Water Circuits Lab

Sensor Systems B232-E141030

May 23, 2024

1 Introduction

This lab simulates a water tank filling system with adjustable parameters for flow rate, heater power, and fan power. The purpose is to demonstrate the effects of heat on water properties, such as temperature and volume, and how these changes impact the water level and flow rate over time. Various sensors are used to measure the system's behavior, providing a comprehensive understanding of the water circuits.

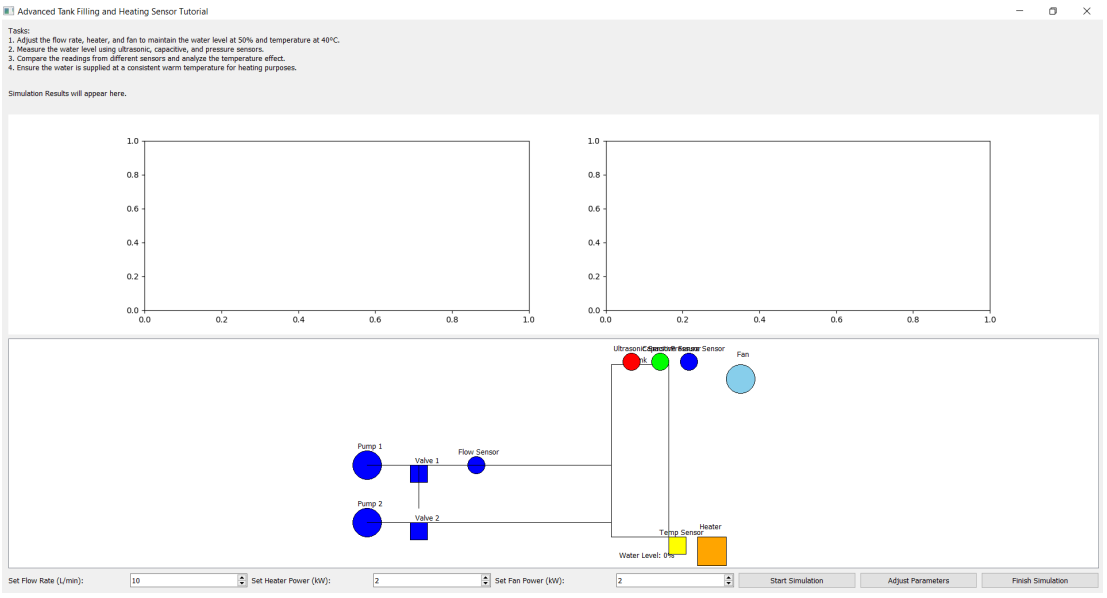

Figure 1: Lab tutorial

2 Objectives

1. Adjust the flow rate, heater, and fan to maintain the water level at 50% and temperature at 40°C.
2. Measure the water level using ultrasonic, capacitive, and pressure sensors.
3. Compare the readings from different sensors and analyze the temperature effect.
4. Ensure the water is supplied at a consistently warm temperature for heating purposes.

3 Theory

The simulation models the following aspects of the water circuit:

3.1 Flow Rate

The flow rate Q (in L/min) is the amount of water entering the tank per unit time. A pump controls it and can vary non-linearly over time:

$$Q(t) = Q_0 + 0.5 \sin(0.1t)$$

where Q_0 is the initial flow rate set by the user.

3.2 Heat Transfer

The heater adds heat to the water, while the fan removes heat. The net heat transfer ΔQ affects the water temperature:

$$\Delta Q = P_{\text{heater}} - P_{\text{fan}}$$

where P_{heater} and P_{fan} are the power of the heater and fan in kW, respectively.

The change in water temperature ΔT is given by:

$$\Delta T = \frac{\Delta Q \cdot 1000}{m \cdot c}$$

where m is the mass of the water in kg, and c is the specific heat capacity of water (4.18 kJ/kg°C).

3.3 Thermal Expansion and Water Level Changes

As water temperature changes, its volume changes due to thermal expansion. The volumetric thermal expansion coefficient α for water is approximately $0.000214\,^{\circ}\text{C}^{-1}$. The change in volume ΔV due to a change in temperature ΔT can be calculated as:

$$\Delta V = V_0 \cdot \alpha \cdot \Delta T$$

where V_0 is the initial volume of water.

The corresponding change in water level ΔH in the tank is:

$$\Delta H = \frac{\Delta V}{A}$$

where A is the cross-sectional area of the tank. Therefore, the water level H at any time can be expressed as:

$$H = H_0 + \Delta H$$

where H_0 is the initial water level.

3.4 Summary of Water Level Changes

The heater increases the water temperature, causing the water to expand and the water level to rise. Conversely, the fan decreases the water temperature, causing the water to contract and the water level to fall. These effects, combined with the flow rate changes, determine the overall water level in the tank.

4 Simulation Setup

4.1 Running the Simulation

1. Ensure Python and the necessary libraries (`numpy`, `matplotlib`, `PyQt5`) are installed.
2. Run the python file named `water_circuits.py`.

4.2 Using the Simulation

1. Adjust the flow rate, heater power, and fan power using the provided controls.
2. Click "Start Simulation" to begin.
3. Monitor real-time data and plots to observe changes in flow rate, water level, and temperature.
4. Adjust parameters during the simulation to see their immediate effects.
5. Click "Finish Simulation" to stop and review the final results.

5 Analysis

5.1 Flow Rate and Water Level

The flow rate affects the water level in the tank. As the flow rate changes non-linearly over time, it impacts the rate at which the tank fills. The relationship can be observed in the flow rate and water level plots.

5.2 Temperature Effects

The heater and fan impact the water temperature. As the temperature increases or decreases, it affects the water's volume due to thermal expansion. This relationship is visualized in the temperature plot. The mathematical relationship is given by:

$$\Delta V = V_0 \cdot \alpha \cdot \Delta T \quad \text{and} \quad \Delta H = \frac{\Delta V}{A}$$

5.3 Sensor Readings

Different sensors provide various perspectives on the water level and temperature:

- **Flow Sensor**: Measures the rate of water entering the tank.
- **Ultrasonic Sensor**: Uses sound waves to measure the water level.
- **Capacitive Sensor**: Measures water level based on capacitance changes.
- **Pressure Sensor**: Measures the pressure at the bottom of the tank, related to water level.
- **Temperature Sensor**: Measures the water temperature.