Comparison of Defuzzification Methods: Automatic Control of Temperature and Flow in Heat Exchanger

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Abstract. The objective of this work is to analyze the behavior of the traditional control and the fuzzy control, applying them in the flow and temperature control to the load of current of a heat exchanger, as well as the analysis of different methods of defuzzification, utilized just as itself this carrying out the fuzzy control. Acting on the structure of the fuzzy controller some changes of form are carried out such that this tune in to be able to obtain the answer but optimum. In the same way proceeds on the traditional controller, and in this way comparisons on these two types of controls are established. Inside the changes that are carried out on the fuzzy controller this form of defuzzification the information, that is to say the methods are exchanged defuzzification in order then to realize comparisons on the behavior of each one of these.

1 Introduction

In many of the sectors of the industry where include itself thermal processes, is important the presence of a heat exchanger [1] [2]. Said processes do part of the everyday life of an engineer that has as field of action the control, therefore is considered interesting to realize a control to this type of tools. This work in its content studies two large aspects: A comparison between the traditional control and the fuzzy control, and an analysis between some of the different methods of defuzzification that are utilized in the fuzzy logic [3], doing an analysis of each one of they taking in consideration contribute them that other authors have done and leaving always in clear, that the alone results obtained will be applicable al moment of doing control on an exchanger of heat [4]. The system this composed one for two exchangers of heat [5], one of concentric pipes and the other of hull and pipes, to which implemented them an automatic control of the temperature and the flow to the load of the current of heating (Fig. 1).

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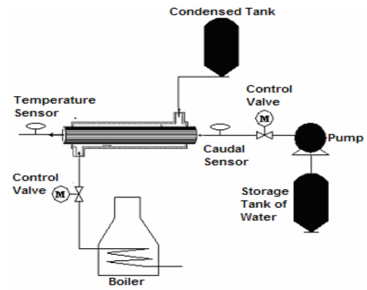


Fig. 1. Assembly of the system.

This control is realized through two proportional valves, one to the input of the water, that is the responsible for maintaining the value of order of the water and the other installed in the line of input of the vapor (source of heat), that is responsible of maintaining the quantity of necessary vapor to obtain the target temperature. The measurement of the flow [6] is realized by means of a sensor of rotary palette and the measurement of the temperature by means of thermocouples [7] [8] [9]. The signals supplied by these sensors are acquired by means of the FieldPoint systems of National Instruments [10], the same one that takes charge of sending the signal to the valves of control, after to be processed the data by the controller [11].

2 Software of Fuzzy and Classic Control

The software of control designed, is formed of two sections, the program of fuzzy control, and the program of the PID (Proportional/Integral/ Derivative) control. These controllers are elaborate in environment Labwindows/CVI, software of the company National Instruments, which permits to realize the pertinent operations with the data captured through the modules of FieldPoint, and that, are utilized in the control of the system. The fuzzy control interface, is the responsible for taking the data of the sensors, so much of temperature, for the case of the control of temperature, as of the sensor of flow, for the control of the same one, to process, and according to an order established, to determine an response, which is sent to the actuators. Basically, this program is responsible of: to schematize the fuzzy sets, according to established by the user, defuzzification of the inputs, to realize the inference of these inputs in the rules, to realize the aggregation in the outputs sets, and to execute the process of defuzzification, to determine the response that help to the system to obtain the stable state. The program of the classic control PID, is the responsible for taking the data of the sensors, so much of temperature, for the case of the control of temperature, as of the sensor of flow, for the control of the same one, to process, and according to an order established, to determine an response, which is sent to the actuators. Basically, this program is entrusted of to execute the three actions of control, proportional, derivative and integral to determine the responses that help to the system to obtain its target state. The PID control system general is represented in figure 2, where R(s), is the signal target or set point, U(s), is the output of the PID controller that goes toward the plant G(s), and Y(s), is the value taken of the variable to control, which reduces to the reference and the error is determined (controller input).

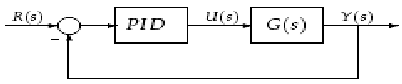


Fig. 2. System of Control PID.

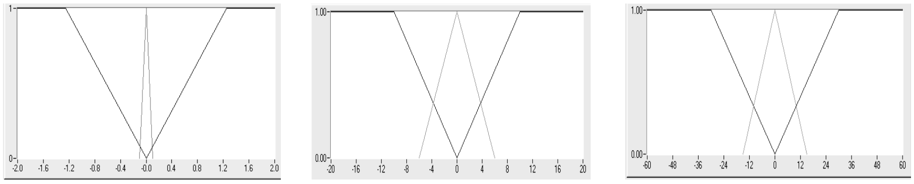
The control of Temperature, have as an objective to obtain that the water that the exchanger of heat leaves achieve the value of the target temperature and then to keep it in the value even with external disruptions. That is to say, should operate on the valve of control who is the one that supplies the quantity of vapor that heats the water. The input to this system of control will be the error of temperature, obtained since the thermocouple placed on the exit of the exchanger, and the exit will control the quantity of necessary current to open or to close the proportional valve (Plant). This control is realized through a PID controller. The flow control has as an objective to obtain that the mass flow of water that enters to the exchanger of heat, achieve the target value, and can to keep it during its operation, and even with disruptions. This means that should operate on the valve of control, who is the one that strangles the quantity of water that enters to the system. The input of the system will be the error obtained through the sensor of flow installed in the input of the system, and the PID controller will control the quantity of necessary current to manipulate the proportional valve. Both processes begin, calculating the difference between the measured temperature and the temperature target or of the flow measured and the flow desired. In this form, know the error. Then, the values of the parameters of control are taken, and the output is calculated that goes toward the plant. This output, will obtain values since 0 to 20 mA, they will represent angles of opening of the proportional valve.

3 System of Fuzzy Control

The input to this system of control will be the error of temperature and the gradient, obtained since the sensor placed on the way out of the exchanger, and the exit will control the quantity of necessary current to open the proportional valve. The rules of the system and function of membership are obtained in the table 1 and figure 3, respectively.

Table 1. Temperature control rules assembly.

Error / Δ Error	Negative	Zero	Positive
Negative	Open	Open	Not operation
Zero	Open	Not operation	Close
Positive	Not operation	Close	Close



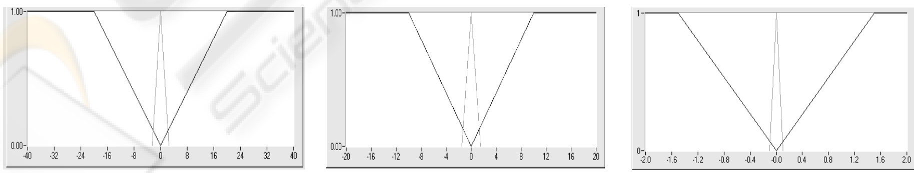
Functions of membership for the current at the outset — Functions of membership for the variable derived from the Error — Functions of membership or the variable Error

Fig. 3. Functions of membership temperature control.

The control of flow has as objective to obtain that the mass flow of water that enters to the exchanger of heat, achieve the value of order, and can to keep it during its operation, and even before disruptions. This means that should act on the valve of control who is the one that strangles the quantity of water that enters to the system. The input of the system, they will be the error obtained through the sensor of flow installed to the entrance of the system, and the change of the error in the time, and the output will control the quantity of necessary current to manipulate the proportional valve. Both processes begin, calculating the difference between the measured temperature and the temperature desired, or of the flow measured and the flow desired. In this form know the Error. Then, calculate the gradient, reducing the new error of the previous one. Once known these variables, that constitute the inputs of the fuzzy logic controller, proceeds to realize the fuzzification, the inference and the defuzzification to obtain the output of the controller. This output, will obtain values since 0 to 20 mA, who will represent angles of opening of the proportional valve. The rules of the system and function of membership are obtained in the table 2 and figure 4, respectively.

Table 2. Flow control rules assembly.

Error / **Δ Error**	**Negative**	**Zero**	**Positive**
Negative	Close	Close	Not operation
Zero	Close	Not operation	Open
Positive	Not operation	Open	Open



Functions of membership for the variable Error — Functions of membership for the variable derived from the Error — Functions of membership for the current at the outset

Fig. 4. Functions of membership flow control.

3.1 Comparative Results between the Methods of Defuzzification Implemented

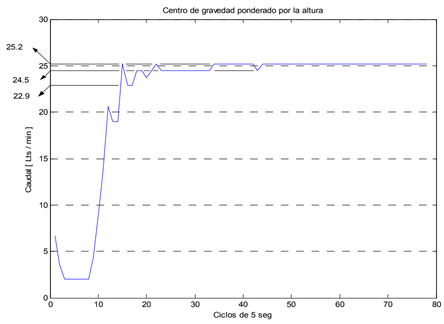
The methods of defuzzification chosen were five; these are know in the area of the control by the names, central gravity weighted by the height, central gravity weighted by the area, average of centers, points of maximum criterion weighted by the height and points of maximum criterion weighted by the area. When refers to the control of a system, the main term on which refers is to the stability that this can offer, for this is necessary to take into consideration, the time that delayed the system in being stabilized, the margin of error between the value desired, (Vc), and the values of stabilization, (Ve) of the system and the influence of the inertia of the system. For the tests of temperature and flow control, is defined a set point of 25 [Lts / min] and 40 [ºC]. The parameters and equations used are observed in the table 3 and the table 4 the different responses are shown in each one of the methods, according to the parameters established in the table 3.

Table 3. Methods and models of defuzzification.

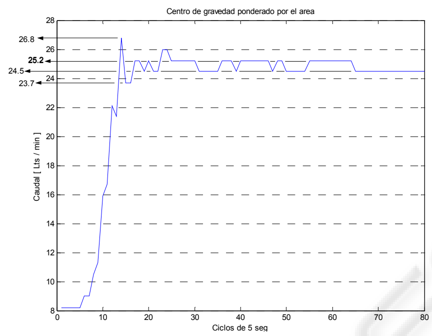
METHODS	EQUATIONS	
1. Central gravity weighted by the height	$\bar{x} = \dfrac{\sum_{i=1}^{n} h_i * w_i}{\sum_{i=1}^{n} h_i}$	Where, *w* is the center gravity of the resultant assembly after realized the fuzzy operation chosen, and *h* is the height of the same assembly.
2. Central gravity weighted by the area.	$\bar{x} = \dfrac{\sum_{i=1}^{n} s_i * w_i}{\sum_{i=1}^{n} s_i}$	Where, *w* is the center gravity of the resultant assembly after realized the fuzzy operation chosen and *s* is the area of the same assembly.
5. Points of maximum criterion weighted by the area.	$\bar{x} = \dfrac{\sum_{i=1}^{n} s_i * G_i}{\sum_{i=1}^{n} s_i}$	Where, *G* is the point of maximum criterion of the resultant set after to realize the fuzzy4 operation chosen and *s* is the area of the same set.
3. Points of maximum criterion weighted by the height.	$\bar{x} = \dfrac{\sum_{i=1}^{n} h_i * G_i}{\sum_{i=1}^{n} h_i}$	Where, *G* is the point of maximum criterion of the resultant set after to realize the fuzzy operation chosen and *h* is height of the same set.
4. Average of centers	$y = \dfrac{\sum_{l=1}^{M} y^{-l}(\mu_{B'}(y^{-l}))}{\sum_{l=1}^{M}\left(\mu_{B'}(y^{-l})\right)}$	Where y^{-l} represents the center of the fuzzy set G^l (defined as the point *V* in which $\mu_{G^l}(y)$ reaches its value maximum), and $\mu_B(y)$ this defined for the degrees of membership resultant of the fuzzy inference.

Table 4. Response in each one of the methods established.

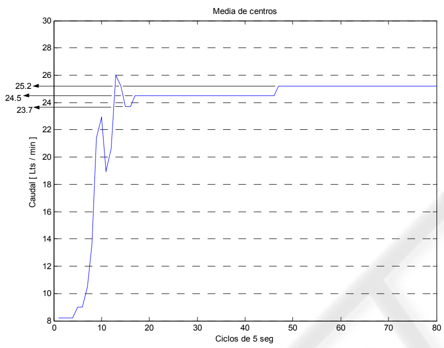
FLOW CONTROL



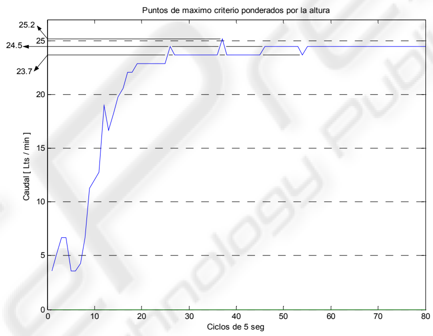
Central gravity weighted by the height



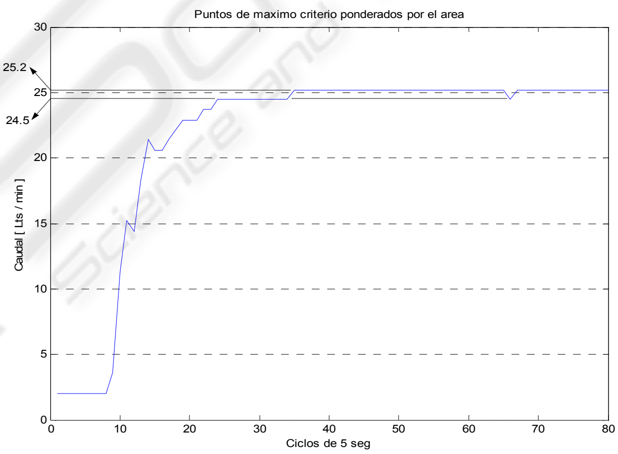
Central gravity weighted by the area



Average of centers



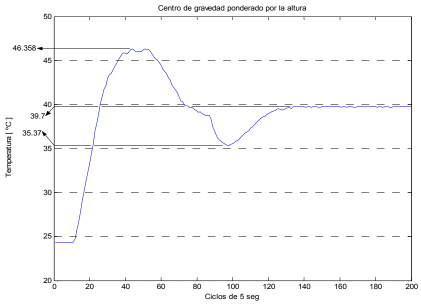
Points of maximum criterion weighted by the height



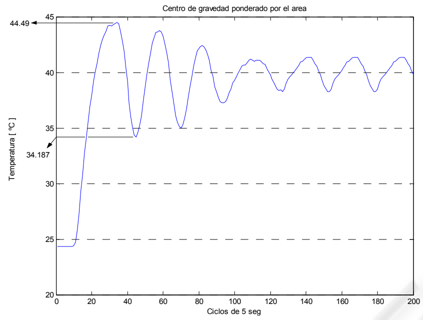
Points of maximum criterion weighted by the area.

Table 4. Response in each one of the methods established (continued).

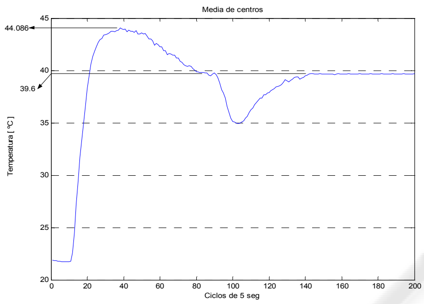
TEMPERATURE CONTROL



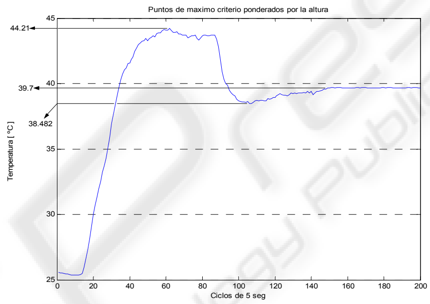
Central gravity weighted by the height



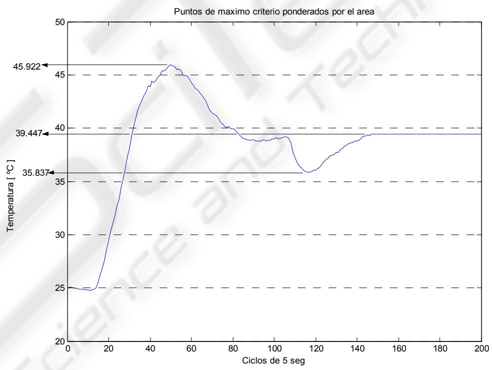
Central gravity weighted by the area



Average of centers



Points of maximum criterion weighted by the height



Points of maximum criterion weighted by the area

A summary of the results obtained in the different methods is shown in the table 5 for the control of flow and the table 6 for the control of temperature.

Table 5. Response of the methods of defuzzification in the control of flow.

Defuzzification Method	Time of stability [sec]	Margin of error (Vc - Ve)	Influence of the inertial of system
Central gravity weighted by the height	105	0.8% above of the set point 2% underneath of the set point	0.8% above of the set point 8.4% underneath of the set point
Central gravity weighted by the area	125	0.8% above of the set point 2% underneath of the set point	7.2% above of the set point 5.2% underneath of the set point
Average of centers	85	0.8% above of the set point 2% underneath of the set point	4% above of the set point 5.2% underneath of the set point
Points of maximum criterion weighted by the height	230	2% underneath of the set point	0.8% above of the set point 5.2% underneath of the set point
Points of maximum criterion weighted by the area	120	0.8% above of the set point 2% underneath of the set point	0.8% above of the set point 2% underneath of the set point

Table 6. Response of the methods of defuzzification in the control of temperature.

Defuzzification Method	Time of stability [sec]	Margin of error (Vc - Ve)	Influence of the inertial of system
Central gravity weighted by the height	670	0.75% underneath of the set point	40.895% above of the set point 11.575% underneath of the set point
Central gravity weighted by the area	Not stabilized	Not stabilized	11.25% above of the set point 14.5325% underneath of the set point
Average of centers	710	1% underneath of the set point	10.215% above of the set point 12.5% underneath of the set point
Points of maximum criterion weighted by the height	745	0.75% underneath of the set point	10.525% above of the set point 3.795% underneath of the set point
Points of maximum criterion weighted by the area	735	1.38% underneath of the set point	14.805% above of the set point 10.4075% underneath of the set point

3.2 Comparative Analysis between the Classic Controller and Fuzzy Controller

To be able to realize this analysis should make use of concepts that be fundamental at the moment of to evaluate the efficiency of a controller. The concepts to take into consideration in this case are, the time that delayed the system in being stabilized, margin of error between the value of order, (Vc), and the values of stabilization (Ve), of the system and the Influence of the inertia of the system. For the comparative analysis between the fuzzy controller and the PID controller in the control of flow made use of the tests realized to each one of these controllers, with a set point of 25 [Lts / min] and 40 [ºC]. The results obtained are shown in the table 7.

Table 7. Response of the controllers.

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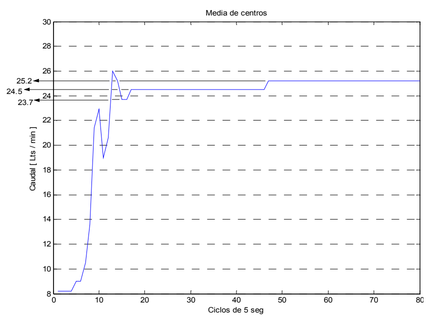
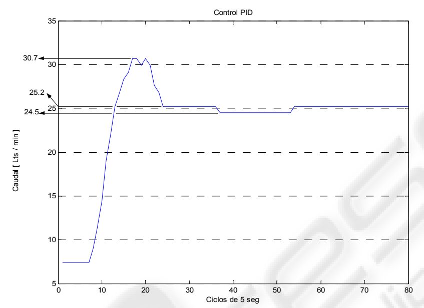
<tr><td>FLOW CONTROL</td><td>
</td><td>
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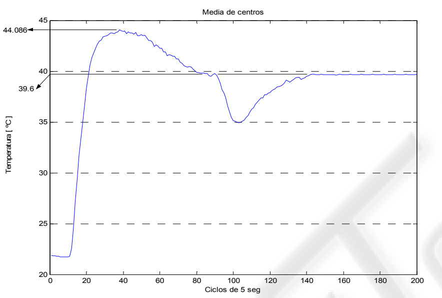
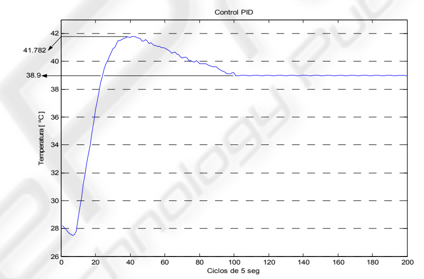
<tr><td>TEMPERATURE CONTROL</td><td>
</td><td>
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A summary of the results obtained in the different methods is shown in the table 8 for the control of flow and the table 9 for the control of temperature.

Table 8. Response of the methods of defuzzification in the control of flow.

Controller	Time of stability [sec]	Margin of error (V_c - V_e)	Influence of the inertial of system
FUZZY CONTROL	85	0.8% underneath of the set point 2% above of the set point	4% underneath of the set point - 5.2% above of the set point
PID CONTROL	115	0.8% underneath of the set point 2% above of the set point	22.8% underneath of the set point 2% above of the set point

Table 9. Response of the methods of defuzzification in the control of temperature.

Controller	Time of stability [sec]	Margin of error (V_c - V_e)	Influence of the inertial of system
FUZZY CONTROL	710	1% underneath of the set point	10.215% above of the set point 12.5% underneath of the set point
PID CONTROL	505	2.75% underneath of the set point	4.455% above of the set point 2.75% underneath of the set point

4 Conclusions

The results obtained in this work show the technical viability of the utilization of the fuzzy logic in the control of flow and temperature to the warming-up current input of an exchanger of heat. With respect to the control of flow and temperature implementing fuzzy logic, can tell that possesses the advantages of need not a mathematical model of precision of the control system. As disadvantage can tell itself, that the design should be realized generally with the method of test and error. Is possible to control through fuzzy techniques industrial process, with the greater facility and with the minimum of errors, suffices with knowing its general behavior to structure a series of fuzzy sets and its respective rules. The tuning of the fuzzy controller, besides depending on the rules matrix, also, depends on the size of the sets of the variable, already itself of input or output. This depends on the same behavior of the system. For the implementation of a fuzzy control, is necessary, the establishment of the methods and alternatives utilized in each one of the blocks that conform it. In this form, can be obtained best results, at the moment of the tuning of the system. The answer of the fuzzy controller does not depend on the method of defuzzification utilized, if not of the adequate utilization of the functions of membership, and of the numbers of linguistic variables utilized for each one of the variables of input and output of the system. Also, depends on the type and of the size of the sets utilized.

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