# IMPLEMENTATION OF A HEATING SYSTEM IN A PETROLEUM MEASUREMENT EVALUATION LABORATORY

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***Abstract.*** *The main goal of the Petroleum Measurement Evaluation Laboratory of the Universidade Federal do Rio Grande do Norte (UFRN) is to assess flow and Basic Sediment and Water (BS&W) gauges, where a simulation of the largest number of operating variables in the field ensures an assessment with fewer uncertainties. Temperature is a parameter that influences the accuracy of flow and BS&W measures.*
*The aim of this study was to design a heating system that will enable safe and efficient temperature control in the laboratory.*
*The system is implemented with immersion resistances, where laboratory requirements are taken into account, such as the conditions and restrictions that it is under (Díaz-Amado J,2007). A thermal exchange simulation was conducted, where the fluid and working temperature used under normal laboratory procedures were considered (Díaz-Amado J,2008) .*
*The system was installed in the laboratory after design analyses had been performed. Control strategies were determined, combining PID control methods and fuzzy logic, which were evaluated and compared, depending on the different operating circumstances of the laboratory (Díaz-Amado J,2008) . Results showed better performance using methods based on fuzzy logic than on a classic PID.*

***Keywords****: BS&W , heating system, thermal exchange simulation, fuzzy logic control.*

## 1. INTRODUCTION

The Petroleum Measurement Evaluation Laboratory was constructed at the Universidade Federal do Rio Grande do Norte to calibrate the different types of in-line gauges installed in the petrochemical industry to continuously monitor oil flow (BS&W). The facility enables the simulation of different field gauge operating conditions, such as simulating water and oil mixtures at varied ratios and flows (Quintaes, Filipe, 2007).

Temperature is the most influential variable in the measure of flow and BS&W, since it directly affects the viscosity and density of the fluid. Laboratory tests are currently conducted with fluids at ambient temperature (around 30°C), in contrast to what occurs in the field, where the instruments work with flows at temperatures near 60°C.

Thus, according to the requirements for calibrating oil flow meters, established by joint ANP/INMETRO 2000 regulations, a heating system will be developed to simulate the real thermal conditions of oil producing facilities. This system is very important for the equipment to be able to simulate the thermal conditions of a petroleum producing field. Considering maximum flow and temperature test values, the system requires considerable heat transfer.

Immersion resistances were used to implement the heating system, according to the following laboratory requirements: Electrical installations in potentially explosive areas, electrical power, thermal exchange area, and physical installation area. Finally, simulations were performed to assess system behavior under different conditions.

When a controller is designed, process modeling is normally based on approximations, given that the system is non-linear and time-invariant. The design of fuzzy controller does not require a mathematical modeling process (Quintaes, Filipe, 2007). The non-linearity and complex modeling of thermal systems are peculiarities that make fuzzy control a very attractive solution for this type of system, and for this reason it was considered a solution method for controlling a heating system.

## 2. INFLUENCE OF TEMPERATURE ON FLOW AND BS&W GAUGES FORMAT

During the production process of an oil well, the simultaneous production of water and oil is common, owing to the properties of the oil reservoir or as a consequence of water injection used in the secondary recovery process (E.Thomas J, 2001).

The knowledge of BS&W is very important in petroleum engineering, since this parameter represents the ratio between water-sediment mixture flow and oil-water-sediment mixture flow (Frick, Thomas C, 1962). From the gross oil flow, it is possible to determine the well oil flow (Lima, C. E. G, 2000).

The calibration of flow and BS&W oil gauges is performed to establish, under specific conditions, the relationship between the values indicated by a measuring instrument and the corresponding established standard values, to ensure measurement trackability.

Temperature influences the calculation of specific mass uncertainties in the oil and water, thereby interfering in the calibration of BS&W gauges (Quintaes, Filipe, 2007). However, to compensate for the influence of temperature on oil and water density, the Petrobras technical bulletin is used (de F. Maciel, Itamar, 2001).

When flow gauges are calibrated (Quintaes, Filipe, 2007) temperature is assessed because of the volumetric variation of the water and oil, where the temperature correction table contained in the Petrobrás technical bulletin is used (de F. Maciel, Itamar, 2001).

In Brazil, ANP/INMETRO legislation for fiscal measurement systems approves the following oil flow measurement technologies in pipelines, which is the case for LAMP: turbines, positive, ultrasonic and mass displacement. The measurements are corrected with the following factors: thermal dilatation between the base temperature and the temperature under the measurement conditions. The following volume calculation norms are used to make the corrections: ISO 91.2/API 7.2.

Although there are temperature correction tables, they should not be relied on for calibrations, given that they may increase the final measurement error (Donald E. Beasley, 2007).

## 3. IMPLEMENTATION OF THE HEATING SYSTEM

All the equipment installed in the LAMP plant must be certified to be used in classified areas, because the laboratory testing area is in the zone 1 classification area. The use of internal resistances matches the laboratory needs perfectly, since models with the required certification can be easily found on the market.

Immersion or internal resistances, flanged electrical tubular resistances installed in the inner pipe walls, are in direct contact with the fluid. They are widely used in the petrochemical industry for heating system solutions, for both gases and liquids.

Some of the advantages of this resistance are related to energy loss because it is immersed in the piping, that is, in direct contact with the fluid to be heated, owing to the fact that it experiences minimum or practically no heat loss, increasing its efficiency and decreasing fluid recirculation time through it.

The design includes an adapted recirculation line, which will be detoured to outside the classified area and a 12” line will be inserted to ensure sufficient internal space to install the resistances.

### 3.1. Electrical Power

To assess the influence of recirculation on the decrease in required electrical power, a calculation was made, fixing the power to be used (Incropera, F.P, 1992). The power value is 100kW, which is the amount currently available in the laboratory. Therefore, knowing that the specific mass of water ($\rho$) is 1000kg/m$^3$, specific heat ($Cp$) is 4.18 kj/kg.K, the temperature variation is 30ºC; and considering the mean volume used in the tests 4m$^3$, it is possible to calculate the time needed for heating using the following equation (1):

$$100kW= 1000kg/m3 \text{ x } 4m3 \; t(s) \text{ x } 4.18 \; kj/kg.K \text{ x } 30K \tag{1}$$

t(s) = 1672,3s = 83,6mim

### 3.2. Simulation

The results obtained in simulations, using CFX software (ANSYS CFX, 2006) helped to better understand the effect of the power supplied by the electrical resistances to a specific area of the fluid (Creech, D, 1998).

The same conditions formulated in analytical development were used: fluid (water and air) initial temperature (30ºC), flow (6m$^3$/h and 12m$^3$/h), working pressure (0.5 bar), amount of heat supplied by the electrical resistances (100kW as a maximum) and the specification of the piping material (carbon steel).

Fig. 1 shows simulation images taken in CFX, in which the first uses water as fluid, where the arrows indicate the direction of the flow that passes through the piping; the red region indicates where there is greater heating through the resistances, whose variation is between 300 and 305 Kelvin. The fluid used in the second simulation was air, showing a change from 300 to 312 Kelvin.

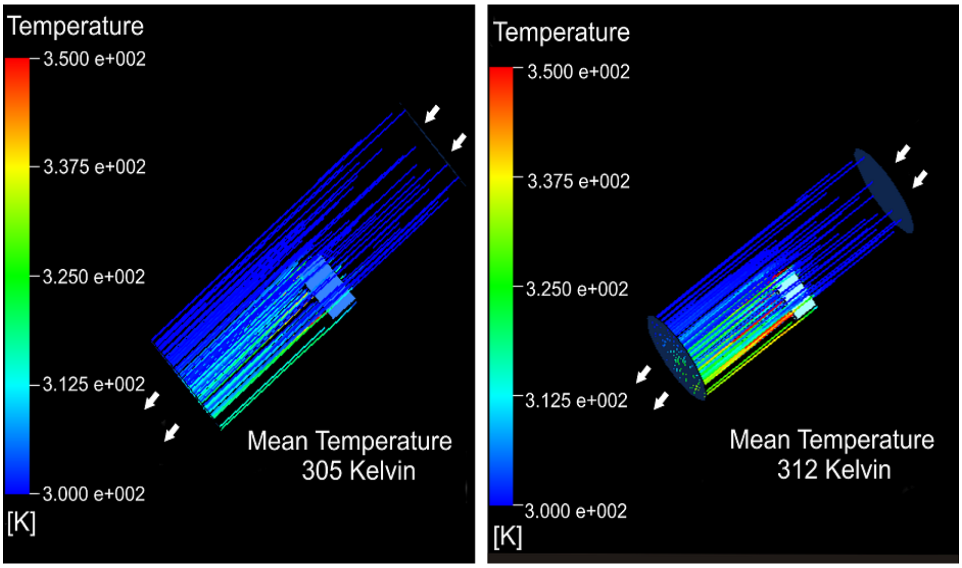


Fig. 1. Heating in 6 Water-Air Heating

For the following simulations water flow will be considered as an evaluation source. The maximum ($12m^3/h$) and half of the maximum flow ($6m^3/h$), respectively were used in LAMP and two resistances (Fig. 2).

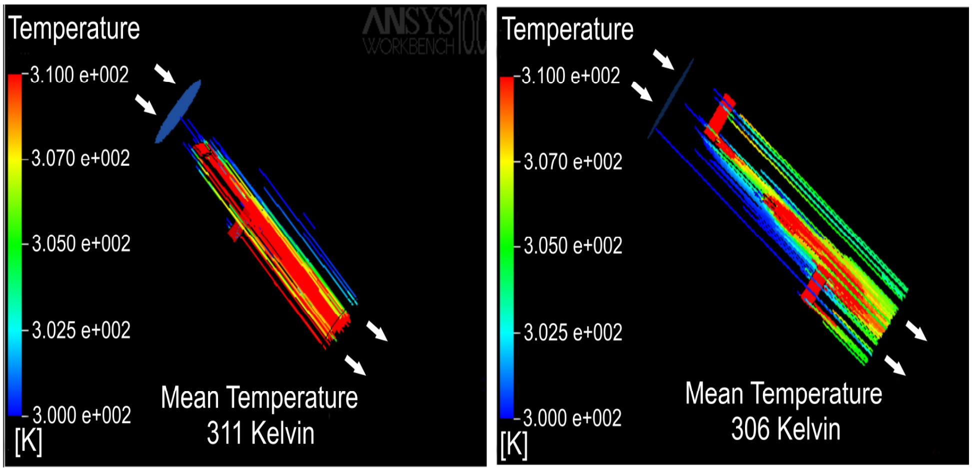


Fig. 2. Water-Air Heating 6m3/h and 12m3/h

The influence of flow on the heating system is very important, because for the greatest flow used in a test, less fluid heating occurred than with a lower flow, as shown in the figure above

### 3.3. Implementation

The piping system in the laboratory was adapted to perform the mechanical setup, which is located in the recirculation area of the mixing tank, Fig. 3


Fig. 3. Heating System

### 3.3. Communication system

A process controller was used to acquire the correct information about the system. The controller had four on/off outputs, one self-tuning PID control outlet, one analogue input, RS-485 communication and the Modbus protocol.

The transfer of these variables to the control room will be done by RS-485 communication, which is widely in industry. Data acquisition is distributed by the Modbus protocol, which aims at establishing master – slave client / server communication between intelligent devices (Fig. 4).

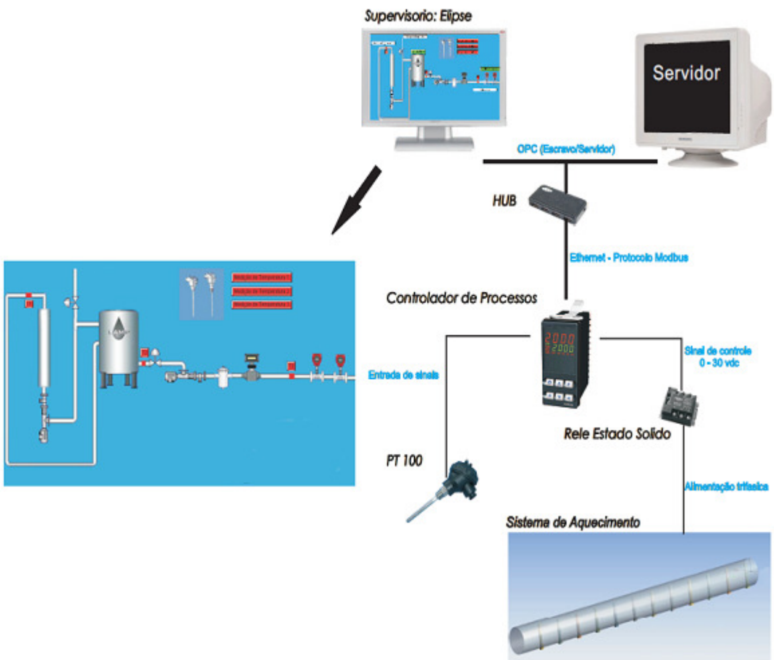


Fig. 4. Communication System

## 4. IMPLEMENTATION OF THE HEATING SYSTEM CONTROL

Traditional control systems (P, PD, PID) are the results of decades of research and one of the means used to obtain an ideal mathematical model of the process to be controlled. Restrictions are generally imposed, such as process linearization, that is, input variations produce proportional output variations. Fuzzy control offers an alternative to processes that do not have mathematical modeling or are complex (non-linear). In this case, a system based on empirical rules may be more efficient that one based on purely analytical expressions (Shaw, Ian S, 1999).
The control implemented was Fuzzy-PID, as shown in fig. 5.

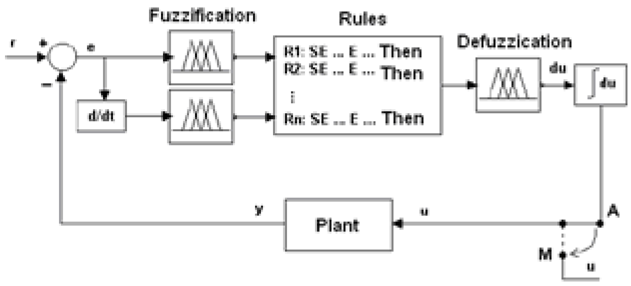


Fig.5 Fuzzy-PID Control

Control was implemented using LabView graphical programming language (Jurizato, Luís A, 2003). In addition to control, the program has a user-friendly graphical interface, see Fig. 6, that is responsible for supervising process variable, set point, fuzzy rules, alarms, serial communication, Modbus protocol.

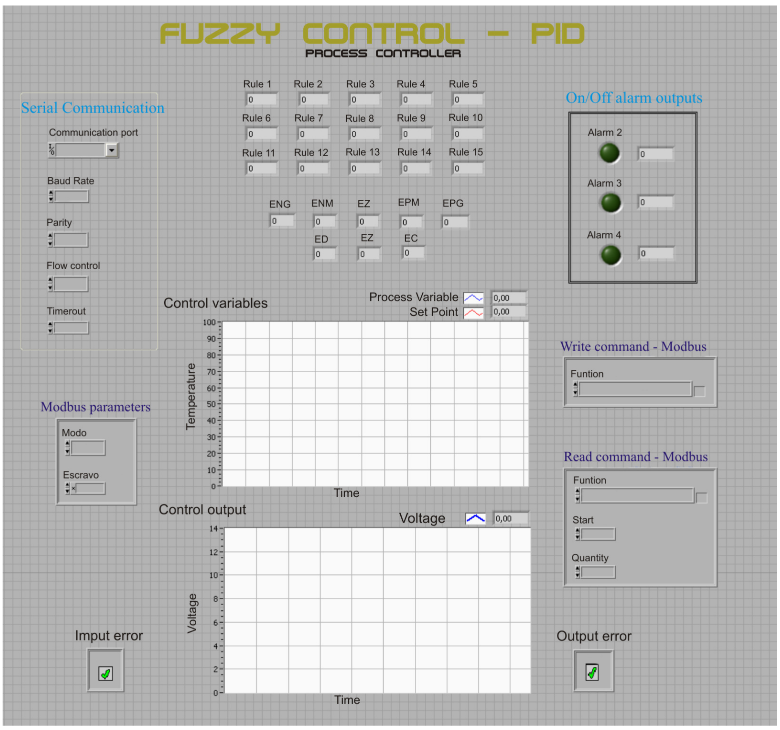


Fig. 6. Graphical Interface: Process controller

To implement the fuzzy system, triangular pertinence functions were used, five in the error and five in error variation, totaling 25 rules. Fuzzification was based on Mandani's min-max method; in the defuzzification stage, the method used was COM- center of maximums.

Figures 7 show the progressive behavior of the system to reach the target temperature, in this case 60ºC and to determine the behavior of the control signal

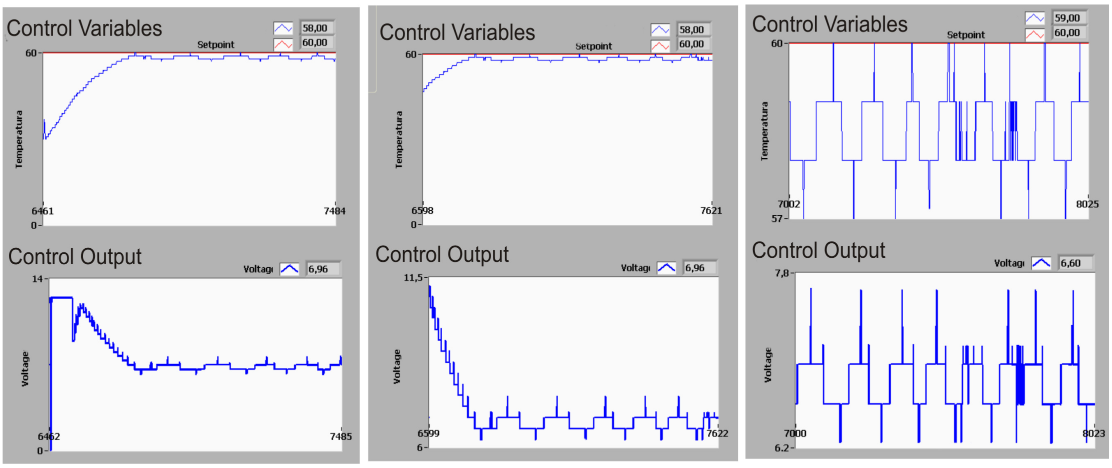


Fig. 7. Process the Fuzzy-PID control

For purposes of performance analyses, a comparison of the PID control (of the process controller itself) and the fuzzy-PID controller (implemented) will be presented. Accordingly, one hundred evaluations were conducted in the heating system, working with a sampling of five measures per second.

Figure 8 shows the behavior of the PID controller variables, where it can be observed that the rise time was around 571s for a temperature of 56ºC, illustrated in the first figure. The second figure shows total test time (1002s for a temperature of 57ºC).

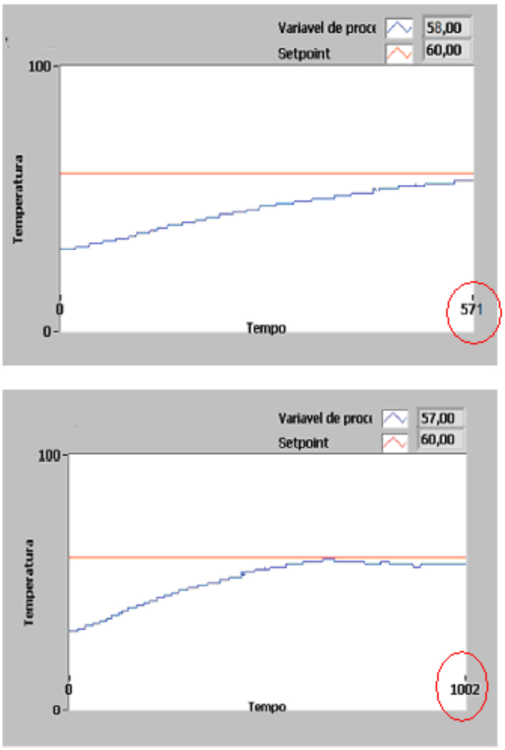


Fig. 8. PID control

The performance of the PID-fuzzy controller in relation to rise time is shown in figure 9 (401s for a temperature of 56ºC). The second figure shows total test time (1007s for a temperature of 57ºC).

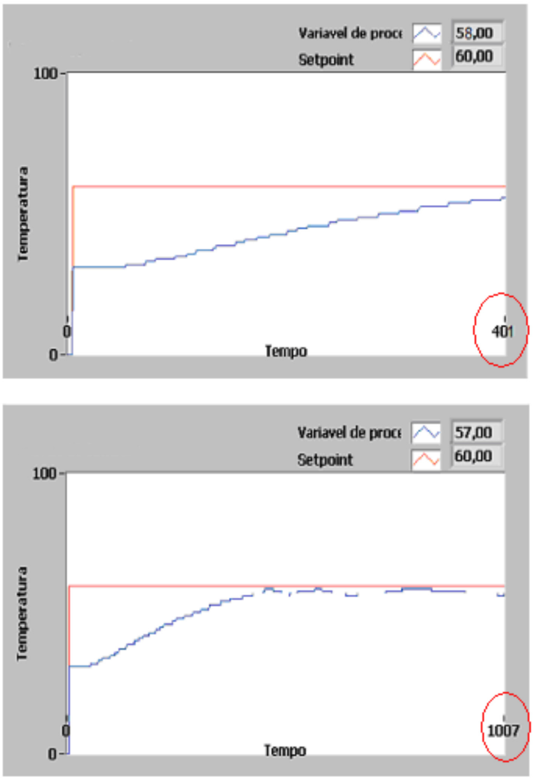


Fig. 9 Fuzzy-PID control

## 5. CONCLUSIONS

Temperature, an important variable that directly influences the calibration of flow and BS&W gauges, often has to be corrected to minimize uncertainty. These corrections must be made to be able to estimate the influence of normal temperature in the working field, compared to the normal temperature used in the test to which the gauges are submitted.

The immersion resistances were assessed with respect to laboratory requirements, and a number of simulations, under different circumstances, were performed. These simulations showed that they were an adequate alternative to the heating system of the laboratory.

The performance of fuzzy interference systems depends directly on several aspects related to its implementation structure. The number of sets associated to each variable, the shapes of the pertinence functions, implication functions, t-norm and t-conorm operators, defuzzification method, in addition to scale factors enable fuzzy controllers to have a vast actuation field, owing to its inherent non-linearity. This capacity, associated to its robustness, is being once again underscored, since the PID-fuzzy controller implemented plays an important role in the heating process, reducing response time in the system. Compared with a PID controller tuned by a same process controller, it promotes more uniform control, thus providing conditions for a final product with higher quality.

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