MODELLING OF FUZZY-BASED CONTROLER FOR A TYPICAL GAS ABSORBER SYSTEM

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***Abstract*—This paper presents the research efforts that has been carried out on control of gas absorbers/gas reactors. Also new approach to fuzzy control design for a gas absorber system has been introduced. The approach incorporates a linear state-estimation to generate the internal knowledge-base that stores input-output pairs. This collection of pairs is then utilized to build a feedback fuzzy controller. The closed-loop fuzzy control system is guaranteed to be asymptotically stable while manipulating its time response. Simulation studies are carried out to illustrate the gas absorber system performance.**

***Keywords*—Gas Absorber, Gas Absorber Control, Fuzzy Control, Gas Separator, Gas Separator Control..**

I. Introduction

The current state of the art of a modeling and dynamic simulation system for complex chemical and biochemical processes was discussed in [11]. Process modeling activity involves modeling a physical plant and external tasks imposed on the plant, and details of both aspects were discussed. Typical software structure was concerned with a model builder, result analyzer, translator, solution methods, model library and external software interface. Some of them are explained in moderate depth. Recent progress of functionality and numerical methods was presented. Numerical methods incorporating symbolic and structural techniques improve accuracy and efficiency. In order to illustrate benefits of employing dynamic simulation tools, one typical chemical process consisting of a mixing tank, tubular reactor and gas absorber was chosen and dynamic simulation was carried out. Taking into account the work in this paper, some suggestions for future development of a unified framework of a modeling package were made.

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A major direction in systems engineering design has been focused on the use of simplified mathematical models to facilitate the design process. This constitutes the so-called model-based system design approach, an overview of the underlying techniques can be found in [1]. Most of the available results have thus far overlooked the operational knowledge of the dynamical system under consideration. On the other hand, a knowledge-based system approach [7] has been suggested to deal with the analysis and design problems of different classes of dynamical systems by incorporating both the simplest available model as well as the best available knowledge about the system. For single physical systems, one of the earlier efforts along this direction has been on the development of an expert learning system; see [3-6] and their references. An alternative approach has been on integrating elements of discrete event systems with differential equations [2].

A third approach has been through the use of fuzzy logic control by successfully applying fuzzy sets and systems theory [8]. In the cases where understood there is no acceptable mathematical model for the plant, fuzzy logic controllers [9] are proved very useful and effective. They are generally base on using qualitative rules of thumb, that is, qualitative control rules in terms of vague and fuzzy sentences. It has been pointed out [10] that fuzzy control systems possess the following features:

Hierarchical ordering of fuzzy rules is used to reduce the size of the inference engine.

Real-time implementation, or on-line simulation, of fuzzy controllers can help reduce the burden of large-sized rule sets by fusing sensory data before imputing the system's output to the inference engine.

In [12], a fuzzy control system was organized and applied to the control of ethanol concentration in a fed-batch cultivation process for emulsan production by Acinetobacter calcoaceticus RAG-I. The membership functions and fuzzy rules were determined by sets of data and experiences obtained from the preliminary culture experiments. The input variables, error(the difference between the set point va1ue and the process variable) and the change of the error, were fuzzified by using the membership functions and the output variable, change of the ethanol feed rate, was inferred based on the membership functions and the given fuzzy rules. To obtain the numerica1 va1ue for the output variable, the center-of-gravity method was used in the defuzzification procedure. The results showed that the ethanol concentration was well regulated around optima1 level and the emulsan yield was increased compared with that of the cultivation controlled by the conventiona1 feedback control loop.

This paper contributes to the further development of fuzzy control techniques by presenting a new approach to fuzzy control design for a gas absorber system. It provides a new and efficient procedure to construct the inference engine by incorporating a linear state-estimator in generating and storing input-output pairs. This collection of pairs is then utilized to build a feedback fuzzy controller. By fine-tuning of the controller parameters, it is shown that the gas absorber system has always a guaranteed stability. Numerical simulation of a six-order gas absorber is carried out and the obtained results show clearly that the proposed estimator-fuzzy controller scheme yields excellent performance.

II. A Gas Absorber System

A. *Brief Account*

Separation processes play an important role in most chemical manufacturing industries. Streams from chemical reactors often contain a number of components; some of these components must be separated from the other components for sale as a final product, or for use in another manufacturing process. A common example of a separation process is gas absorption (also called gas scrubbing, or gas washing) in which a gas mixture is contacted with a liquid (the absorbent or solvent) to selectively dissolve one or more components by mass transfer from the gas to the liquid. Absorption is used to separate gas mixtures; remove impurities, contaminants, pollutants, or catalyst poisons from a gas; or recover valuable chemicals. In general, the species of interest in the gas mixture may be all components, only the component(s) not transferred, or only the component(s) transferred. Absorption is frequently conducted in trayed towers (plate columns), packed columns, spray towers, bubble columns, and centrifugal contactors. A trayed tower is a vertical, cylindrical pressure vessel in which vapor and liquid, which flow countercurrently, are contacted on a series of metal trays or plates; see Fig. 1. Components that enter the bottom of the tower is the gas feed stream are absorbed by the liquid stream, that flows across each tray, over an outlet weir and into a downcomer, so that the gas product stream (leaving the top of the tower) is more pure.

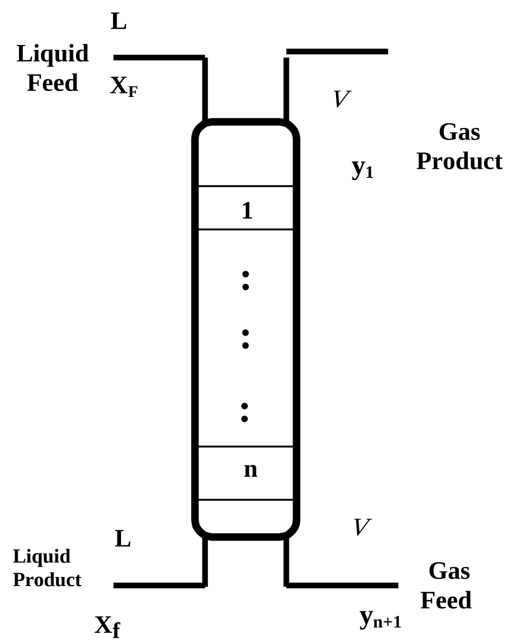

FIG.1 Gas absorption column, n stages

B. *Assumptions and Definitions:*

The basic assumptions used are:
A1) The major component of the liquid stream is inert and does not absorb into the gas stream.
A2) The major component of the gas stream is inert and does not absorb into the liquid stream.
A3) Each stage of the process is an equilibrium stage, that is, the vapor leaving a stage is in thermodynamic equilibrium with the liquid on that stage.
A4) The liquid molar holdup is constant.

We now introduce the following variable definitions:
L = moles inert liquid per time: = liquid molar flow rate.
V= moles inert vapor per time: = vapor molar flow rate
M= moles liquid per stage: = liquid molar holdup per stage

W= moles vapor per stage: = vapor molar holdup per stage

x_j= moles solute (stage j) per mole inert liquid (stage j)

y_j= moles solute (stage j) per mole inert vapor (stage j)

C. Dynamic Model

The concept of an equilibrium stage is important for the development of a dynamic model of the absorption tower. An equilibrium stage is represented schematically in Fig. 2. The total amount of solute on stage j is the sum of the solute in the liquid phase and the gas phase (that is, M xj + W yj). Thus the rate of change of the amount of solute is d(M xj + W yj)/dt and the component material balance around stage j can be expressed as:

$$\frac{d(M\,x_j + W y_j)}{dt} = L\,x_{j-1} + V\,y_{j+1} - L\,x_j - V\,y_j$$

$$\frac{dM\,x_j}{dt} \cong L\,x_{j-1} + V\,y_{j+1} - L\,x_j - V\,y_j \qquad (1)$$

where we assumed that in accumulation, liquid is much more dense than vapor. Under assumption A4), then (1) simplifies into:

$$\frac{d\,x_j}{dt} \cong \frac{L}{M}x_{j-1} + \frac{V}{M}y_{j+1} - \frac{L}{M}x_j - \frac{V}{M}y_j \qquad (2)$$

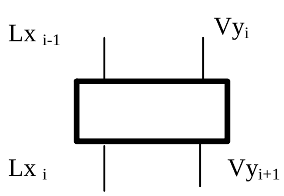

FIG. 2 A typical gas absorption stage.

Under assumption A3), we let

$$y_j = d\;x_j \qquad (3)$$

which expresses a linear relationship between the liquid phase and gas phase compositions at stage j with d being an equilibrium parameter. Using (3) into (2) and arranging we get:

$$\frac{d\,x_j}{dt} = \frac{L}{M}x_{j-1} - \frac{(L + V\,d)}{M}x_j - \frac{V\,d}{M}x_{j+1} \qquad (4)$$

For n-stage gas absorber, (4) is valid for j =2,…,n-1. At the extreme stages, we have:

$$\frac{d\,x_1}{dt} = -\frac{(L + V\,d)}{M}x_1 - \frac{V\,d}{M}x_2 + \frac{L}{M}x_f \qquad (5)$$

$$\frac{d\,x_n}{dt} = -\frac{(L + V\,d)}{M}x_n + \frac{L}{M}x_{n-1} + \frac{V}{M}y_{n+1} \qquad (6)$$

where x_f and y_{n+1} are the known liquid and vapor feed compositions, respectively. On combining (4-6), we reach the state-space model:

where A an (nxn) system matrix with a tridiagonal structure, B is an (nxm) input matrix and C is an (nxp) output matrix given by:

$$\begin{aligned} \dot{x}(t) &= A\;x(t) + B\,u(t) \\ y(t) &= C\,x(t) \end{aligned} \qquad (7)$$

$$A = \begin{bmatrix} -\frac{L+M}{M} & \frac{Vd}{M} & 0 & 0 & 0 & 0 & \cdots & 0 \\ \frac{L}{M} & -\frac{L+Vd}{M} & \frac{Vd}{M} & 0 & 0 & \cdots & & 0 \\ 0 & \frac{L}{M} & -\frac{L+Vd}{M} & \frac{Vd}{M} & 0 & \cdots & & 0 \\ 0 & & \ddots & & & & & 0 \\ \vdots & & & \ddots & & & & \vdots \\ \vdots & & & & \ddots & & & \\ 0 & & & & & \frac{L}{M} & & -\frac{L+Vd}{M} \end{bmatrix}$$

$$B = \begin{bmatrix} \frac{L}{M} & 0 \\ 0 & 0 \\ \vdots & \vdots \\ \vdots & \vdots \\ \vdots & \vdots \\ \vdots & \vdots \\ \vdots & \frac{V}{M} \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

III. A Short Account of Fuzzy Systems

Fuzzy control is by far the most successful application of fuzzy sets and systems theory to practical problems. Numerous applications of fuzzy logic controllers to a variety of consumer products and industrial systems have been recorded [8].

Fuzzy systems are linguistic knowledge based system. The heart of a fuzzy system is what so-called fuzzy IF THEN rules. These rules are statements in which some words are described by continuous membership function. For example,

IF vessel temperature High THEN fuel value opening Small.
IF vessel temperature Low THEN fuel value opening Wide. (8).

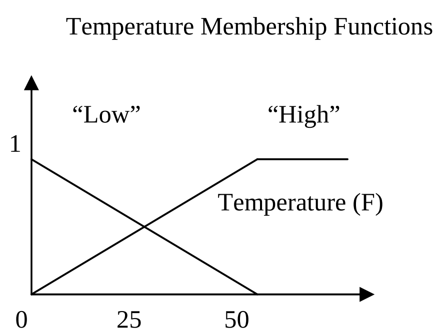

Fig. 3.a Temperature Membership Functions

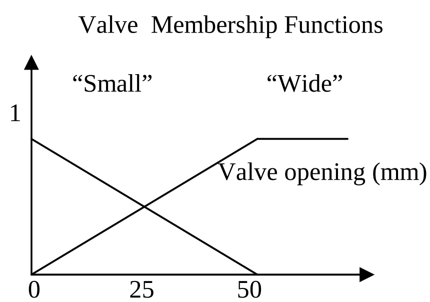

Fig. 3.b Valve opening Membership Functions

In general, the starting point of constructing a fuzzy system is to obtain a collection of fuzzy IF-THEN rules from human experts, experiments or based on domain knowledge.

The next step is to combine these rules into a single system. There are three types of fuzzy system that are commonly used:

(1) Pure fuzzy systems,
(2) Takagi–Sugeno–Kang (TSK) fuzzy system, and
(3) Fuzzy system with fuzzifier and defuzzifier.

The three systems are described briefly hereinafter.

The configuration of a fuzzy system is illustrated in Fig. 4. The fuzzy rule base represents the collection of fuzzy IF-THEN rules. The fuzzy inference engine combines these fuzzy IF THEN rules into a mapping from fuzzy set in the input space $U \subset Rn$ to fuzzy sets in the output space $V \subset R$ based on fuzzy logic principles. If the dashed feed back line in Fig. 4 is exists, the system becomes a fuzzy dynamic system (FDS).

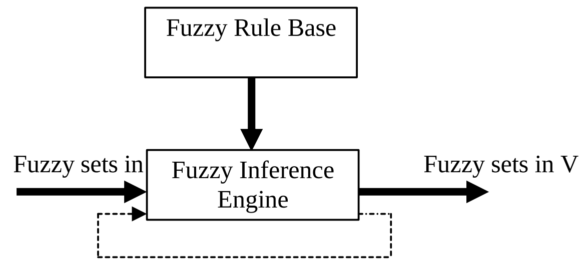

Fig. 4 Basic configuration of pure fuzzy systems

The main disadvantage in the pure fuzzy system is that its input and output is fuzzy set, whereas in design and engineering the input and output are real-valued variables.

Takagi, Sugeno and Kang (Takagi and Sugeno [1985] and Kang [1988]) introduced another fuzzy system whose input and outputs are real-valued variables. This system uses rules in the following:

IF the input x is high then the output $y = cx$ (9)

Where the word high has the same meaning as in (8), and c is a constant. Comparing (8) and (9) we can see that the THEN part of the rule changes from linguistic to into a simple mathematical formula, which leads to combine the rule easier. In fact, the TSK fuzzy system is a weighted average of the value in the THEN parts of the rules. Fig. 5 shows the basic configuration of TSK fuzzy system.

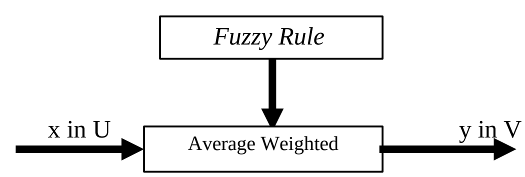

Fig. 5: TSK fuzzy system

The main problem with TSK fuzzy system is its THEN part may not reflect a good framework to represent human knowledge. To solve this problem, the third type of fuzzy systems is used. Fig. 6 illustrates the main structure of the fuzzy system with fuzzifier and deffuzzifier.

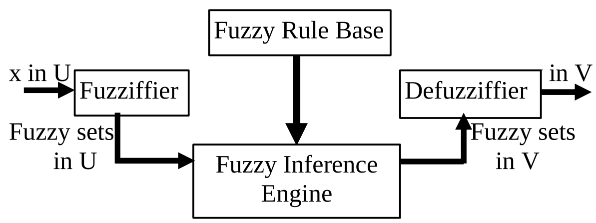

Fig. 6: fuzzy system with fuzzifier and deffuzzifier

Comparing this system with pure fuzzy system, we can see that the only different between the two system that are the fuzzifier that transfer the real-valued variable into a fuzzy set, and the deffuzzifier that transfer the fuzzy set into a real-valued variable.

IV. Fuzzy Controller Design

Following (8), the design of a fuzzy controller can be implemented by the following steps:

Step1: Supposed that the output y (t) takes values in internal U = [α, β] $\subset$ R. Define 2N+1 fuzzy Al in U that are normal, consistent and complete with the triangular membership functions shown in Fig. 7. That is, we use the N fuzzy sets A1, ---, AN to cover the negative interval [α, 0), the other N fuzzy sets AN+2,---, A2N+1 to cover the positive interval (0, β], and choose the center x N+1 of fuzzy set AN+1 at zero.

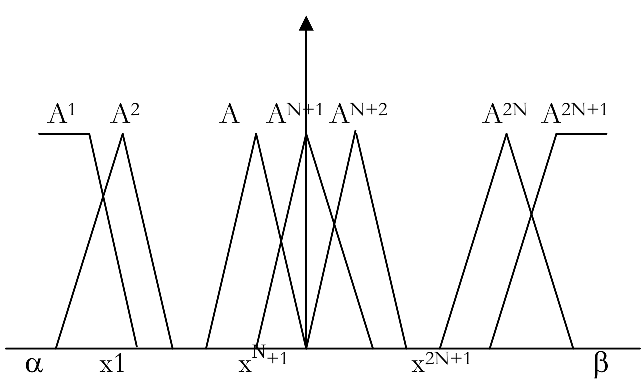

Fig. 7 Membership functions for the fuzzy controller.

Step 2: Consider the following 2N+1 fuzzy IF-THEN rules:

$$\text{IF } y \text{ is } A^l, \text{ THEN } u \text{ is } B^l \qquad (10)$$

Where l = 1, 2, ---, 2N+1, and centers $\bar{y}^l$ of fuzzy set B^l are chosen such that,

$$\bar{y}^l \begin{cases} \leq 0 & \text{for } l = 1,\text{---}, N \\ = 0 & \text{for } l = N+1 \\ \geq 0 & \text{for } l = N+2,\text{---}, 2N+1 \end{cases} \qquad (11)$$

Step 3: Design the fuzzy controller from the 2N+1 fuzzy IF THEN rules (10) using product inference engine, singleton fuzzifier and center average defuzzifier; that is, the designed fuzzy controller is

$$v = -f(y) = \frac{\sum_{l=1}^{2N+1} \bar{y}^l \mu_A{}^l(y)}{\sum_{l=1}^{2N+1} \mu_A{}^l(y)} \qquad (12)$$

Where $\mu_A{}^l(y)$ are shown in Fig. 7 and $\bar{y}^l$ satisfy y (11).

To estimate the range of the input-output pairs {v_i, y_i}, full order estimator [1] can be used.

V. Simulation Studies

Consider a gas absorber system with the following parameters: L=80, M=200, V=100 and d=0.5. Thus,

$$\frac{L+Vd}{M} = -0.65, \quad \frac{L}{M} = 0.4, \quad \frac{V\,d}{M} = 0.25, \quad \frac{V}{M} = 0.5$$

A MATLAB program is written to simulate the gas absorber system. Different positive and negative step input are applied to estimate the outputs. The results of two cases are illustrated in Fig. 8 and Fig. 9. The tracking behavior of the outputs is shown.

From the input-output pair obtained, the behavior of the system is examined and the ranges of its outputs (controllers inputs) are predicted. Fig. 10 illustrates a block diagram of the gas absorber and the fuzzy controller array.

To control the response of the gas absorber, the range of linguistic values of the output of each feedback fuzzy controller is tuned between (– 3) and (3). Comparison between the output response with fuzzy controller (when the number of linguistic values of the controller input – output pair is three) and without controller is illustrated in Fig.11 and Fig.12.

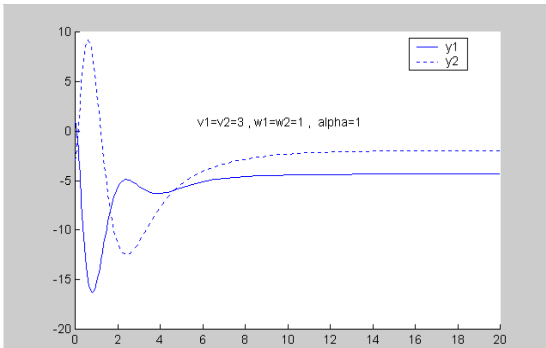

Fig. 8 Output response with positive input signals

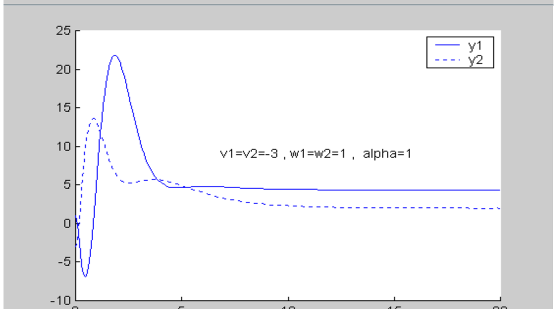

Fig. 9 Output response with nigative input signals

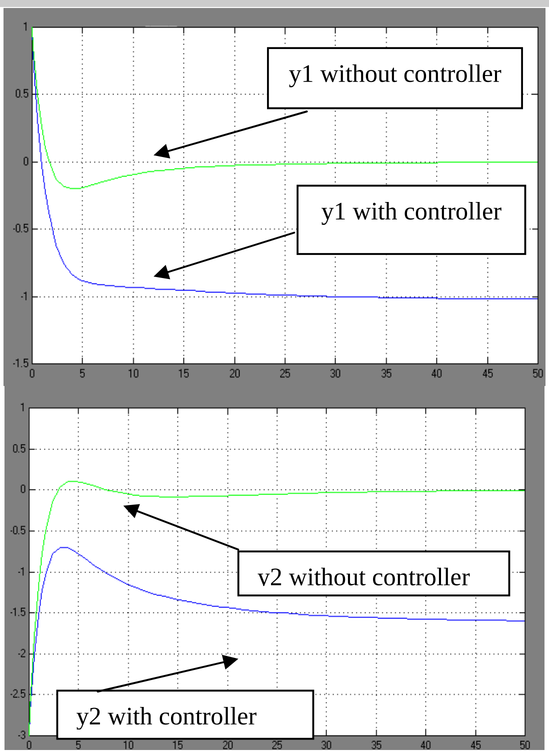

Fig. 11 Controller is tuned to interfere the natural decay of the system.

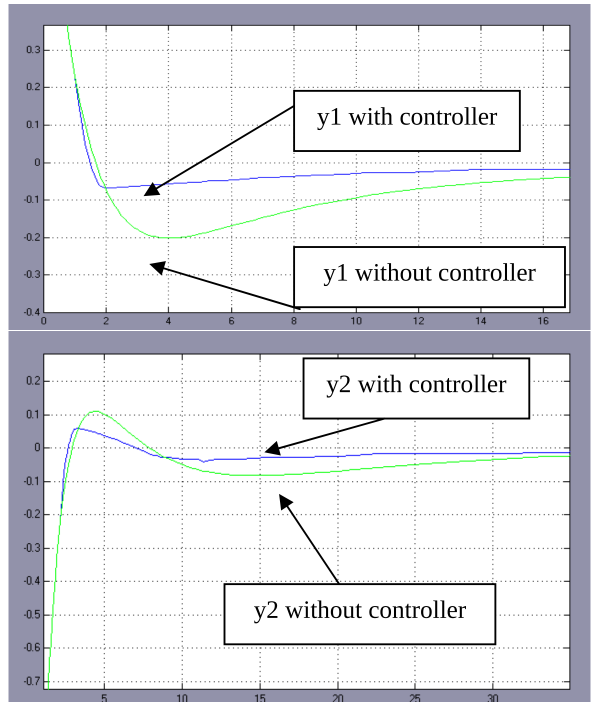

Fig .12 The controller is tuned to improve the response of the system.

. In Fig.11, the controller is tuned to interfere the natural decay of the system. In Fig.12, the fuzzy controller is adjusted to improve the response of the gas absorber. It is noted that the response of controlled system has less overshoot, less steady state error and faster compared to the uncontrolled system

VI . CONCLUSIONS

This paper has presented a new fuzzy control modeling for a gas absorber system. The simulation results have shown that the controller guarantees well-damped behavior of the controlled absorber system

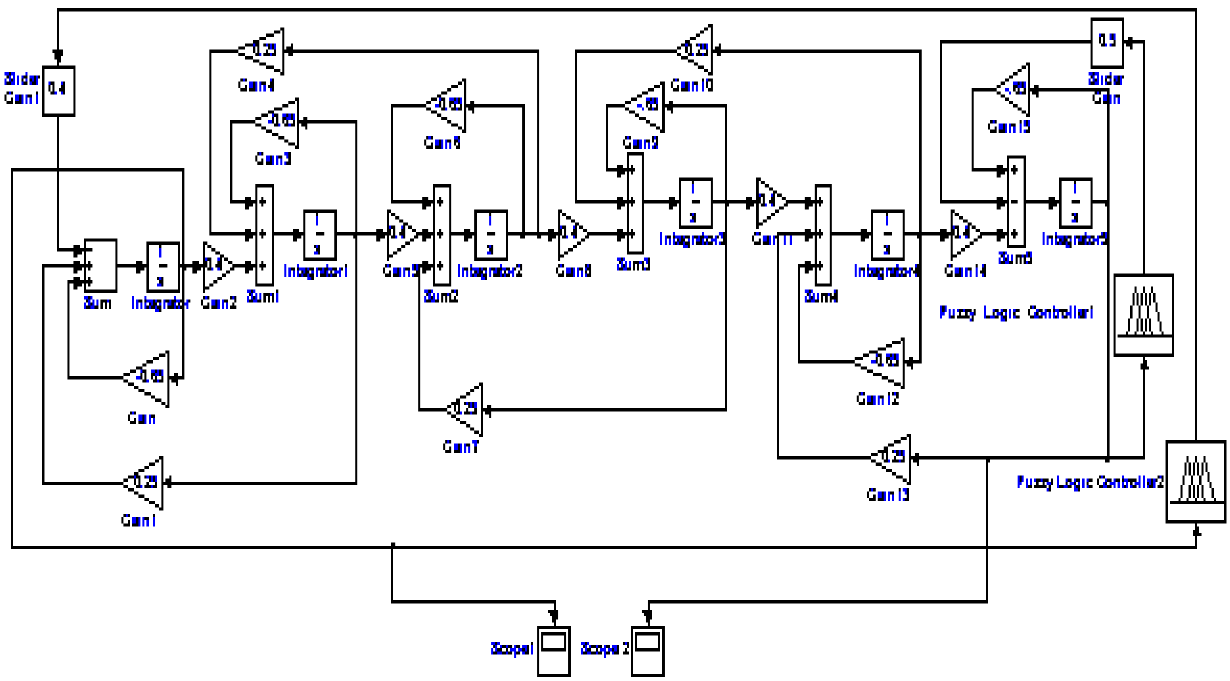

Fig. 10: Block Diagram of gas absorber system and the fuzzy controllers

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I'd like to present this effort to my Sons Ahmed and Kareem, and to my daughter Noor to admit their role in my life, also to encourage them for more learning efforts for better future.

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