Intelligent Controllers of Multiple Effect Evaporators via Simulation

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Abstract

This study deals with studying the dynamics and control of multiple effect evaporators by implementing two intelligent controllers for the evaporation of caustic soda. A mathematical model for evaporator is derived based on mass and energy balance. A dynamic model is designed using "MATLAB/Simulink" program based on the mathematical model derived. The intelligent controllers in this study are fuzzy and neural networks and compared with PID controller. The results showed that a good improvement for caustic soda system is achieved when the fuzzy logic with seven membership functions and neural predictive controllers are used because these methods have more suitable, lower over shoot, less offset value and less integral absolute error within range.

Keywords: Modeling of Evaporator; Fuzzy Logic Controller; Neural Networks Controller; PID Controller.

Nomenclature

\( c_{s, in} \): mass fraction of soluble solids in feed
\( c_s \): mass fraction of soluble solids in product
\( c_{l, in} \): mass fraction of liquid in feed
\( c_l \): mass fraction of liquid in product
\( G(s) \): Transfer function
\( H \): Enthalpy of product (kJ/kg)
\( H_C \): Enthalpy of condensate (kJ/kg)
\( H_{in} \): Enthalpy of feed (kJ/kg)
\( H_{st} \): Enthalpy of steam (kJ/kg)
\( H_{vap} \): Enthalpy of saturated vapor (kJ/kg)
\( m \): Mass holdup, (kg)
\( m \): Mass flow rate of product, (kg/sec)
\( m_{in} \): Mass flow rate of feed, (kg/sec)
\( m_{st}, m_c \): Mass flow rate of steam and condensate, (kg/sec)
\( m_{vap} \): Mass flow rate of vapor, (kg/sec)
\( Q_{steam} \): Heat of steam (kJ/sec)
\( t \): Time, (sec)
\( T \): Temperature of product (°C)
$T_{in}$ : Temperature of feed (°C)

Subscript
- c : condensate
- in : input
- l : liquid
- s : solid
- st : steam
- vap : vapor

Greek letters
- $\tau$ : Time constant, (sec)
- $\tau_D$ : Derivative time constant, (sec)
- $\tau_I$ : Integral time constant, (sec)

1. Introduction

The multiple effect evaporators are used for concentration of solution containing nonvolatile solute and a volatile solvent by a vaporizing a portion of the solvent. The evaporator is affected by the characteristics of the solution such as temperature sensitivity, concentration, foaming and scale. The response of product concentration is affected by disturbances of concentration, temperature and flow rate of feed. Control of evaporator temperature is an important aspect in evaporation system control, because it affects efficiency and safety of the system directly. Different studies of advanced control methods have been conducted in the field of evaporator. Because of large time delays and process disturbances, the tight exact control of product temperature is difficult [1].

Due to increasing application of multi effect evaporators in food industry, the exact modeling of these processes is important. Because of large time delays and process disturbances, the tight exact control of product temperature is difficult. Vlassov and Riehl [2] presented a mathematical model of a loop heat pipe (LHP). They concluded that a mathematical model able to predict the transient behavior of a LHP with integrated reservoir has been proposed. José and William [3] studied the development of the mathematical model and simulation of multiple effect evaporation. The model carried out reflected of an acceptable form the dynamic conduct of the process of evaporation. Shah [4] described a steady state model of multiple effect evaporators for simulation purpose. This system shows that results are obtained for steam economy 3.5%. Kumar et al. [5] attempted to develop an unsteady-state model for the Multi-effect evaporator system of a paper industry to obtain the dynamic response of the system. They showed that the steady state is reached more quickly for temperature in comparison of the solid concentration and all of the responses converge in a smooth fashion.

Control of evaporator temperature is an important aspect in evaporation system control, because it affects efficiency and safety of the system directly. Different studies have been conducted in the field of evaporator’s control. Bakker et al. [6] designed of a cascade controller to control the product concentration in a two-effect falling-film evaporator. They concluded that the responses can be enhanced by the use of a cascade architecture. Farsi and Jahanmiri [7] studied a non-linear dynamic modeling and simulation of a three-effect falling film evaporator and are compared with results of conventional PID control. Atuonwu et al. [8] applied a recurrent neural network-based nonlinear model predictive control (NMPC) scheme in parallel with PI control loops and developed a simulation model of an industrial-scale five-stage evaporator. The results show significant improvements in control performance by the new parallel NMPC–PI control scheme.
Zhang et al. [9] designed fuzzy sliding model controller to control superheat of the evaporator in a waste heat utilizing system. The proposed controller is used to control the outlet temperature of evaporator and the simulation results show that the fuzzy inference mechanism can reduce the chattering and the closed-loop system has satisfactory performance. Chai et al. [10] developed a mathematical model of the evaporation system in the form of a state space model with multiple time delays is constructed. Simulation study showed that the results obtained by the optimal control are superior to those obtained by the level controller used in the current practice and the model predictive control (MPC). Srinivas et al. [11] designed the neural network based model predictive controller to control the concentration of the double effect evaporator. Aminu et al. [12] used a boiling point rise technique of indirect measurement of solid concentration in the thick output liquor. As the technique is based on the measurement of two temperatures and a pressure, commonly used sensors and data acquisition circuit can serve the purpose very well. This approach permits a fast and online measurement of concentration, thus making the control loop act fast and the control system inexpensive. The overshoot value and settling time are used to evaluate the performance of advanced control strategy. They concluded that the neural networks model predictive controller has a superior performance than conventional PID controller. Ahmed et al. [13] proposed a nonlinear neural network model predictive control for a diary falling film evaporators. The results showed this method can be used efficiently in control such systems. The purpose of this paper is to study the dynamics behavior of the multiple effect evaporators and the process control implemented for different control method, and the evaporator is carried out at different conditions. The simulation of the multiple effect evaporators process is built by using MATLAB to study the response of the process at different operating condition. The dynamic behavior study is carried out by measuring the responses of the temperature of outlet vapor to step change in steam flow rate, temperature, and flow rate of feed. The implemented control strategies are PID, fuzzy logic and neural network individually to compare the effectiveness of these controllers.

2. Mathematical modeling of the evaporator

The evaporation process involves mass and heat transfer. The solution was considered as a binary solution of water and caustic soda, both considered inert in a chemical sense. Under these considerations, an effect of the industrial evaporator can be represented. These relationships have been rearranged from non-linear algebraic equations from literature, with the experience issued from the experimental site. The composition and temperature inside each evaporator is homogenous, solution level evaporator and the density of solution are constant, thermodynamic equilibrium (liquid–vapor) for the whole modeled system and the evaporation process is under atmospheric pressure. The modeling of an evaporator includes the formulation of total mass and component balances together with an energy balance. The evaporator is simulated based on the model equations presented below:

Total mass balance at unsteady state

\[
\frac{dM}{dt} = m_{in} - m - m_{vap}
\]  

(1)

-Component mass balance with respect to soluble solids

\[
\frac{d(c_s(t)M)}{dt} = m_{in}c_{s,in}(t)
\]  

(2)

Equation (2) can be written as:
Substituting equations (1) and (3) in Eq. (2) gives:

\[ M \frac{dc(t)}{dt} = c_{s,\text{in}}(t)m_{\text{in}} - c_s(t)(m_{\text{in}} - m_{\text{vap}}) \]  

(4)

Rearranging of equation (4):

\[ M \frac{dc(t)}{dt} + c_s(t)(m_{\text{in}} - m_{\text{vap}}) = c_{s,\text{in}}(t)m_{\text{in}} \]  

(5)

Dividing of equation (5) by \((m_{\text{in}} - m_{\text{vap}})\) gives:

\[ \tau_1 \frac{dc(t)}{dt} + c_s(t) = k_1 c_{s,\text{in}}(t) \]  

(6)

Where \( \tau_1 = \frac{M}{(m_{\text{in}} - m_{\text{vap}})} \) and \( k_1 = \frac{m_{\text{in}}}{(m_{\text{in}} - m_{\text{vap}})} \)

Taking Laplace transform of equation (6):

\[ \tau_1 s c_s(s) + c_s(s) = k_1 c_{s,\text{in}}(s) \]  

(7)

Finally, the transfer function of system can be represented by first order system:

\[ G(s) = \frac{c_s(s)}{c_{s,\text{in}}(s)} = \frac{k_1}{\tau_1 s + 1} \]  

(8)

Total energy balance at unsteady state

\[ \frac{d(M\text{in})}{dt} = m_{\text{in}}H_{\text{in}} - mH - m_{\text{vap}}H_{\text{vap}} + Q_{\text{steam}} \]  

(9)

Where \( Q_{\text{steam}} \) is the steam generating in the power plant

\[ Q_{\text{st}} = m_{\text{st}}(H_{\text{st}} - H_c) \]  

(10)

and the enthalpy of product concentration

\[ H = c_p T \]  

(11)

\[ c_p = 4.1868 + 2.261 c_s \]  

(12)

Substitute equations (10, 11 and 12) in (9) gives:

\[ M c_p \frac{dT}{dt} + T(t) \left[ m_{\text{in}} c_p - m_{\text{vap}} c_p - 2.261m (c_s(t) - c_{s,\text{in}}(t)) \right] = m_{\text{in}} c_p T_{\text{in}}(t) + m_{\text{st}}(H_{\text{st}} - H_c) \]  

(13)

Dividing of equation (13) by \( m_{\text{in}} c_p - m_{\text{vap}} c_p - 2.261m (c_s(t) - c_{s,\text{in}}(t)) \) gives:
\[ \frac{d T}{d t} = \frac{Mcp}{m_{in} \cdot cp - m_{vap} \cdot cp - 2.261 \cdot m \cdot \left(c_s(t) - c_{x,in}(t)\right)} + \frac{T(t)}{m_{in} \cdot cp_{in}} \]

\[ + \frac{T(t)}{m_{in} \cdot cp - m_{vap} \cdot cp - m_b \cdot \left(c_s(t) - c_{x,in}(t)\right)} \cdot T_{in}(t) \]

\[ + \frac{T(t)}{m_{in} \cdot cp - m_{vap} \cdot cp - 2.261 \cdot m \cdot \left(c_s(t) - c_{x,in}(t)\right)} \cdot m_{af}(t) \]

(14)

Let:

\[ \tau_2 = \frac{Mcp}{m_{in} \cdot cp - m_{vap} \cdot cp - 2.261 \cdot m \cdot \left(c_s(t) - c_{x,in}(t)\right)} \]

\[ k_2 = \frac{m_{in} \cdot cp_{in}}{m_{in} \cdot cp - m_{vap} \cdot cp - 2.261 \cdot m \cdot \left(c_s(t) - c_{x,in}(t)\right)} \]

\[ k_3 = \frac{H_s - H_s}{m_{in} \cdot cp - m_{vap} \cdot cp - 2.261 \cdot m \cdot \left(c_s(t) - c_{x,in}(t)\right)} \]

\[ \tau_2 \frac{dT}{dt} + T(t) = k_2 T_{in}(t) + k_3 m_{af}(t) \]

(15)

Taking Laplace transform of equation (15):

\[ T(s) = \frac{k_2}{\tau_2 s + 1} T_{in}(s) + \frac{k_3}{\tau_2 s + 1} (s) m_{af} \]

(16)

At steady-state of \( T_{in} \) then equation (16) became:

\[ G(s) = \frac{T(s)}{m_{af}(s)} = \frac{k_3}{\tau_2 s + 1} \]

(17)

3. Fuzzy logic controller

Fuzzy logic control has become an important methodology in control engineering. Fuzzy Control Systems explores one of the most active areas of research involving fuzzy set theory. The contributors address basic issues concerning the analysis, design, and application of fuzzy control systems. The various paradigms include fuzzy reasoning models, fuzzy neural networks, fuzzy expert systems, and genetic algorithms [14]. The fuzzy logic system design is not based on the mathematical model of process. The fuzzy controllers designed using fuzzy logic implements human reasoning that has been programmed into membership functions, fuzzy rules and rule interpretation [15]. Fuzzy control uses the principles of fuzzy logic based decision making to achieve the control tasks. The decision making approach is typically based on rule of inference. A fuzzy rule in the knowledge base of the control task is generally a linguistic relation.

In this study, the input to the fuzzy control is outlet temperature of evaporator and the result of a control action being a change in the inlet flow rate of steam. A fuzzy controller has four parts, the first a rule base, the second a fuzzy inference mechanism, the third an input fuzzification interface, and the fourth an output defuzzification interface. The rule base is designed by an expert who writes a set of if–then rules to describe what he thinks is the best way to control a variable. The controller interface applies the actions indicated by these rules one rule at a right time. The measured value of the controlled variable is “fuzzified” (ie, separated into several states such as high,
medium or low), transforming its numeric values into fuzzy states, before it enters the controller. The knowledge base consists of the fuzzy linguistic control rules and the fuzzy reasoning mechanisms. The control rules are expressed in an if-then format and represent the accumulated control knowledge acquired from the domain experts. The fuzzy reasoning mechanism executes fuzzy logic operations so as to infer the appropriate fuzzy control action based on the fuzzy inputs provided. At the output of the controller, “defuzzification” combines the conclusions reached by the rules (ie, increase drug infusion rate slightly), converting them from their fuzzy state to a numeric value, so as to drive the infusion pump. The resulting set of fuzzy control actions are translated into non-fuzzy actions; the controller executes these actions on the process under study [16].

Fuzzy membership functions may be in the form of a triangle, a trapezoid, a bell, or another appropriate form. \( \mu(u_i) \) is a membership function, which is used to calculate the membership degree of the crisp input value. A membership function (MF) is a curve that defines how each point in the input space is mapped to a membership value or degree of membership) between 0 and 1 and five triangular membership functions employed for one input: Negative Big(NB), Negative Small(NS), Zero(Z), Positive Small(PS) and Positive Big(PB) and also five membership functions used for output of fuzzy controller: Negative Big(NB), Negative Small(NS), Zero(Z), Positive Small(PS) and Positive Big(PB); and seven triangular membership functions employed for one input: Negative Big(NB), Negative(N), Negative Small(NS), Zero(Z), Positive Small(PS), Positive(P), and Positive Big(PB). The fuzzy logic controller must convert its internal fuzzy output variables into crisp values so that the actual system can use these variables. This conversion is called defuzzification. One may perform this operation in several ways. One of the most common ways is to use the method of height. In the height method, first of all, the centroid of each membership function for each rule is evaluated, and then the final output is calculated as the average of the individual centroid and weighted by their heights. Also seven membership functions used for output of fuzzy controller: Negative Big(NB), Negative(N), Negative Small(NS), Zero(Z), Positive Small(PS), Positive(P) and Positive Big(PB).

4. Neural network controller

Neural networks have been applied very successfully in the identification and control of dynamic systems. The universal approximation capabilities of the multilayer perceptron make it a popular choice for modeling nonlinear systems and for implementing general-purpose nonlinear controllers. This introduces three popular neural network architectures for prediction and control that have been implemented in Neural Network Toolbox: Model Predictive Control, NARMA-L2 (or Feedback Linearization) Control and Model Reference Control. Each controller has its own strengths and weaknesses. The word network in the term artificial neural network refers to the inter–connections between the neurons in the different layers of each system. The first layer has input neurons, which sends data via synapses to the second layer of neurons, and then via more synapses to the third layer of output neurons. More complex systems will have more layers of neurons with some having increased layers of input neurons and output neurons. The synapses store parameters called "weights" that manipulate the data in the calculations. An artificial neural network is a computational model consisting of simple processors called neurons or nodes with numerous connections between them inspired by the neuronal architecture of the brain. Connections have numerical values called weights associated with them. Each neuron has an activation value that is a function of the sum of inputs received from other neurons through the weighted connections. The first and last layers are for input and output, while the others are the hidden layers. The network is said to be fully connected when any node in a given layer is connected to all
the nodes in the adjacent layers. A multi-layer perceptron can learn when presented
with input and output pairs. Learning or training involves modifying the connection
weights and bias until the network is capable of reproducing the target output for the
respective input pattern. Training takes place in an iterative fashion [17].
In this study, a multilayer feed forward neural network was applied to the evaporator
with four input neurons, nine output neurons from hidden layer and one output neurons
from output layer and with the (Tan-Sigmoid transfer function) activation function in
hidden output and the (Linear transfer function) activation function in network output,
as shown in Fig. 1. Operating parameters for caustic soda system are shown in Table. 1.

Than attempt to survey the many ways in which multilayer networks have been used in
control systems, we will concentrate on two typical neural network controllers: model
reference control and model predictive control. These controllers are representative of
the variety of common ways in which multilayer networks are used in control systems,
as shown in Figs. 2. and 3.

5. Simulation works

The simulated forward feed four effect evaporator of caustic soda, as shown in Fig. 4., a
forward feed, four-effect evaporator for combined concentration of raw solution. A 50.8
mm diameter, 6 m height, 107 number of tube, 102 m2 area, 795 m3 volume and 437
m3/s volumetric flow rate. Heat is supplied to the process by steam generating in the
power plant. Excess vapor is condensed, and waste heat is transferred to cooling water
and subsequently discharged from the process to atmospheric air flowing through
cooling towers installed in the water circuit. The evaporation of raw solution must be
carried out in the pressure range below the atmospheric pressure as pumps externally
control the pressure. The temperature of each effect was set by the vapor temperature

![Studied Neural Network Structure for evaporator.](image)

**Table 1** Operating parameters.

| Parameter                                           | Value |
|-----------------------------------------------------|-------|
| Feed Flow rate (m in), kg/hr                        | 10,000|
| Inlet concentration of caustic soda (cs,in), kg solid/kg solution | 0.05  |
| Steam Temperature, °C                               | 100   |
| Feed Temperature (Tin), °C                          | 75    |
Fig. 2. Model Reference Control system.

Fig. 3. NN Model predictive control system.

from the previous effect and the head pressure, which was adjusted to meet solid content specifications. Steam entered the system at the concentrator in first stage. Levels of concentrate per effect are controlled to avoid low levels and also to get an adequate global heat transfer coefficient. A simulation program is built for the evaporator by using the program MATLAB / Simulink version (R2011a) from (Mathworks), which is a software modeling dynamical systems and simulation and analysis, whether linear or non-linear and also based on modeling systems both in the constant time and the continuous time. By using Simulink we can build models from scratch or amendment to existing models and of interest is the study of the characteristics of control and dynamic situation. The mathematical model is built for the evaporator in the form of a set of systems, and each system component with a set of subsystems which represents the mathematical model equations for evaporator. The simulation results are showed qualitatively acceptable behavior for all systems. The model is developed consists of differential and algebraic equations that validated using a parameter sensitivities method that uses data collected in the industrial plant. The unsteady step change simulation runs were conducted by introducing the steam flow rate, feed flow rate, temperature and concentration of feed to the first evaporator and measuring the output temperature of all evaporators. After running the dynamic model that has been developed using Simulink and determining the extent of the system’s response to some of the changes, the control system is built for this model using fuzzy control method (Fuzzy logic). After running the dynamic model that has been developed
using Simulink and determining the extent of the system's response to some of the changes, the control system is built for this model using neural control method (neural model reference and neural predictive. After running the dynamic model that has been developed using Simulink and determining the extent of the system's response to some of the changes, the control system is built for this model using a conventional control (PID).

![Multiple effect evaporation equipment](image)

**Fig. 4.** Multiple effect evaporation equipment.

### 6. Result and Discussion

#### 6.1 Dynamics of Evaporator

Simulation results for the evaporator temperature responses for different step changes in steam flow rate, flow rate and temperature of feed were obtained in simulation. The most common model identification methodology in continuous processes is the step response analysis. The open-loop simulation runs were carried out to determine process characteristics for the implementation of the fuzzy logic controller and training of neural networks controller. Step testing approximation was used for predicting a transfer function of the multiple effect evaporator which was regarded as a first order system, the Table 2 show the parameters of this system at different disturbance variables. The outlet temperatures of evaporators are increased by increasing steam flow rate for System. This is because high heating occurs as steam flow rate is increased. It is observed from temperature response curves, that the third effect evaporator is compared with first and second effects evaporator which reached to new steady state condition with more time delay. The response of fourth and third evaporators have more time delay compared with first and second evaporator. In the discussion of the transfer function parameter, it was found that time constant decreases with increasing steam flow rate, as shown in Fig. 5. Feed flow rate is one of the main causes in existing of disturbances in evaporation processes. The time constant of third evaporator is larger than the first and second evaporator. Fig. 6. presents the responses of outlet temperature of multiple effect evaporator for caustic soda system. It seen the temperature is decreased and faster response appears , this is because the time constant of the evaporator is small. Outlet caustic soda temperatures are increased by increasing temperature feed. It is observed from temperature responses third and fourth effects evaporator compared with first and second effects evaporator reached to new steady state condition with more time delay. In the discussion of the transfer function parameter, it was found that time constant decreases with increasing temperature feed, as shown in Fig. 7.
Table 2: The parameters of the evaporator system

| Disturbance Variable | Evaporator No. 1 | Evaporator No. 2 | Evaporator No. 3 | Evaporator No. 4 |
|----------------------|------------------|------------------|------------------|------------------|
|                      | $K_P$            | $\tau$, sec.    | $K_P$            | $\tau$, sec.    |
| Steam flow rate      | 14.41            | 1.51             | 14.79            | 1.96             |
| Feed flow rate       | -2.25            | 1.33             | -12.31           | 1.79             |
| Feed Temperature     | 9.78             | 1.45             | 9.11             | 2.63             |

Fig. 5. Temperature response of evaporators to step change in steam flow rate from 2381 to 2619 kg/hr.

Fig. 6. Temperature response evaporators to step change in feed flow rate from 10000 to 11000 kg/hr.

Fig. 7. Temperature response evaporators to step change in temperature feed from 75 to 85°C.

6.2 Control of Evaporator
After the basic knowledge about the process was acquired from the open-loop experiments, the fuzzy logic and neural networks controllers were constructed and implemented on the evaporator system to compare with PID controller. Testing of a
controller should be performed to ensure some desired performance criteria, such as it is robust, closed-loop system must be stable, rapid, smooth response is obtained, offset and overshoot are eliminated, excessive control action is avoided. However, it is important to evaluate the robustness of these controllers with respect to changes in operating and process parameters. The controller of evaporator’s temperature is presented and the control signals were calculated to regulate the flow rate of steam.

6.3 PID Controller
The process reaction curves method developed by Cohen-Coon method is used for determining the values of the controller parameters which required the transient responses for outlet temperature of evaporator to step change in flow rate of feed and step change in temperature of feed. Table 3. includes our attempts to tuning parameter of PID controller.

Table 3 Cohen-Coon Parameters for PID Controller.

| Variable of step change | Value of step change | $K_C$ | $\tau_I$ | $\tau_D$ |
|-------------------------|----------------------|-------|----------|----------|
| Feed flow rate, (kg/hr.) | 10000 – 11000        | 0.3   | 0.2      | 0.03     |
| Temperature of feed, (°C) | 75 – 85              | 0.44  | 0.15     | 0.022    |

Response of temperature for evaporator using PID feedback controller to step change in flow rate of feed and step change in temperature of feed are done on the simulation program for PID controller as shown in Fig. 8.. Integral absolute error (IAE) for PID simulation is given in Table 6. It can be seen that IAE value of PID simulation needed long time to reach to steady state.

![PID controller graph](image)

Fig. 8. Temperature responses of first evaporator for PID control to a step change in flow rate of feed from 10000 – 11000 kg/hr and a step change in temperature of feed from 75 – 85°C at set point =91°C.

6.4 Fuzzy Logic Controller
In this study, a rule base with a set of the rule form. The input and the output are related through twenty-five rules is given in Table 4. Each rule output is determined by "MIN-MAX" inference. The input and the output are related through forty seven rules is given in Table 5. Each rule output is determined by "MIN-MAX" inference. The outlet temperature of evaporator by using simulated fuzzy logic controller to step disturbances in flow rate of feed and temperature of feed, ss shown in Figs. 9 and 10. Integral absolute error (IAE) for these two controllers are given in Table 6. It can be seen that a better performance for fuzzy logic controller compared with the PID controller because fuzzy controller reached the desired value faster than PID controllers with minimum (IAE) value. This superiority appeared because fuzzy controller was built on logical functions which gave an output action consistent with the input error, these functions led to a fast
response. However, over shots above the desired value and simple fluctuations were occurred in fuzzy controllers.

**Table 4** Rules of Fuzzy Logic Controller (5MF).

| E | CE | NB | NS | Z | PS | PB |
|---|----|----|----|---|----|----|
| NB | NB | NB | NB | NB | NS | Z |
| NS | NB | NS | NS | Z | PS |   |
| Z  | NB | NS | Z  | PS | PB |   |
| PS | NS | Z  | PS | PB |   |   |
| PB | Z  | PS | PB | PB | PB |   |

6.5 Neural Network Controller

The temperature of evaporator by using simulated neural network controller to step disturbances in flow rate of feed and temperature of feed. As shown in Figs. 11 and 12. Integral absolute error (IAE) for these three controllers are given in Table 6. It is clear that neural controller is the best and gives better results than PID controller because neural controller has less offset value, neural controller has more suitable, The temperature response reach the steady state value in less time and neural controller has lower over-shoot.

**Table 5** Rules of Fuzzy Logic Controller (7MF).

| E | CE | NB | N  | NS | Z  | P  | PB |
|---|----|----|----|----|----|----|----|
| NB | NB | NB | NB | NB | N  | N  | Z  |
| N  | NB | N  | N  | N  | NS | Z  | P  |
| NS | NB | N  | NS | NS | Z  | PS | P  |
| Z  | NB | N  | NS | Z  | PS | P  | PB |
| PS | N  | NS | Z  | PS | P  | P  | PB |
| P  | N  | Z  | PS | P  | P  | P  | PB |
| PB | Z  | P  | P  | PB | PB | PB |   |

![Fig. 9. Temperature responses of first evaporator under five and seven membership functions fuzzy logic controller to a step change in flow rate of feed from 10000 – 11000 kg/hr. at set point =91°C.](image-url)
6.6 Comparison of temperature control of evaporator between three methods

The quantitative performance values, IAE, for the PID, fuzzy and neural controllers are given in Table 6. The control of evaporator temperature using PIDs are not significantly worse than that of using fuzzy logic and neural network. The control of the processes using PID showed a large degraded performance, as displayed in figures below. From the performance of the PID controller, it can be seen that the temperature has severe non-linear dynamics that depended on evaporation systems. The fuzzy and neural
controllers respond as quickly as PID. This indicates that the fuzzy and neural give smoother and better control performance than the PID controllers with smaller IAE error values, when disturbances are introduced into the systems. The figures illustrate that fuzzy and neural strategy brought the evaporator temperature to the set points by gradual increase of the flow rate which gives a smooth control response. The PID control in turn brought the evaporator temperature to the set point by rigorous adjustment of the flow rate causing overshoot in the systems response with a long response time. This indicates that fuzzy and neural controllers give less error and give better control results. The outlet temperature responses to all set point changes are similar with small overshoot and, importantly, the control does not exhibit notable oscillations at any of the set points. The satisfactory performance is due to the full representation of the non-linear dynamics of the evaporator by fuzzy logic and neural network models. Comparing these areas of the results illustrates the significant improvement of controllers using fuzzy logic and neural network models over PID controller, as shown in Figs. 13 to 16.

![Figure 13. Comparison between PID and fuzzy logic (five and seven membership functions) controllers in first evaporator to a step change in feed flow rate from 10000 – 11000 kg/hr. at set point =91°C for caustic soda system.](image)

| Control Method                          | Variable of step change | IAE       |
|----------------------------------------|-------------------------|-----------|
| PID controller                         | Feed flow rate, (kg/hr) | 0.4777    |
|                                        | Temp. of feed, (°C)     | 1.3867    |
| Fuzzy logic controller (5 MF)           | Feed flow rate, (kg/hr) | 0.1377    |
|                                        | Temp. of feed, (°C)     | 0.8488    |
| Fuzzy logic controller (7 MF)           | Feed flow rate, (kg/hr) | 0.0897    |
|                                        | Temp. of feed, (°C)     | 0.8135    |
| Neural Network controller (Reference)   | Feed flow rate, (kg/hr) | 0.7668    |
|                                        | Temp. of feed, (°C)     | 0.9667    |
| Neural Network controller (Predictive)  | Feed flow rate, (kg/hr) | 0.5283    |
|                                        | Temp. of feed, (°C)     | 0.7563    |

Table 6 The integral absolute error (IAE) for control methods.
Fig. 14. Comparison between PID and neural network (reference and predictive) controllers in first evaporator to a step change in temperature of feed from 75 – 85 °C, at set point =91°C for caustic soda system.

Fig. 15. Comparison between PID, fuzzy logic (seven membership functions) and neural network (predictive) controllers in first evaporator to a step change in feed flow rate from 10000 – 11000 kg/hr, at set point =91°C for caustic soda system.

Fig. 16. Comparison between PID, fuzzy logic (five membership functions) and neural network (reference) controllers in first evaporator to a step change in temperature of feed from 75 – 85 °C, at set point =91°C for caustic soda system.

7. Conclusion

From the present study, the following conclusions were drawn regarding the dynamic behavior and control of the multiple effect evaporator. The process identification procedure using process reaction curve methods showed that in most cases the system can be described as first order lag. The integral of the absolute value of the error (IAE)
for performance measure indices are used to make a fair comparison between the control methods. It can be clearly seen that the PID controller has a higher IAE value compared to the fuzzy and neural controllers. Comparison of performance with the conventional PID controller indicated that fuzzy controller with seven membership functions and neural predictive were more robust than the PID controller and gave better results in cases involving disturbances. The results so obtained show that the PID controller gives high overshoot and settling time. Results have shown priority of neural predictive and fuzzy with seven membership functions controllers in caustic soda system which gives less offset value and the temperature response reach the steady state value in less time with lower over-shoot compared with PID controller. The performance of PID are oscillator. It can be seen that performance of PID simulation needed long time to reach to steady state.

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