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Modeling and Optimisation of a Rinsing Process in a Recycled Plastic Plant

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Abstract

A rinsing step in a recycled plastic plant is known as a large amount consumed water process. To reduce its water consumption, an optimization technique has been used to determine optimal operating conditions. Therefore, the mathematical model of this process has been developed, and the Imperfect mixing coefficients (IMC) are evaluated. The problem statement is minimising the cleaning agent concentration at the work-piece at the last stage, and the model is used as the constraints in the optimisation problem. The optimisation results show that the optimal water consumption is between 17 and 23 litres and the optimal drag-out volume is between 0.6 and 1.2 litres.

Keywords rinsing process, recycled plastic plant, modeling, optimisation

1. Introduction

Plastic is a highly demand products because of its good properties, however, plastic products become a lot of garbage because of hard degradation. Several recycle methods have been proposed to manage this garbage [1]. Basically, the recycled plastic will be cleaned and blended with new plastic gains to produce new products. In the step of rinsing, it consumes a lot of water to rinse the cleaning agent from the plastic [2 – 5], therefore, this work focuses on mathematical modeling and optimization of a rinsing process to achieve optimal water consumption and wastewater discharge.

2. Modeling of recycled plastic rinsing process

A mathematical model of the recycled plastic rinsing process developed by [6] has been used here to estimate the contaminants on the work-piece surface after rinsing. It is assumed that an average concentration C_n at the work-piece after rinsing in the n^{th} rinse stage is a combination of the concentration C_{n-1} of the inlet solution (concentration at the work-piece after rinsing in the $(n-1)^{th}$ rinse stage) and an average final concentration Z_n of stages taken in a suitable proportion. Then, the average concentration of the work-piece is

$$C_n = a_n C_{n-1} + (1 - a_n) Z_n \qquad (1)$$

The coefficient a_n, known as the imperfect-mixing coefficients (IMCs), indicates the contribution from the initial concentration to the average final concentration at a work-piece after rinsing. The IMCs are a_n=0 in the case of perfect mixing. It also depends on the rinsing techniques and character of the withdrawn film on the work surface.

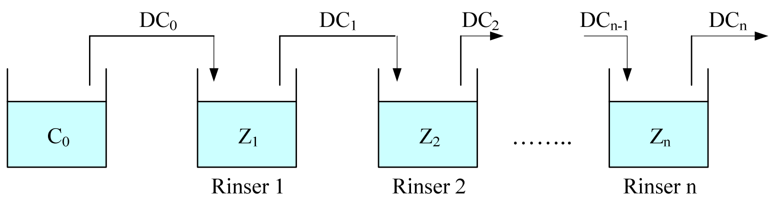

Figure 1 Rinsing system

To develop a continuous-rinsing operation model, additional assumptions: equal volume of each rinser (V) and identical amount of drag-in and drag-out (D), have also been made. Under these assumptions, the mass balance equation of the system can be derived as follows.

$$DC_{n-1} = V\frac{dZ_n}{dt} + DC_n \qquad n = 1,2,3,... \qquad (2)$$

It should be noted that the initial condition $Z_n(t=0)$ =0. In the case of incomplete mixing, equation (1) and (2) can be rearranged in the form:

$$\left.\begin{aligned} C_n &= C_0\left(1-\sum_{j=1}^{n}\alpha_n^j \exp(-kb_j t)\right) \\ Z_n &= C_0\left(1-\sum_{j=1}^{n}\beta_n^j \exp(-kb_j t)\right) \end{aligned}\right\} \quad n = 1,2,3,... \qquad (3)$$

Where $b_n = 1 - a_n \quad k = \frac{D}{V}$

Here, three stages rinsing has been studied. The mathematical models used to determine the cleaning agent concentrations in rinse water (Z_n) are:

$$Z_1 = C_0\left[1 - \beta_1^1 \exp(-kb_1t)\right] \tag{4}$$

$$Z_2 = C_0\left[1 - \beta_2^1 \exp(-kb_1t) - \beta_2^2 \exp(-kb_2t)\right] \tag{5}$$

$$Z_3 = C_0\left[1 - \beta_3^1 \exp(-kb_1t) - \beta_3^2 \exp(-kb_2t) - \beta_3^3 \exp(-kb_3t)\right] \tag{6}$$

Where $\beta_1^1, \beta_2^1, \beta_3^1, \beta_2^2, \beta_3^2, \beta_3^3, b_1, b_2$ and b_3 in equations (4)-(6) can be obtained from fitting curve between model and the experimental points.

3. Optimisation

To rinse the recycled plastic cleanly, the concentration of the cleaning agent on the plastic should be as less as possible. Thus, the objective function is to determine either the volume of rinsing water (V) or the drag out volume (d) minimising cleaning agent concentration on the work-piece at the last stage rinser (C_3) with respect to the system equations, limitation of cleaning agent concentration in the last stage at final of rinsing cycle (Z_3) and lower-upper bounds of the decision variables (volume of rinsing water or drag-out volume).

$$\min_{V \text{ or } d} C_3 = a_2C_2 - (1 - a_2)Z_2 \tag{7}$$

$$\textit{Subject to} \quad V\frac{d}{dt}Z_1 = (D - a_1D)C_0 - (1 - a_1)DZ_1 \tag{8}$$

$$V\frac{d}{dt}Z_2 = (D - a_2D)C_1 - (1 - a_2)DZ_2 \tag{9}$$

$$V\frac{d}{dt}Z_3 = (D - a_3D)C_2 - (1 - a_3)DZ_3 \tag{10}$$

$$Z_3^L \le Z_3 \quad (11) \qquad Z_3 = Z_3(t_N) \quad (12)$$

$$V^L \le V \le V^U \quad \text{Or} \quad d^L \le d \le d^U \tag{13}$$

Case 1 Determine the optimum volume of rinse water with respect to volume of rinsing water (V) with the lower and upper at 0 and 50 litres.

Case 2 Determine the optimum drag-out volume with respect to drag-out volume (d) with its lower and upper bounds are 0 and 2 litres.

4. Experimental study

The calibration curve, a relationship between the cleaning agent concentration and a value of pH, was prepared to determine the cleaning agent concentration in each stage after rinsing. The three rinsing stages were set up and fixed at 20 litres of fresh water in each stage, and the ordinary drag-out volume (d) of each tank was set at 0.7 l. The holding time (t_D) is 6 s. The recycled plastic (200 g) from the factory was packed in the basket. The initial concentration of cleaning agent (C_0) was prepared with 5 g/l. Then, the basket was dip into the cleaning agent stage for 5 s, and then immersed in the rinse water at stage 1, 2 and 3 respectively under determined rinsing time. The rinsing time in each stage was set at 5, 15 and 25.

5. Results and discussion

5.1. Modeling of recycled plastic rinsing process

The imperfect mixing coefficients (a_n) are obtained from the best fit of the theoretical curve to the experimental points. The values of these coefficients in each rinsing stage are listed in Table 1. The IMC can express the condition of agitation in each rinsing stage. It is indicated that the highest of agitation will be occurred in the first stage and lower with number of stage increasing.

Table 1 Imperfect-mixing coefficients for various rinsing times.

Run	Rinsing time (s)	Imperfect-mixing coefficients (a_n)		
		Stage 1	Stage 2	Stage 3
1	5	0.75	0.970	0.991
2	10	0.82	0.981	0.995
3	15	0.82	0.945	0.984
4	20	0.86	0.982	0.995
5	25	0.82	0.964	0.984
6	30	0.85	0.978	0.992

5.2. Optimisation

Case 1 Determine the optimal volume of rinse water

As shown in Figure 2, considering the feasible area, it was found that decreasing in drag-out volume directly affects to the process time; less drag-out requires longer process time. However, large process time with less drag-out volume is not appropriate, so the drag-out volume should not be less than 90 % of its original volume. Moreover, if the volume of the rinse water is over 23 litres, then the water will overflow from the rinsing stages, and if the volume is less than 17 litres, then the water does not enough for carrying out the rinsing. Thus, feasible rinsing water volume in each stage is between 17 and 23 litres.

Case 2 Determine the optimal drag-out volume

The optimum volume of drag-out is proportional to the rinse water volume as shown in Figure 3. The optimisation result indicated that if the optimum volume is less than 0.65 litres, the factory must increase process time of rinsing process. Therefore, the feasible area of water volume change is between 90 to 120 % of ordinary volume – that is between 0.6 and 1.2 l.

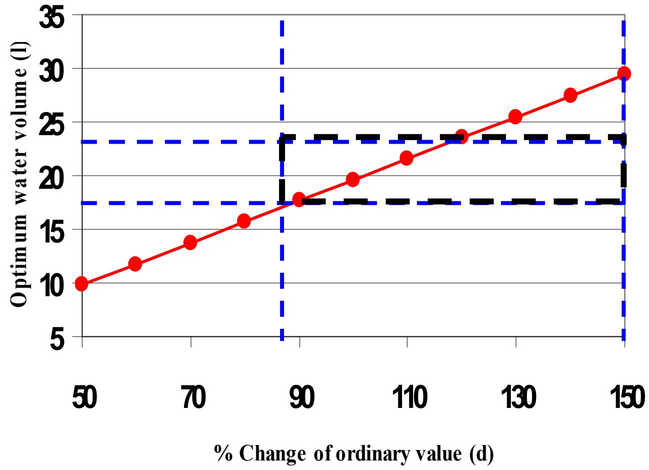

Figure 2 Optimal volume of rinse water with respect to drag-out volume change

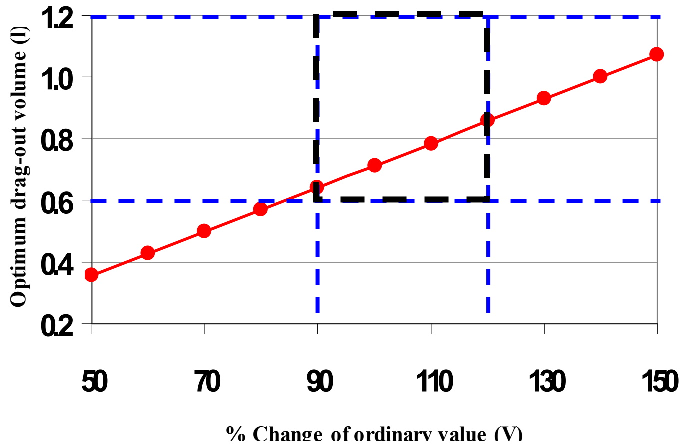

Figure 3 Optimal volume of drag-out with respect to water volume change

6. Conclusions

The mathematical models of a recycled plastic rinsing process describing dynamic behavior of cleaning agent concentration in each rinsing stage have been studied, and the IMC values are determined. The IMC values indicate that the agitation will be decreased with increasing of number of stage. The feasible changes in rinse water and drag-out volume are between 17-23 litres and 0.6-1.2 litres, respectively.

Nomenclature

a_n coefficient of imperfect mixing

C_n concentration at the workpiece after the n^{th} rinse (g/l)

C_0 concentration in initial bath (g/l)

Z_n concentration in the stage after the n^{th} rinse (g/l)

d volume of solution dragged out by the workpiece (l)

D volume of solution dragged out by the workpiece in the unit time (l/s)

k effective mixing rate; D/V (l/s)

n rinsing stage number

t time (s)

V volume of rinse water (l)

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