Optimization of circulation rate on the performance of phosphorus recovery process to improve particle size

S.G. Won[1], S.M. Shim[2], S.S. Kim[2], J.W. Park[2], T. Yuliani[2], N. Qambrani[2], G.Y. Kim[3], C.S. Ra[2]

[1]Department of Animal Resources, Daegu University, Gyeongsan, Gyeongsangbuk-do, 38453, South Korea
[2]Division of Animal Resource Sciences, Kangwon National University, Chuncheon, Gangwon-do, 24341, South Korea
[3]Division of Applied Animal Sciences, Kangwon National University, Chuncheon, Gangwon-do, 24341, South Korea
Keywords: Phosphorus, Particle size, Circulation rate, Fluidized bed reactor.
Presenting author email: swon@daegu.ac.kr

Phosphorus obtained from phosphate rock is an essential element for all living organisms but its deposits are very disproportionate only in a few countries. Due to the characteristics of limited deposits and slow-cycle resource regarded as non-renewable material, its exhaustion has been expected with-in 90 years (Shu et al., 2006), whereby phosphate rock was categorized into one of supply-risk minerals in Europe. As a result, the research on the recovery of phosphorus have been actively conducted for the sewage and livestock manure containing high concentrations of nitrogen and phosphorus. Struvite crystallization as one of phosphorus recovery methods has been widely studied in order to improve pollutant treatment and nitrogen/phosphorus recovery efficiency (Ali et al., 2006). Struvite, that is expressed in $MgNH_4PO_4 \cdot 6H_2O$ as magnesium ammonium phosphate (MAP) is a crystal of equimolar concentrations of magnesium, ammonium, and phosphate. The fluidized bed is the preferred method for operating struvite production processes because it induces complete mixing of internal solids and observes high mass and heat exchange rates, making it easy to handle internal materials. Especially, the mixing speed in the fluidized bed reactor is a factor that physically originates from the collision of particles to form struvite. Therefore, it is necessary to confirm the effect of mixing rate on the improvement of struvite production efficiency or particle size. This study was carried out to calculate the optimal circulation rate for particle size improvement.

In order to confirm the optimum circulation rate in the phosphorus recovery reactor, the operating conditions were set to the range of 50 ~ 150 g of the struvite particles, the circulation rate (CR) of 5 ~ 10 Q (83.3 ~ 166.7 mL/min) of the upward circulation line, and the circulation rate of 10 ~ 17 Q (166.7 ~ 283.3 mL/min) of the downward circulation line. A reactor (3 L) based on fluidized bed to derive struvite crystallization was made by transparent acryl to see the internal flow in the reactor, and it was composed of the recovery zone, reaction zone, and settling zone.

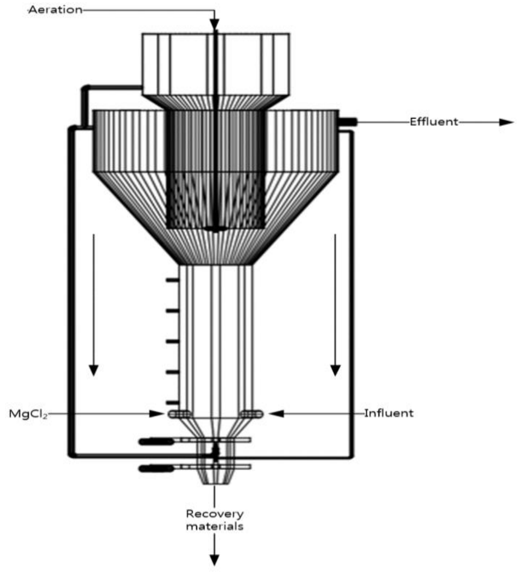

Figure 1. Schematic layout of phosphorus recovery process.

The aeration was provided in the settling zone that raised pH value by causing CO_2 stripping. The turbulent flow in reaction zone was made by circulating inside material from the top tube in the settling zone to the bottom tube that was divided by upward and a downward circulation line in a recovery zone. The upward and downward nozzle settled struvite particles floating in the reaction zone. Prevention of struvite dissolution in the reaction tank was done by an artificial saturating solution of pH 9. The struvite was recovered in the struvite recovery process and dried for 48 h at room temperature, and particle size was 42.9 µm. The CR of 1 Q was set at 16.7 mL/min for HRT of 3 h. The operating period of each experiment in the lab-scale reactor was 1 h. Aeration rate in the recovery process was 0.03 $m^3/m^3 \cdot min$ to generate downstream in the reactor. The particle size in the recovery zone and the reaction zone was analyzed for each experimental condition, and the total phosphate (TP) in the effluent was analyzed. The optimum condition derivation of each operating parameter was done by using the response surface methodology (RSM). Three operating conditions were divided into three levels, and experiments were designed using a central composite design (CCD). The reaction surface was analyzed for particle size and TP concentration of effluent according to the experimental conditions. 18 experiments were designed to calculate the optimum circulation rate for each circulation line in the reactor.

Averages of particle size in the reaction zone and the recovery zone were 46.12 and 54.97 µm, respectively and the difference was 8.85 µm. The smaller the difference of particle sizes in each zone, the greater the uniformity of the reactor mixing. In general, lower the amount of particles provided lower TP concentrations of effluent in each run and lesser the external leak of struvite particles. However, as the amount of internal particles was expected to exceed 150 g after 95 h after operation of phosphorus recovery process, the net circulation rate was estimated in the 150 g treatments of the amount of the particles. Based on the results of the analysis, we calculated the predicted value of particle size and TP concentration by substituting the coded values of each operation factor into the equation derived from the statistical analysis. As a result, the particle sizes of recovery zone and reaction zone were affected by particle amount and the TP concentration of the effluent was greatly influenced by the three operating factors. Especially, particle size model equation of recovery zone had statistical significance with real measured value. The p-value calculated by the ANOVA analysis was 0.0037 and included within the 99% confidence level, and the regression coefficient was 0.90 indicating statistical significance. Also p-value of TP concentration was 0.0142, and the regression coefficient was 0.86, indicating statistical significance. According to contour plot of derived statistical response factors levels, particle size in recovery zone was the largest when the circulation rate of downward circulation line was 10 Q or 17 Q and circulation rate of upward circulation line was 7-8 Q. The particle size of the reaction zone was found to be larger as the circulation rate of upward and downward circulation line were lower. The TP concentration of the effluent was found to be lower as the circulation rate of the downward circulation line was lower regardless of the circulation rate of the upward circulation line. As a result of confirming the optimal conditions of the operating factors that maintain the maximum particle size in the reactor, the circulation rate of the upward circulation line was 5 Q and the circulation rate of the downward circulation line was 12.1 Q. The higher the circulation rate, the more physical collision of the particles causes the particles to increase (Ronteltop et al., 2010). However, it is appropriate to lower the circulation rate of the upward circulation line to the lowest level in order to lower the loss and to adjust the particle size.

Consequently, the particle size was mainly dependent on a downward circulation line, generating turbulent flow to float the particles in the recovery zone, and the upward circulation line to stay in the reaction zone in order. Optimal operational conditions for the maximum particle size were upward circulation line of 5 Q and downward circulation line of 12.1 Q in the reactor. Through the particle-size control of struvite, the effective application of struvite for an industrial sector may be feasible with respect to the economic gain in the empirical process and commercialization as an organic-slow release fertilizer.

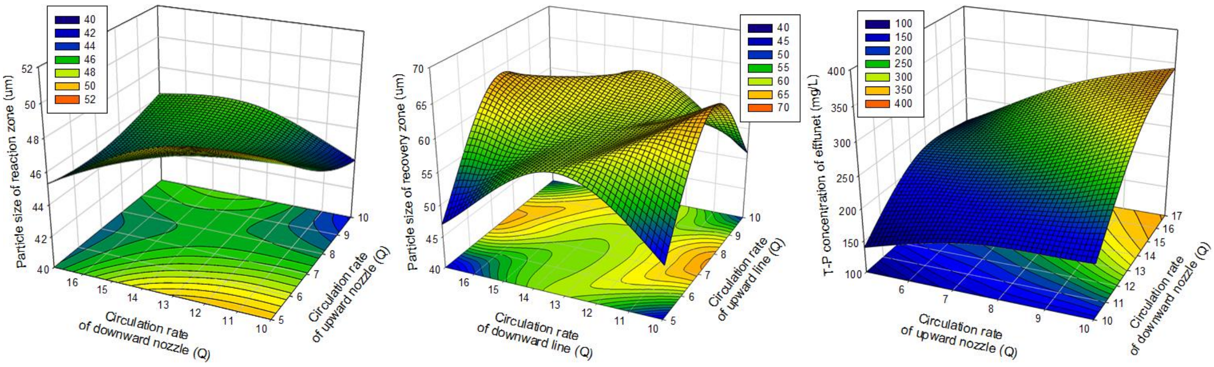

Figure 2. Particle size & T-P concentration rate of each lines in phosphorus recovery reactor.

Acknowledgements

This research was achieved with the financial supports by the Rural Development Administration (Project number, PJ011623), and the authors are also grateful to the personnel in the Animal Environment and Bioresource Engineering Lab of Kangwon National University.

References

Ali, M. I., Schneider, P.: A fed-batch design approach of struvite system in controlled supersaturation. Chem. Eng. Sci. 61, 3951-3961 (2006)

Ronteltop, M., Maurer, M., Hausherr, R., Gujer, W.: Struvite precipitation from urine-Influencing factors on partile size. Water Res. 44, 2038-2046 (2010)

Shu, L., Schneider, P., Jegatheesan, V., Johnson, J.: An economic evaluation of phosphorus recovery as struvite from digester supernatant. Bioresour. Technol. **97**, 2211-2216 (2006)