HEATING CONTROL SYSTEM FOR EXPERIMENTAL BIOGAS FERMENTORS

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Abstract: Proper temperature is needed to assure the right conditions for microorganisms producing the biogas. Mesophilic temperature range is 30–35°C. The goal was to design a device that can log the temperature and control the heating bath temperature at desired level with maximum setpoint overshoot of 0.5°C and temperature stability of ±0.2°C. The system identification was used to design and simulate control algorithm (PSD) of the heater in the Matlab Simulink software.

Key Words: Raspberry Pi, UniPi, Python, Matlab, Simulink, PID, PSD

INTRODUCTION

The Republic reference laboratory of biogas transformations is used to perform various tests of biogas production. One of experimental systems is the set of reactors with volume of 3 dm^3 of material.

Proper temperature is needed to assure the right conditions for microorganisms producing the biogas. Methane is produced at temperatures from 0–80°C. The anaerobic archaea can be divided in three groups. Psychrophilic (20°C), mesophilic (20–40°C) and thermophilic (50–60°C). The largest amount of anaerobic archaea is present in mesophilic environment at 30–35°C and in thermophilic environment at 50–60°C. (Gerardi 2003)

The goal was to design a device that can log the temperature and control the heating bath temperature at desired level and that has better temperature stability control than the actual one. Maximum setpoint overshoot required was 0.5°C. Temperature range was set for mesophilic tests. Required temperature stability was ±0.2°C. These requirements were set to improve the current state and to test the possibilities of the used hardware.

MATERIAL AND METHODS

Current state

The whole experimental system consists of several parts. The reactors are made out of glass bottles and are placed in the plastic tank isolated with polystyrene on the outside. This tank filled with distilled water is used as a heating bath. Plastic tank has volume of 50 dm^3 and the bath uses 27 dm^3 of water. Typical experiment uses 6 to 8 reactors in the heating bath. Temperature control uses capillary thermostat with 2°C hysteresis. The heater has a power of 600 W. There is also a pump used to circulate the water and to even the temperature in the bath. Each reactor has volume of 3 dm^3 of material.

Used hardware and methods

Whole temperature control and logging was done using Raspberry Pi (https://www.raspberrypi.org/ – Raspberry Pi foundation) computer with UniPi (http://unipi.technology – UniPi expansion board) expansion board. This board allows using 1-wire DS18B20 digital temperature sensors and has digital outputs and inputs ready for use with other hardware. Temperature sensor has output resolution of 0.05°C and 0.5°C accuracy. It was calibrated using the Omega CL26 temperature calibrator with 0.1°C accuracy.

To control output power of the heater the duty cycle control was used. This method is basically PWM with 10 s period. Using this method the power can be controlled from 0 to 100%. According to needed power the heater is set at full power for certain part of the cycle length. Full power is represented by full 10s time, 50% by 5s, 11% by 1.1s and so on. To control the heater the zero-crossing solid state relay switched on by the digital output of UniPi board was used.

Discrete PID (PSD) control algorithm (Franklin et al. 2005) was used as a method of temperature control.

Control algorithm was implemented in Python 3.2 (https://www.python.org/) language that communicates with evok (https://github.com/UniPiTechnology/evok – evok gihub repository) API that is used for communication between Raspberry Pi and UniPi board. Control program also logs the temperature every 5s. Object oriented programming was used to create entire control program.

System identification was needed to design proper temperature control. This was done using the heater in the bath with the reactors heating at full power. The step response of the system was obtained this way by logging the temperature rise in the bath every 5s. This system can be described as system with one energy storage (Noskievic 1999), hence it can be approximated with first order continuous transfer function with transport delay (1) in Laplace transformation.

$$G_s(s) = \frac{K}{Ts+1} \cdot e^{-T_d s} \tag{1}$$

RESULTS AND DISCUSSION

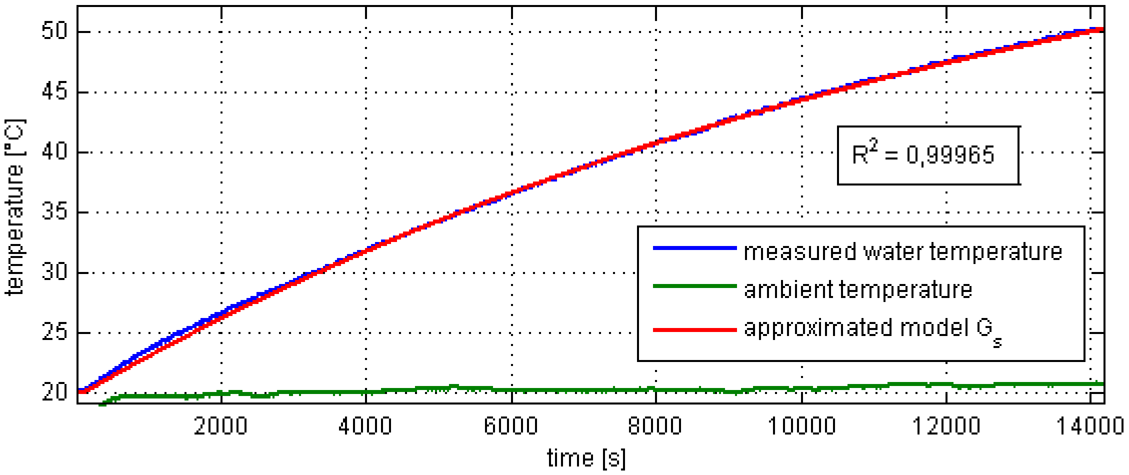
System identification

The whole response was not measured because of the pump temperature limitations. System identification was done in Matlab 2014a. The system was approximated with first order system transfer function with transport delay. (Ahmed et al. 1999) Transport delay was 100 s. The transfer function G_s is in equation (2).

$$G_s(s) = \frac{46}{13200s+1} \cdot e^{-100s} \tag{2}$$

Step response of the system with approximated system is in Figure 1.

Figure 1 System identification



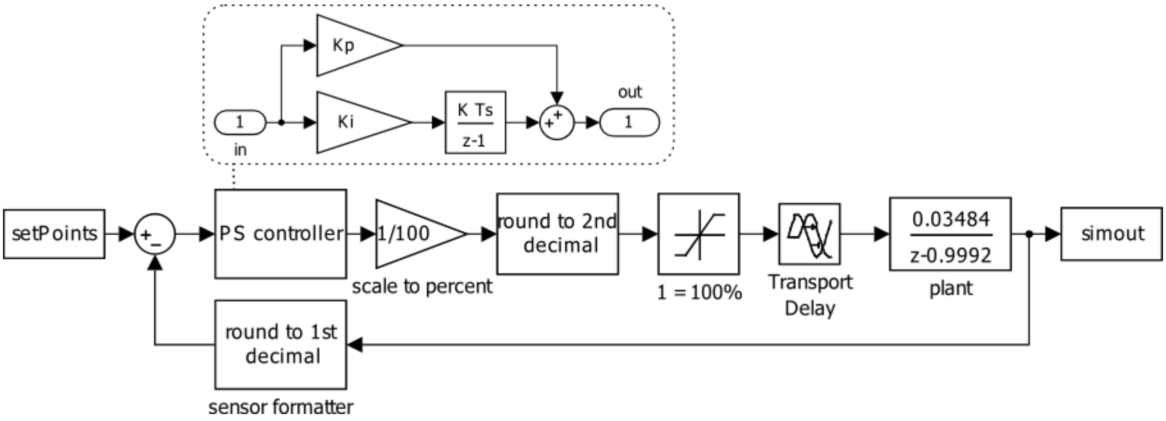
For the purpose of simulation the identified continuous system was discretized using Z transformation in Matlab 2014a software using *c2d* function. Sample time was set to 10s. Discrete-time transfer function of the system is in equation (3).

$$G_s(z) = \frac{0.03484}{z-0.9992} \tag{3}$$

Simulation and control algorithm design

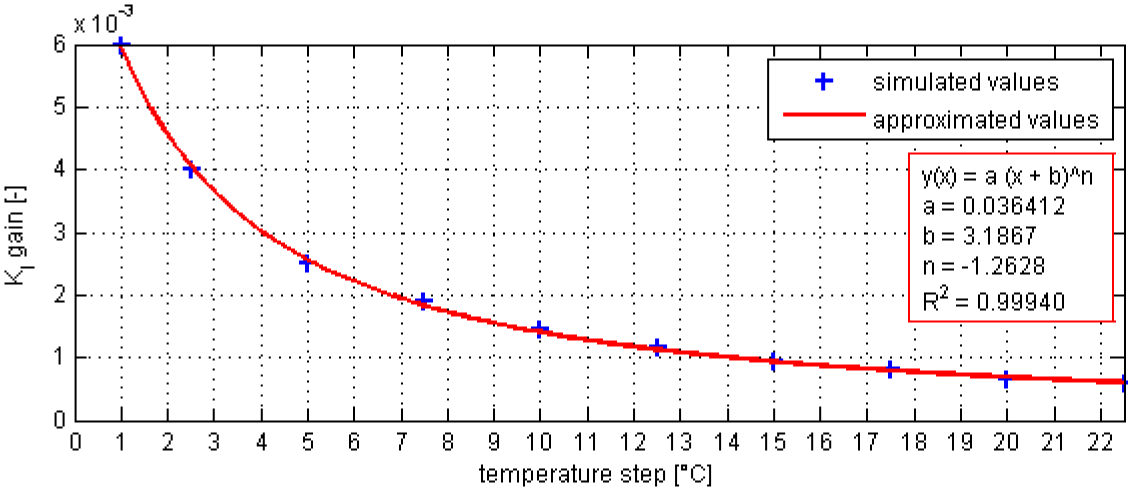
Simulation was done in the Matlab 2014a Simulink software. The block diagram can be seen in Figure 2. Blocks rounding signal were added to represent actual values coming from the temperature sensors. Controller saturation was added to simulate power limit of the heater. Derivative part (of controller was not needed hence only the PS version of controller was used. This kind of control is usual for this type of systems. (Sulc, Viteckova 2004).

Figure 2 Simulink block diagram



For the first K_P and K_I gain estimation the *PIDtool* function in Matlab was used. Proportional and integration gain constants were found to have maximum overshoot of 0.2°C at 20°C step (step up from the current temperature). After initial simulation the K_P gain was set to 24. To meet the criteria of constant overshoot for every step size the K_I gain values were simulated for steps of 2.5–22.5°C with 2.5°C step. Approximated K_I gain function for temperature steps is in Figure 3. This function is used for every step size in the control algorithm to find and set the K_I gain.

Figure 3 Approximation of K_I gain function



The main control algorithm uses 10s loop in which the temperature is measured, the new output for the heater is calculated and measured temperatures are written to the log file. Every time the setpoint is changed (typically by the user) the new K_I gain is computed from the approximated function (Figure 3). Only this way the constant overshoot for any temperature step size can be achieved. If the fixed K_I constant is used the setpoint overshoot rises with the step size. This is caused mainly by the saturation of the controller output (the heater has finite maximum power).

Simulated temperature control and actual measured data are in Figure 4 and Figure 5. Figure 4 shows constant overshoot for setpoint change (30°C, 35°C, 40°C, 42°C) every 4 hours. Figure 5 shows difference between simulated control and actual measured data for 45°C setpoint.

Figure 4 Simulated steps and measured temperature

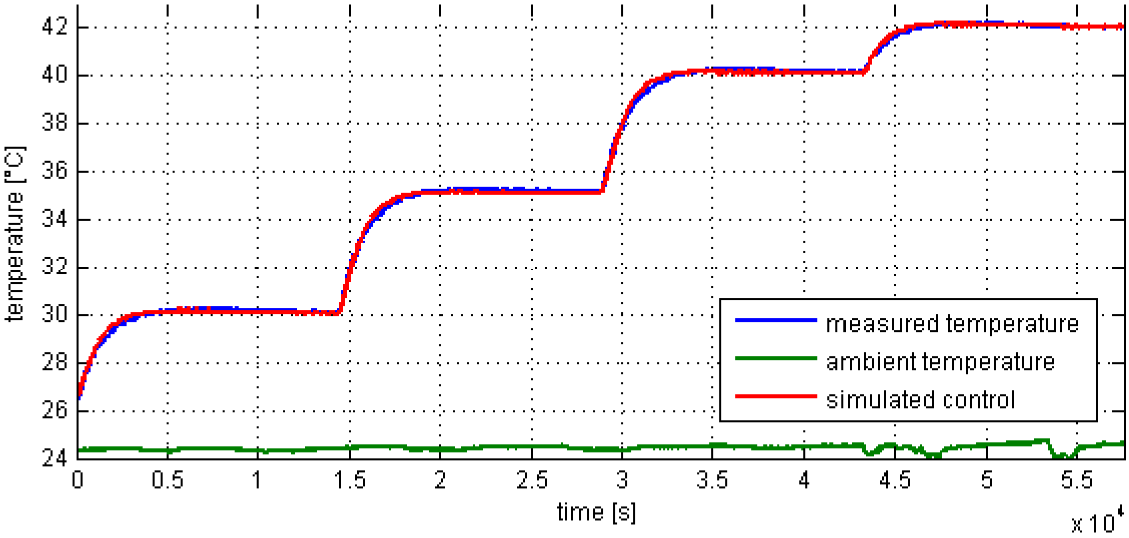
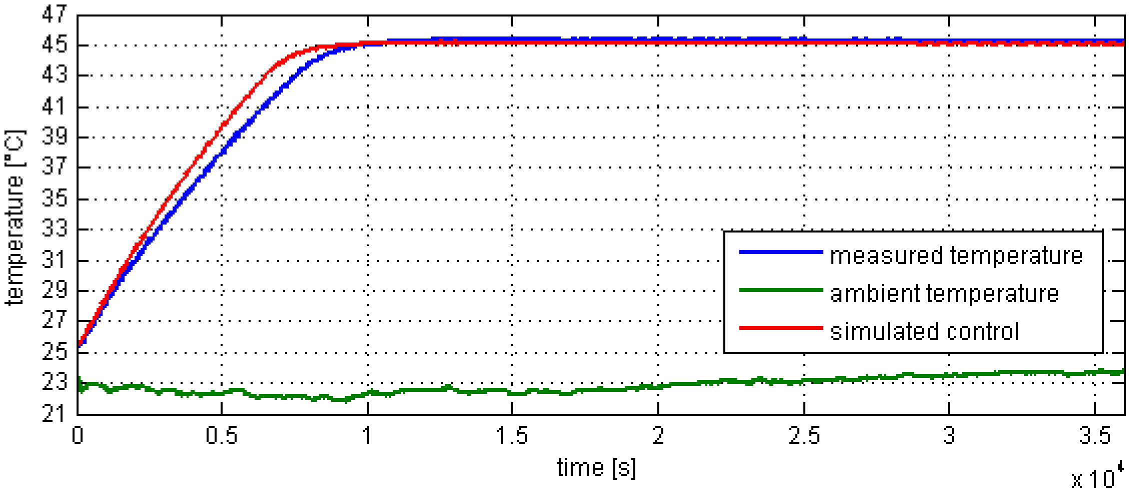


Figure 5 Temperature control for 45°C setpoint (20°C step)



CONCLUSION

Heating control system for experimental biogas fermenters was described. Using the system identification and simulation the control algorithm was designed and implemented. This device was based on the Raspberry Pi computer running Raspbian linux with UniPi expansion board. Control program was written in Python 3.2 language using object oriented programming.

The setpoint overshoot was simulated to be 0.2°C. Maximum measured overshoot was 0.45°C for 20°C step size. Time to reach setpoint was 799 s longer than in simulation (Figure 5). Maximum setpoint overshoot for 5°C steps was 0.25°C for every step and time to reach the setpoint was 800s longer than in simulation for the first step setpoint (30°C) and 60s longer for next setpoints (35°C, 40°C, 42°C).

After reaching the overshoot maximum the temperature lowers down to the setpoint where it stays with the ±0.1°C stability. All the requirements for the device were met.

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