Control System for Water Level Control of Flash Chamber in a Spray Flash Desalination System via Stochastic Processes

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Abstract

In this research, water level control of flash chamber in a spray flash desalination system is investigated. A water level model is constructed by introducing white Gaussian processes to water level and valve opening in an existing model. The valve opening is determined by PI controller with saturation. In order to check the influence of white Gaussian processes, some kinds of simulations were carried out.

1 Introduction

Spray flash desalination is one of the desalination technologies to generate fresh water from seawater. For this system, in [1], a model for numerical simulation of a spray flash desalination system was constructed. In [2], water level control of after condenser in a spray flash desalination system was investigated by employing stochastic process [3]. Furthermore, in [4], water level control of a spray flash desalination system was dealt with by considering the dynamics of flash chamber outlet valve. However, as verified in this research, the simulation results using the model in [4] are not necessarily close to the experimental ones.

Therefore, in this research, a control system for the water level control of flash chamber is considered by introducing stochastic processes to the conventional model.

2 Spray Flash Desalination System

The structure of a spray flash desalination system at Institute of Ocean Energy, Saga University (IOES) is shown in Fig. 1.

![Fig. 1: System structure of a spray flash desalination system](image)

The warm seawater obtained from sea surface is flowed into the decompressed flash chamber for the water to be partly flashed. The rest of liquid salty water is stored in the bottom of the flash chamber. The water level \( l_F(t) \) should be kept constant for steady operation of the spray flash desalination system. The detailed principle and experimental setup of the spray flash desalination system are explained in [5].

3 Control System Using Stochastic Processes

In this research, water level model constructed in [4] is employed. The model has external inputs of 4 flow rates, 2 pressures and 3 temperatures. As the control input to the model, in this research, valve opening...
\( u_{\text{FL}_{LO}}(t) = K_p \left( \int_0^t e^{FL}(\tau) d\tau \right) \),

\[
e^{FL}(t) = t_{\text{FL}} - e^{FL}(t),
\]

The valve opening has the saturation nonlinearity:

\[
\begin{align*}
\tilde{u}^{FL}_{LO}(t) &= \begin{cases} 
U^{FL}_{\text{max}} & (U^{FL}_{\text{max}} \leq u^{FL}_{LO}(t)) \\
U^{FL}_{LO}(t) & (U^{FL}_{\text{min}} \leq u^{FL}_{LO}(t) \leq U^{FL}_{\text{max}}) \\
U^{FL}_{\text{min}} & (u^{FL}_{LO}(t) \leq U^{FL}_{\text{min}})
\end{cases}
\end{align*}
\]

The simulation conditions for initial water levels \( \ell^{FL}(0) = 300 \, [\text{mm}] \) and \( \ell^{FL}(0) = 500 \, [\text{mm}] \) were listed in Table 1 and Table 2, respectively. The parameters \( K_p \) and \( T_i \) in (1) were determined by simulations using conventional model (i.e., \( w_i(t) \equiv 0 \) and \( w_v(t) \equiv 0 \)).

The control input \( u^{FL}_{LO}(t) \) for the water level \( \ell^{FL}(t) \) to track the desired water level \( \ell^{FL}_{\text{ref}} \) is given by the following PI controller:

\[
\ell^{FL}_{\text{ref}} = 400 \, [\text{mm}]
\]

\[
U^{FL}_{\text{max}} = 100 \, [%]
\]

\[
U^{FL}_{\text{min}} = 0 \, [%]
\]

\[
K_p = -0.5 \, [%/\text{mm}]
\]

\[
T_i = 50 \, [\text{s}]
\]

\[
\mu_v = 4.973 \, [\text{mm}]
\]

\[
\mu_r = 4.375 \, [%]
\]

\[
\sigma_i = 15.53 \, [\text{mm}]
\]

\[
\sigma_v = 0.6907 \, [%]
\]

Table 1: Simulation condition for \( \ell^{FL}(0) = 300 \, [\text{mm}] \)

| Parameter   | Value   |
|-------------|---------|
| \( \ell^{FL} \) | 400 \, [\text{mm}] |
| \( U^{FL}_{\text{max}} \) | 100 \, [%] |
| \( U^{FL}_{\text{min}} \) | 0 \, [%] |
| \( K_p \) | -0.5 \, [%/\text{mm}] |
| \( T_i \) | 50 \, [\text{s}] |
| \( \mu_v \) | 4.973 \, [\text{mm}] |
| \( \mu_r \) | 4.375 \, [%] |
| \( \sigma_i \) | 15.53 \, [\text{mm}] |
| \( \sigma_v \) | 0.6907 \, [%] |

Table 2: Simulation condition for \( \ell^{FL}(0) = 500 \, [\text{mm}] \)

| Parameter   | Value   |
|-------------|---------|
| \( \ell^{FL} \) | 400 \, [\text{mm}] |
| \( U^{FL}_{\text{max}} \) | 100 \, [%] |
| \( U^{FL}_{\text{min}} \) | 0 \, [%] |
| \( K_p \) | -0.5 \, [%/\text{mm}] |
| \( T_i \) | 50 \, [\text{s}] |
| \( \mu_v \) | 2.995 \, [\text{mm}] |
| \( \mu_r \) | -0.03097 \, [%] |
| \( \sigma_i \) | 17.41 \, [\text{mm}] |
| \( \sigma_v \) | 7.896 \, [%] |

\( \ell^{FL}(i) \) and \( \tilde{u}^{FL}_{LO}(i) \) are also shown in Fig. 8, Fig. 9 and Fig. 10, respectively. To check the difference \( \ell^{FL}(i) \) and \( \tilde{u}^{FL}_{LO}(i) \) between simulation results and experimental data at IOES. Here, it is noted that in the experiments the valve opening \( \tilde{u}^{FL}_{LO}(t) \) was calculated by (1), (2) and (3) and the calculated results were inputted manually by the operator with about 7 \, [\text{s}] \) interval. Therefore, the experimental data of the valve opening \( \tilde{u}^{FL}_{LO}(t) \) may contain the uncertainty came from the manual operation.

Simulation results of control systems in Fig. 2, Fig. 3 and Fig. 4 with initial water level \( \ell^{FL}(0) = 300 \, [\text{mm}] \) are shown in Fig. 5, Fig. 6 and Fig. 7, respectively. Simulation results of control systems in Fig. 2, Fig. 3 and Fig. 4 with initial water level \( \ell^{FL}(0) = 500 \, [\text{mm}] \) are also shown in Fig. 8, Fig. 9 and Fig. 10, respectively.
Fig. 2: Block diagram of control system

Fig. 3: Block diagram of control system without $w_v(t)$

Fig. 4: Block diagram of control system without $w_L(t)$

Fig. 5: Simulation result for $FL(0) = 300$ [mm]
Fig. 6: Simulation result for $\ell^{FL}(0) = 300 \text{ [mm]}$ without $w_v(t)$

Fig. 7: Simulation result for $\ell^{FL}(0) = 300 \text{ [mm]}$ without $w_L(t)$

Fig. 8: Simulation result for $\ell^{FL}(0) = 500 \text{ [mm]}$

Fig. 9: Simulation result for $\ell^{FL}(0) = 500 \text{ [mm]}$ without $w_v(t)$
5 Discussion

The simulation results in Fig. 5 and Fig. 8 indicate that the noises $w_v(t)$ and $w_{\ell}(t)$ severely affected the control result. However, in both cases, the stability was still maintained. The simulation results without $w_v(t)$ in Fig. 6 and Fig. 9 show that the noise $w_{\ell}(t)$ affected the determination of control input $u_{F L}(t)$. On the other hand, the simulation results without $w_{\ell}(t)$ in Fig. 7 and Fig. 10 clarify that the noise $w_v(t)$ did not affect the output $\ell_{F L}(t)$ since the outputs of conventional result and proposed one were almost same. This means that the control results may not be affected by the manual operation.

The simulation results for initial water level $\ell_{F L}(0) = 300$ [mm] in Fig. 5, Fig. 6 and Fig. 7 also indicate that since the simulation results for intervals 0-50[s] and 200-300 [s] by the conventional model catches the behavior of experimental results, the introduction of the noises $w_v(t)$ and/or $w_{\ell}(t)$ for these intervals might not be required. Furthermore, the simulation results for initial water level $\ell_{F L}(0) = 500$ [mm] in Fig. 8, Fig. 9 and Fig. 10 also show that since the simulation results for interval 150-300[s] (or steady state part) by the conventional model catches the behavior of experimental results, the introduction of the noises $w_v(t)$ and/or $w_{\ell}(t)$ for this interval might not be required. These facts mean that the introduction of noises $w_v(t)$ and/or $w_{\ell}(t)$ to the steady state part is not necessarily needed, and therefore, further improvements of the model is required.

It is also noted that the validity of the assumption on the white Gaussian noises should be verified. Moreover, many other simulations with different random series for white Gaussian processes should be conducted to verify the behavior as a stochastic system.

6 Conclusions

In this research, a model for the water level control of flash chamber in a spray flash desalination system was constructed by introducing white Gaussian noises to an existing model. White Gaussian noises were added to the valve opening and the water level. In order to check the behavior of the control system using the proposed model, some simulations were performed. The simulation results clarified that the noise for the water level affected the behavior of not only the output of the water level but also the manipulated variable of the valve opening. On the other hand, the noise for the valve opening did not severely affect the behavior of the output. Although the stability of the control system was not affected by the stochastic processes, some improvements on the noise representation should be required.

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