**ECE 560**

**Title: Raw Water Alum Application pH Controller**

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1. **Introduction:**

Water treatment is a vital process that ensures water is safe and suitable for human consumption and various industrial applications. The quality of water affects not only health and safety but also the efficiency of industrial processes. Ensuring that water is free from contaminants and maintains a balanced pH level is fundamental to these objectives. The water treatment process typically involves a series of carefully coordinated stages: coagulation, flocculation, and sedimentation.

One of the critical challenges in the water treatment process is maintaining an optimal pH level. The pH affects the effectiveness of the coagulation process and overall water quality. Controlling the pH involves adjusting the alum dosage accurately, as the alum reacts with water to form acidic by-products that can lower the pH. This project focuses on the design and implementation of a control system for a water treatment process that dynamically regulates the alum dosage to maintain the desired pH. This control system incorporates a state observer to estimate internal system variables, providing a more informed basis for control decisions. The use of modern control theory, including state-space modeling and feedback control, enables more precise regulation and system stability. Ultimately, this project aims to demonstrate how advanced control methods can improve the efficiency and reliability of water treatment processes.

2. **Physical System Overview:**

The water treatment system is modeled using a state-space representation that includes three main processes: coagulation, flocculation, and sedimentation. The goal is to control the alum dosage to achieve a desired pH level at the system's output.

A screenshot of a computer

Description automatically generated

**2.2 Flocculation**

Flocculation is the process that follows coagulation, involving the gentle stirring of water to promote the agglomeration of micro-flocs into larger, denser particles called flocs. Slow and controlled mixing is used to encourage collisions between micro-flocs, allowing them to combine and grow into larger flocs.The mixing must be gentle to avoid breaking the flocs apart.

**Purpose: The larger flocs formed in this stage are easier to settle during sedimentation, aiding in the removal of suspended particles.**

**2.3 Sedimentation**

Sedimentation is the final stage in this sequence where the flocs formed during flocculation are allowed to settle at the bottom of a sedimentation tank under the influence of gravity. The water remains still in a sedimentation tank for a specific detention time, allowing the heavier flocs to sink to the bottom.Clear water rises to the top and can be collected for further treatment or distribution.

**Purpose: This process significantly reduces the concentration of suspended solids, leaving clearer water that is more suitable for filtration and further treatment.**

1. **State Space Model:**

**3.1 State Variables:**

* + Concentration of suspended solids (mg/L)
  + : Concentration of flocculated solids (mg/L)
  + pH level of the water (dimensionless)

**3.2 Inputs to the system include:**

Alum Flow Rate : The rate of inflow of alum into the system (m³/s).

**Outputs**

* : Effluent suspended solids concentration (mg/L)
* : pH level of the water (dimensionless)

**3.4 Suspended Solid Dynamics :**

where,

: Flocculation reduces Suspended solid

: Alum dosing reduces suspended solids

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* 1. **Flocculated solid Dynamics :**

where,

: Flocculation increases flocculated solids

: Sedimentation decreases flocculated solids

* 1. **PH level Dynamics :**

where,

: Flocculation increases flocculated solids

: Alum dosing affects the PH level

**Nominal Value of Constant from research**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **k1** | **k2** | **K3** | **K4** | **K5** |
| **0.0166** | **0.01** | **0.0.008** | **0.5** | **0.05** |

**3.6 Plant Dynamics State Space Representation**

*D* = ( 0 0 0)

**3.6 Kalman filter State Estimation**

The Kalman filter estimates the states , particularly , the pH level, based on noisy measurements

where:

* ]T : Estimated states
* : Kalman gain matrix
* : Noisy measurement of outputs
* : Estimated output

**3.8 Control Law:**

**4. State-Space Matrices**

The state-space representation for the system involves constructing the matrices A,B, C, and D based on the above dynamics.

B**=**  **(**Observer Gain Matrix **L) =**

Feedback Gain Matrix K:

**5. The final observer dynamics are represented by:**

**6.1**. **Controllability and Observability Analysis:**

**6.2 Stability Analysis:**

**6.3**. **Simulation and Testing in Simulink:**

**7. What to Expect in the Final Report:**

The final report will include a comprehensive analysis of these tests, supported by detailed plots and discussions. Each section will explain the methods used, the results obtained, and the implications for the system's performance. The report will conclude with recommendations for fine-tuning the control parameters and potential future improvements for real-world applications.

These steps will ensure that the system is rigorously evaluated, confirming that it is well-designed for effective and reliable pH regulation in the water treatment process.

**8. Methodology to test the system**

**Simulate System in Simulink**:

* Running simulations with various initial conditions and disturbances.
* Evaluate system performance, including steady-state behavior and transient response.

**Analyze Results**:

* Assessing pH regulation, response time, and stability through simulation plots.
* Ensuring the system maintains desired pH levels under different flow rates and conditions.

**9. Conclusion**

This project has laid the groundwork for a comprehensive approach to modeling and controlling a water treatment process using modern control theory. By developing a dynamic model that incorporates the key processes of coagulation, flocculation, and sedimentation, we designed and implemented a state observer and state feedback controller. The controllability and observability analyses confirmed that the system could be effectively controlled and monitored, laying the foundation for robust state estimation. The stability analysis using eigenvalues demonstrated that both the system and observer can potentially be stable, with the control strategy designed to maintain the desired pH levels through precise alum dosage adjustments.

While the project has reached an important milestone with the final development of the state observer dynamics, further work is needed to fully simulate and fine-tune the system for optimal performance. The next steps will focus on tuning the control parameters, performing detailed simulations, and validating the control strategy under different operating conditions. Overall, this project has shown that state-space representation, feedback control, and state observers offer a promising method to enhance the efficiency and reliability of water treatment processes, with ong

oing work aimed at refinin

g and implementing these findings in practice.