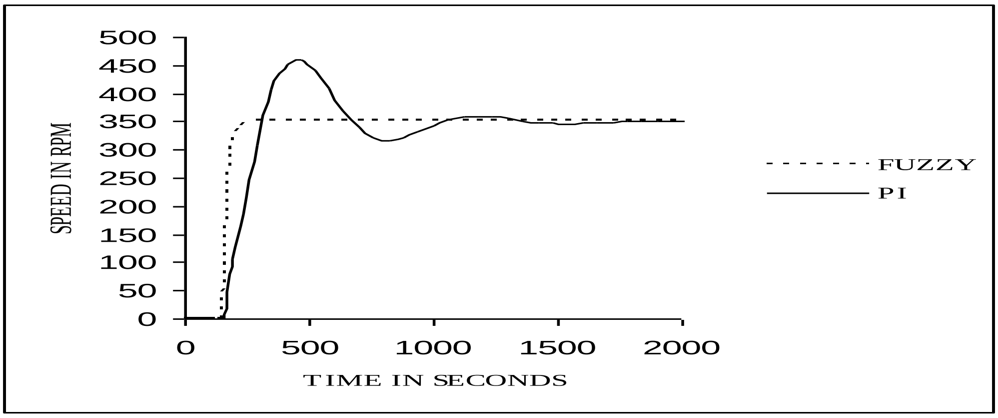


FIGURE 13 Comparison of servo responses of the controllers to set point change 350units

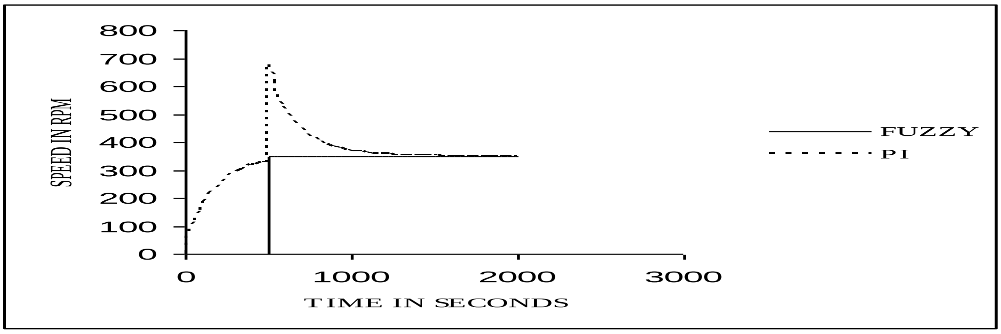


FIGURE 14 Comparison of servo responses of the controllers to load change 350units

TABLE 3 Comparison between PI and Fuzzy controller

Tuning Method	Peak Overshoot	Rise Time	Settling Time	Load ISE	Servo ISE	Decay ratio
PI	2.07	210	4150	429.4750	445.832	0.01225
FUZZY	0	50	2000	250.0	279.1	0

8 Conclusions

In this work model was identified using Sunderson Krishnasamy (SK) algorithm. The results given in Table 3 emphasize that the fuzzy logic controller shows a minimum dynamic response time than the conventional controller, while conventional controllers reaches the set point smoothly. It is evident from Table 3 that the Fuzzy tuned PI controller offers best time domain characteristics such as rise time, settling time, overshot, for the bioreactor process and optimize the agitator speed of the bioreactor.

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