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MIXING AND SOLID SUSPENSION IN A STIRRED PRECIPITATOR

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ABSTRACT

Full-scale mixing and solid suspension studies have been conducted to determine the optimum agitator design for precipitators used in plutonium processing. Design considerations include the geometry of precipitator vessels, feed locations, flow patterns, and product requirements. Evaluations of various agitator designs are based on their capabilities: (1) to achieve uniform mixing of reactants in minimum time, (2) to suspend the slurry uniformly throughout the vessel, and (3) to minimize power consumption without inducing air entrainment. Tests of full-scale agitator designs showed that significant improvements in mixing, solid suspension, and energy consumption were achieved.

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INTRODUCTION

A two-stage precipitation system is currently used at the Savannah River Plant to precipitate plutonium trifluoride (PuF_3). Full-scale laboratory experimental work was conducted to examine key process variables affecting mixing and solid suspension (e.g. blade design, impeller rotational speed, and feed locations). The goal was to identify the optimum design operating conditions for new replacement precipitators. Precipitation objectives are to maximize crystal size for faster filtration, and to minimize plating for fewer cleanouts and less personnel radiation exposure.

Operating criteria for optimum precipitator performance are rapid mixing of feed streams, uniform solid suspension, minimum air entrainment, and minimum power consumption The optimum agitator design and operating condition for the primary precipitator have been identified.

EXPERIMENTAL PROGRAM

A 7-inch-diameter and 19-inch-tall transparent plastic tank was used as a mockup for the primary precipitator. A MixMore® variable speed agitator was used as the mixing unit. Multiple-blade-set agitators were used to meet the minimum solid suspension requirements. Generally, radial-flow impellers are suitable for solid suspension. Multiple blade sets with various combinations of radial and axial flow blades were tested.

Mixing Time

Visual observation of distinct color changes due to an acid-base indicator reaction was adopted to evaluate mixing speed. Mixing times were measured to assess the effects of feed locations, liquid levels, impeller designs and configurations, and impeller speeds.

Solid Suspension

Surrogates such as gypsum crystals, cerium oxalate crytals, and Lucite® (Du Pont) beads were used to simulate the suspension of PuF_3. The influences of bottom clearance between the impeller and the tank, agitator type, and rotational speed were investigated.

Particle Size Measurement

A Coulter Counter® Model TA-II was used to measure the particle size and population of gypsum crystals. These data were used to evaluate the effect of shear force on nucleation during precipitation, and the mechanical impact on particle breakage during digestion.

RESULTS AND DISCUSSION

Mixing Time

The mixing time measured for various runs covered a range of 3.5-11.4 seconds. These measurements showed the dependence on three variables; impeller configuration, rotational speed, and top clearance between the liquid surface and the top edge of the top blade set.

Different combinations for the multiple blade sets produced different flow patterns. The mixing time reflected the existence of interactions among various flow systems. The mixing time shortened as rotational speed increased, with some exceptions as shown by Agitators #3 (1-Radial and 3-Axial Blade Sets) and #4 (4-Axial Blade Sets). This was most likely due to the interference of flow systems generated by adjacent sets of impeller blades. The top clearance had little effect on the mixing time when radial-flow blades were used. Poor mixing near the liquid surface was observed when axial-flow blades were used and the top clearance was more than three inches. According to the results, Agitators #2 (3-Radial) and #4 (4-Axial) performed better than the others in mixing.

Solid Suspension

A common technique that uses Lucite® beads to rate the suspension performance was utilized. Numerical values (Chemineer Suspension Scales) were assigned to reflect degrees of solids distribution uniformity in a stirred vessel. This rating scale has a value range of 0-10. A valve of 3 indicates "off-bottom" suspension and a 10 indicates "uniform" suspension throughout the vessel. However, Lucite® beads settle much faster and are larger than the PuF_3 particles. Therefore, several other surrogates were also used to similate PuF_3 suspension to provide a more realistic assessment of the PuF_3 suspension performance of various agitators.

Generally, solid suspension improves with increasing impeller speed, and the axial-flow impellers perform better than the radial-flow impellers. At 220 RPM and 1" bottom clearance, poor suspension of solids under the shaft due to the low axial velocity was observed. Some solids settled when the bottom clearance increased to 2". Radial-flow impellers (Agitator #2) performed better and were less sensitive to the bottom clearance at 220 r.p.m. However, axial-flow impellers (e.g. Agitator #4) performed as good or better at a higher rotational speed (240 rpm and above). A dish bottom with a cone center to match the flow patterns associated with the axial-flow impellers enhanced the suspension performance at low speed.

Shear Force Affect on Particle Size

Radial-flow impellers produced higher shear than the axial-flow impellers. High shear can also be produced by increasing the impeller speed. The benefit of high shear is faster relief of localized supersaturation (i.e. reduces fines generated from rapid nucleation). However, there are drawbacks associated with the high shear. Smaller particles were produced when higher impeller speed (hence more turbulence and higher shear) was used at the precipitation stage. The formation of smaller particles could be attributed to two factors: (1) secondary nucleation due to the shear, and (2) breakage of already formed crystals due to the mechanical impact and/or shear forces exerted on crystals. The Kolmogroff microscale was used as an indicator of the turbulence intensity level (or the

shear) in the agitated precipitator. Kolmogroff microscale is the smallest eddy size that can exist in a turbulent flow field, and the higher the turbulence the smaller the microscale. Our test results showed that the breakage of crystals in a precipitator is unlikely when the particles are smaller than the Kolmogroff microscale. Therefore, low shear is desirable for the primary stage except in the vicinities of the feed streams. Higher impeller speed can be used at the secondary (digestion) stage to avoid settling of solids without suffering particle breakage, providing that the Komolgroff microscale is larger than the mean particle size.

Air Entrainment

Air entrainment is undesirable for the following reasons: (1) smaller particles are produced because many particles are encapsulated in a thin film of air, which prevents mass transfer to crystal surface, and (2) easier oxidization of Pu^{+3} to Pu^{+4} is conceivable, which would result in some gummy precipitates. Since a radial-flow impeller attracts more air, it is not recommended for the top blade set. In addition, a minimum top clearance between the liquid surface and the axial-flow blades should be maintained (2.5" when operating below 400 rpm).

Feed Locations

The actinide and precipitant feed streams are induced above the liquid surface for existing SRP precipitators. Mixing of two feed streams before dispersing to lower concentration (due to unfavorable flow pattern) could generate fines and cause severe plating.

Faster relief of supersaturation is achieved by utilizing the high-speed flows generated by radial- or axial-flow impellers. A submerged precipitant feed was adopted for the new precipitator which should eliminate the short-circuiting of feed streams.

CONCLUSIONS

To achieve the optimum operating conditions in a precipitator, the following three criteria have to be met: (1) minimum mixing time, (2) maximum solid suspension capability, and (3) minimum turbulence intensity with no air entrainment. Based on the testing results, Agitator #4 (4-Axial Blade Sets) outperformed the other agitators over a wide range of impeller speeds. At 280 RPM, Agitator #4 improved mixing by 90%, solid suspension by 300%, and it drew only 40% more power consumption than the existing precipitator's impeller design.

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