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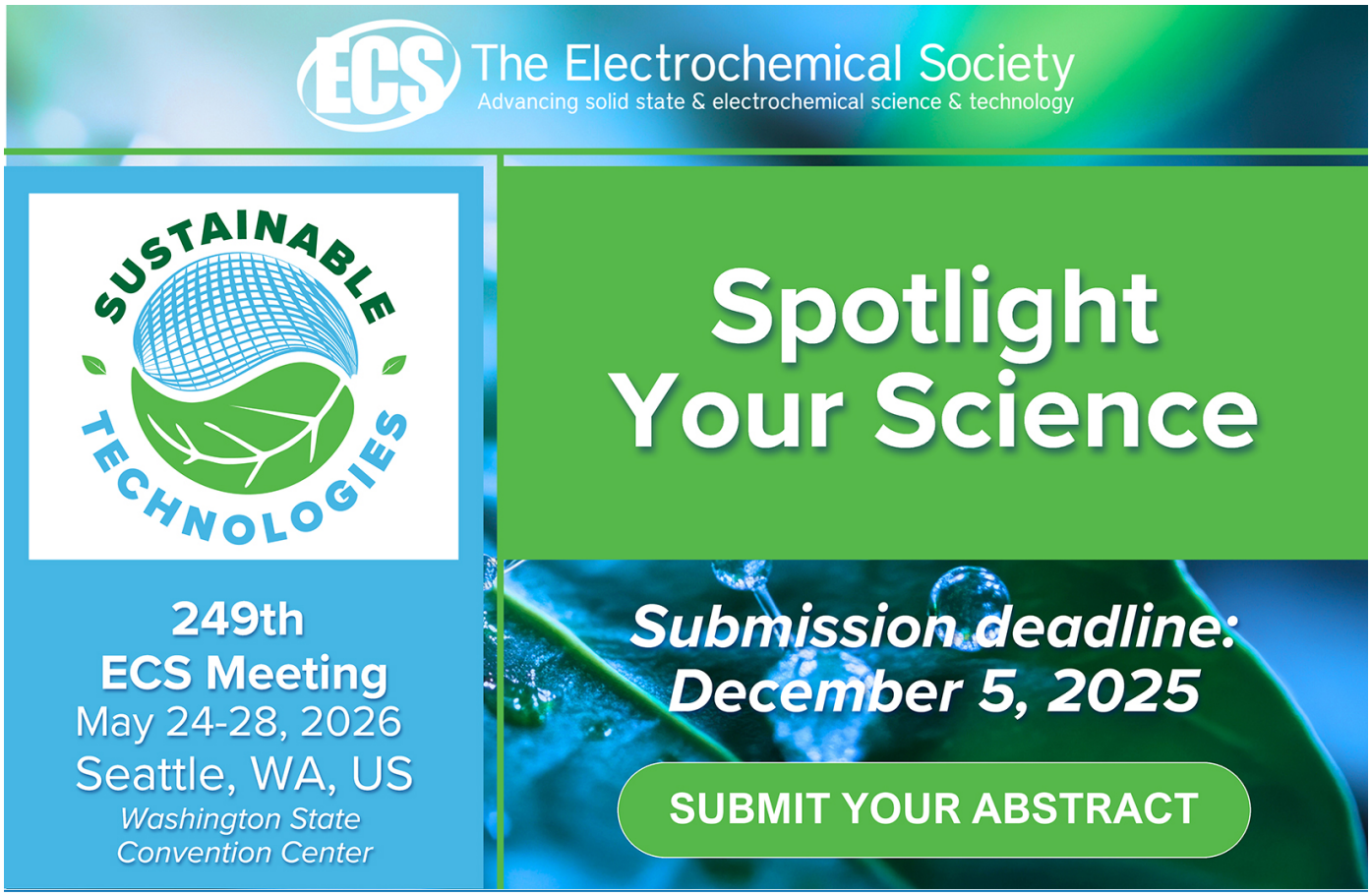
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# Design of a proportional integral derivative controller of temperature regulated for a nursery

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**Abstract.** This article describes the design and simulation of a proportional integral derivative PID controller that operates a proportional control valve to allow the flow of hot water to the radiant floor of a pig farm to maintain the required temperature. In the development of the project physical and mathematical concepts are required for controlling, the temperature oscillations in the range of 25 °C to 35 °C and the heat flux through the radiating surface of the floor, as well as analyzing the parameters involved for the development of the control system; In the control system design the characteristics and parameters involved in the pigs rearing by means of corral were identified; later the thermal analysis of the heating system integrated into the radiant floor that supplies heat to maintain the temperature was carried out, then the response of the temperature control system was simulated in the Scilab software and finally, the programming of the proportional integrative control was carried out. The design considers using gas generated in a biodigester to transfer thermal energy to the heating water that circulates through the floor, transferring heat to the brood module until it reaches and maintains the desired temperature using a control system that involves a proportional valve program in Arduino. The entire system was simulated by means of software including the gas and water circuits according to the heat transfer flow required to maintain the controlled temperature inside the module. The developed design allows controlling the heat flow to maintain the required temperature, stabilizing the process in 20 minutes.

## 1. Introduction

Automation is used in industry to design different types of controllers, including temperature controllers. Currently, the industrial market requires that its processes be adequately controlled and monitored [1]. Process control, which in its beginnings was restricted to sophisticated machines and very complex and expensive processes, is today in practically all human activities. The need to control processes is caused by various factors that can range from technical, economic, environmental to commercial; however, an aspect of great importance today is the development of controlled processes that guarantee the efficient use of energy [2].

Temperature controls are widely used in a wide variety of processes where there are differences in magnitude that generate heat flows. Since heat is the form of energy used for transformation into different types of work, it is necessary to monitor and control the temperature variations that finally become heat flows [3]. To take advantage of the heat flow and generate comfort in a process, it is necessary to guarantee control over the temperatures in the points or areas of importance, since the temperature difference and other aspects such as the materials and the environment generate non-linear characteristics and disturbances that affect heat transfer, disabling the operation or process entirely [4].

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The principle of underfloor heating is considered to maintain the temperature in a pig rearing pen, depending on the need based on the ages and growth stages of the animals [5]. Therefore, the objective of the work is to simulate the operation of a proportional integral and derivative (PID) controller that operates a proportional valve to guarantee the flow of heat to the radiant floor in a way that maintains the required temperature in the pig nursery. Initially, the characteristics and parameters involved in the rearing of pigs in the corral were identified, later the thermal analysis of the heating system integrated to the radiant floor that supplies heat to maintain the temperature was carried out, then the response of the temperature control system was simulated in the Scilab software and finally, the programming of the PID controller was carried out.

The hypothesis raised to control the temperature was verified by means of a PID that operates a proportional valve that regulates the flow of hot water according to the need for heat transfer to maintain the adequate temperature in the rearing of the piglets.

## 2. Materials and methods

The design of the PID controller to maintain the temperature in a pig nursery follow the proposed methodology in Figure 1.

### *2.1. Identify characteristics of the process*

The characteristics of the pig rearing process and the parameters required to maintain adequate temperature conditions in the hatchery based on the age or life stage of the animal were identified in three stages. Initially, the temperature in the nursery was determined according to the age of the piglet, later it was understood how the heating system works and finally the operating conditions of the underfloor heating. In the pig's nursery during the first weeks of the life of the piglets, they must be at an ambient temperature that provides adequate heat for the rapid growth of the pigs, in case of non-compliance it causes a delay in growth and even death; Table 1 stated the temperatures range from 18 °C - 35 °C [6].

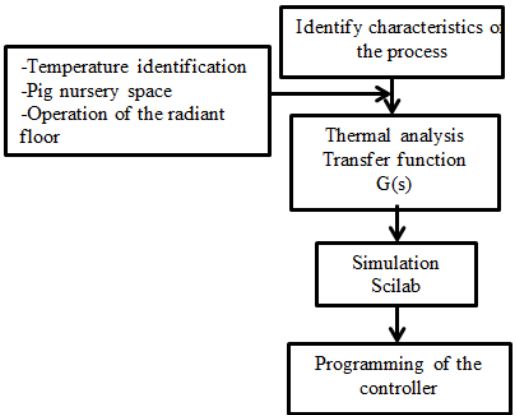



**Figure 1.** Block diagram representing the research development process.

**Table 1.** Temperature by life stages in pig nursery.

| Stage | Temperature |
|---|---|
| Boars-pregnant | 18 °C - 21°C |
| Maternity | |
| Birth | 21°C - 22°C |
| Lactation | 19 °C - 20°C |
| Piglets | |
| Birth 48 h | 35 °C |
| 1 week | 31 °C |
| 2 weeks | 29 °C |
| 3 weeks | 27 °C |
| 4 weeks | 25 °C |
| Fattening | 18 °C - 20 °C |

It was considered a kennel with an area on the floor of 33 m² composed of four pens; radiant floor heating works through a network of plastic pipes through which hot water circulates over the entire surface. The operating cycle of the system begins with the combustion of the fuel (biogas) produced by the biodigester. This combustion is carried out by the burner of the water heater in a controlled way, adapting the fuel input to the heat demand, heating a fluid that circulates through the closed heating circuit. The hot fluid is called carrier heat and in this type of installation it is water. The heat carrier fluid receives this name because it is responsible for transporting the thermal energy that it acquires in the water heater to the emitter in the form of underfloor heat.

The water comes to the water heater from a tank located in the upper part of the structure usually found on upper floors, the energy in the radiant floor, after going through all the pipes installed on the floor, the carrier heat is deposited in a second tank located at level of the floor, the water is subsequently pushed back to the first tank, by means of a pump and thus form a closed circuit. Figure 2 shows the process diagram corresponding to the closed cycle of the heat carrier fluid; once in the emitting element, the heat carrier fluid transfers heat to the radiant floor and from this it is transferred to the air that surrounds it by means of convection. In this way the temperature of the water at this point of the closed cycle decreases and the ambient temperature of the room increases due to the principle of heat transfer.

The basic principle of the heating and cooling system using radiant surfaces consists of the impulsion of water at medium temperature (around 40 ºC in winter and 16 ºC in summer) through circuits of plastic pipes made mainly of polyethylene. Figure 3 shows the operating diagram of the heat emitting source through the form of underfloor heating; to generate the heat that is transferred to the heat carrier fluid, the system uses a gas heater whose operating scheme. The system is designed so that the heater works with the biogas generated by a biodigester; when water is consumed, the diaphragm presents a decrease in pressure and moves upwards so that the valve allows the passage of gas to the burner according to the torque previously given to the adjustment screw. In its operation, the heater does not have the option of monitoring the temperature reached by the fluid to determine if the operation of the brood module is adequate.

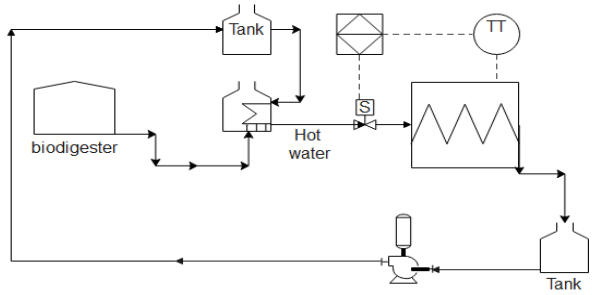



**Figure 2.** Process diagram closed cycle of the heat carrier fluid.

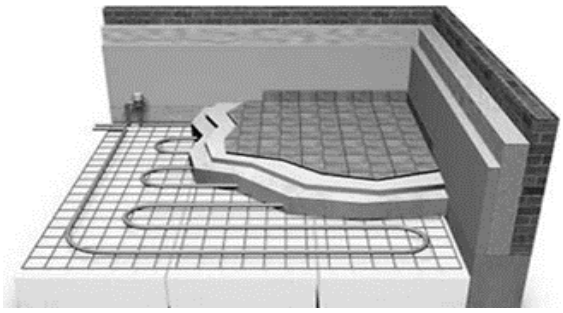
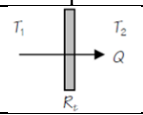
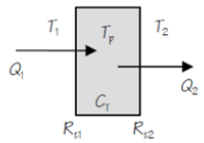


**Figure 3.** Underfloor heating scheme.

*2.2. Thermal analysis (transfer function)*

Thermal systems are those that involve the transfer of heat from one substance to another, these systems are analyzed in terms of resistance and capacitance, to achieve an accurate analysis, distributed parameter models must be used. However, to simplify the analysis, it will be assumed here that a thermal system is represented by a concentrated parameter model, that substances characterized by a resistance to heat flow have negligible thermal capacitance and that substances characterized by a thermal capacitance have negligible resistance to heat flow [7]. In Table 2 shows the equations used to determine heat transfer according to the mathematical models proposed by [8].

**Table 2.** Equation heat transfer for mathematical modeling.

| | Graphical representation | Fundamental equations |
|---|---|---|
| Thin wall (does not absorb heat) |  | $T_1 > T_2: Q = \frac{T_1 - T_2}{R_1}$ |
| Thick wall (with heat storage) |  | $\Sigma Q = C_t \frac{dT}{dt}$<br>$Q_1 = \frac{T_1 - T_2}{R_{t1}}; Q_2 = \frac{T_p - T_2}{R_{t2}}$<br>$Q_1 - Q_2 = C_1 D T_p$ |

According to Table 2 and the calculation of the global heat transfer to the nursery, the transfer function is represented by the Equation (1).

$$G_{(s)} = \frac{Y_{(s)}}{U_{(s)}} = \frac{1}{a_1 s^3 + a_2 s^2 + a_3 s + a_4}. \quad (1)$$

For a floor of 33 square meters, 120 meters of plastic pipe and concrete of 0.05 meters thick, the Equation (1) of the plant results in Equation (2).

$$G_{(s)} = \frac{Y_{(s)}}{U_{(s)}} = \frac{1}{4{,}479*10^{-7}*s^3 + 2{,}288*10^{-3}*s^2 + 2{,}490 \quad s + 611{,}458}. \quad (2)$$

*2.3. Simulation*

Considering the amount of heat supplied by the chemical energy of the gas in the water heater, it is necessary to design the controller that allows the flow of hot water through the interior piping of the radiant floor. This flow must be in accordance with the variation of the temperature in the environment, for which, it is arranged to use a proportional integral derivative PID control, which will receive the signal from a temperature sensor and compare it with the temperature set in the setpoint, depending on error, will make the necessary adjustments to open or close the control valve.

A feedback control system (active) was designed, which operates when the controlled variable communicates continuously with the reference signal and any difference produces an action that tends to reduce the existing deviation. In other words, the control action performed by the control system always depends on the value of the controlled variable therefore, it also takes the name of dynamic control [8]. The Figure 4 shows the block diagram schematic of the feedback control system.

The objective of installing and operating the feedback control system is to ensure that the temperature established in the setpoint remains constant. To control the operation of the gas water heater, an open loop control system was designed, the valve controls the flow of water to the radiant floor, the greater the need for water flow makes the gas valve located inside the heater to open and increase the outlet water temperature. The Figure 5 shows the block diagram schematic of the open loop control system used in the gas heater [9].

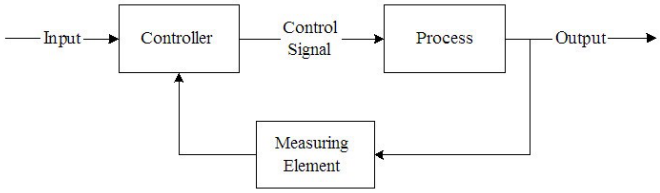



**Figure 4.** Feedback control system block diagram.

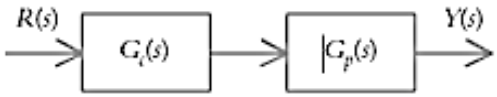



**Figure 5.** Block diagram open loop control system.

The study of the response of a system then consists in determining the response (y) that the system produces before an input (u). The response of a system will then depend on the equation and the excitation applied to it. For the analyzed system, the evaluation of the response was carried out by means of a step input, where the input undergoes an instantaneous and finite change; this can be expressed as the Equation (3) proposed by [10].

$$U(t)=0 \text{ para } t < 0 \text{ ; } H \text{ para } t > 0. \quad (3)$$

Or expressed in place transform as the Equation (4) [10].

$$U(s) = \frac{H}{S}, \quad (4)$$

where H is a constant; when H is equal to 1 the input is said to be a step. The step function is the simplest of the inputs that can be applied to a system, and this is usually the most used because it allows simple analysis of the response of the system. This allows defining the response of the system when the changes are instantaneous and then are maintained over time.

The response of the regulator (PI) is the sum of the responses due to the proportional control (P), which is instantaneous upon detection of the error signal, with a certain delay the integral control (I) in charge of completely canceling the error signal that is mathematically represented by Equation (5). The proportional action opens the control valve, increasing the flow of hot water until the floor reaches the setpoint temperature; once it is reached, the proportional action keeps the temperature stable, sending the signal for gradual closing and opening of the valve to cancel the error. In Equation (6) it represents the proportional-integral derivative function as a function of time [11].

$$m(t) = K_p e(t) + K_I \int_0^t e(t)dtoF(s) = \frac{M(s)}{E(s)} = K_p + \frac{K_I}{s}, \quad (5)$$

$$m(t) = K_p \left[ e(t) + \frac{1}{T_I} \int_0^t e(t)dt \right], \quad (6)$$

where $T_I = \frac{K_P}{K_I}$ is the integral action time.

In the mathematical modeling, an equation of the transfer function of the higher order plant was obtained, this complicates the tuning of the PID; for this reason, SCILAB 5.2.2 was used. The plant is modeled by means of a closed-loop block diagram.

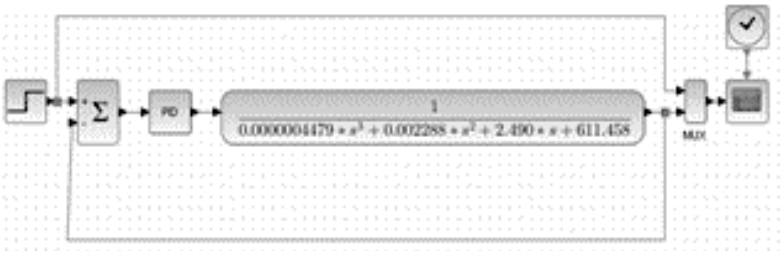



**Figure 6.** Plant diagram in ZCOS – SCILAB.

*2.4. Proportional integrative control configuration in Arduino*

The Arduino platform provides a library for the implementation of a PID control loop without having to create it from scratch, this simplifies the implementation within the firmware, making the code simpler and occupying less memory in the system [12].

In this project the PID controller has been implemented, to control the valve, through this device the flow of hot water that must circulate through the plant has to be controlled, the sensor sends the data to the controller, depending on the error between the data of temperature sent by the sensor and the temperature value established in the setpoint, the controller will send the order to open or close the valve so that the plant can reach the setpoint temperature and maintain that value constant.

In the configuration, a series of values must be determined for the PID to work, which are the constants of the proportional, integral, and derivative processes themselves, for the control of a temperature sensor, the SetPoint is also configured, which is the limit point from which the PID begins to perform the calculations; the values are defined below.

- Kp: constant of proportionality, in our case it is set to 1.
- Ki: integral constant, setto a value of 2.
- Kd: derivative constant, it is set to a value of 0.
- SetPoint: this value is set at 30 °C, which is the comfort temperature where the hatchlings are comfortable.

## 3. Results

With the values shown in the Figure (7), the response of the controller reaches the 2% band and stabilizes 20 minutes after starting the process, this means that the radiant floorwill provide the comfort temperature that the piglets need in their first weeks of life; as can be seen in the Figure (7), band after 20 minutes and then remains within that band in a stable way. The response enters the 2%. The use of a proportional control valve allows the hot water flow to be adjusted in proportion to the floor requirement to reach and maintain the setpoint temperature.

Routh's criteria were verified, and the system is stable, generating no confidence for its operation. The use of a proportional control valve allows the hot water flow to be adjusted in proportion to the heat flow requirement for the underfloor heating to reach and maintain the temperature set in the nursery.

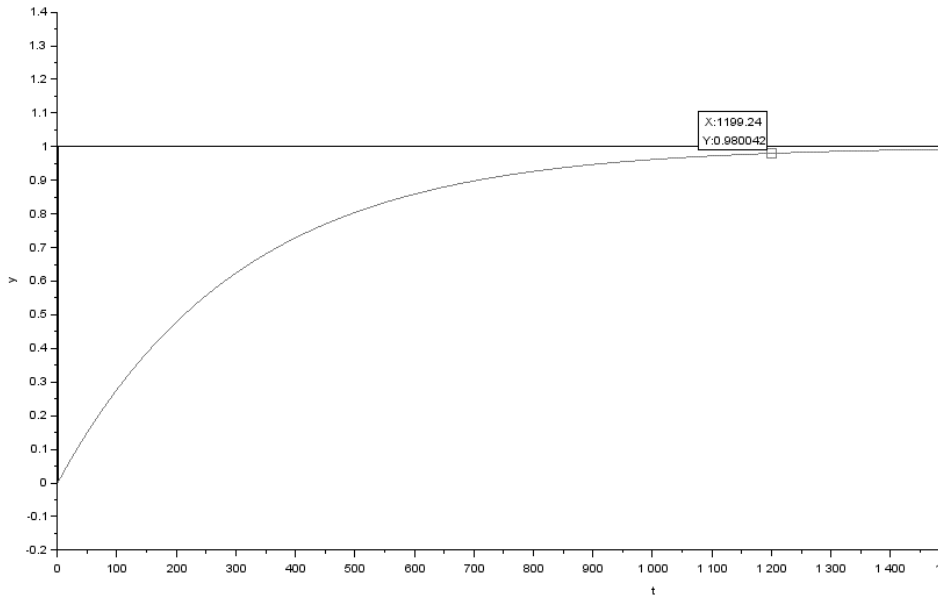



**Figure 7.** Response of the SCILAB system.

## 4. Conclusions

The response of the modeling in SCILAB is slow, but it is within the expected times for a radiant floor heating. According to the modeling, it is guaranteed that the setpoint temperature is reached within 20 minutes of starting the process, also the PID values avoid an overheating of the plant that can occur in a rapid response from the controller. With the use of a control card (ARDUINO MEGA 2560 microcontroller) it can be linked and through a programming language such as ARDUINO IDE, it receives the signal from the SD18B20 temperature sensor, the controller interprets the data and calculates it with the PID values, sending the signal manipulated by a servomotor which performs the gate valve opening and closing control, thus automating the entire process until reaching the setpoint signal and keeping it stable.

Safety in the facilities, since the automated system is in charge of switching the plant on and off, it would no longer be necessary for an operator to manipulate the ignition of the burners.

Through this work, an excellent alternative is proposed for saving energy, since the biodigester would be available for the generation of fuel gas. With the use of this autonomous system, security is also provided to the personnel in charge of caring for the animals, since they would no longer have to manipulate the gas burners. The use of mathematical modeling and technological tools such as SCILAB software is of great help to determine the behavior of the plant before the physical construction of the system.

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