Modeling Pilot-Scale Cross-flow Filtration of Simulated Nuclear Waste

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SAVANNAH RIVER NATIONAL LABORATORY

We Put Science To Work

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Background

- Savannah River Site (SRS) is deploying processes to treat high level radioactive waste
- Treatment includes monosodium titanate (MST) addition to sorb strontium and select actinides followed by filtration to remove MST and entrained sludge
- Baseline technology uses sintered stainless-steel crossflow filter
- Performed pilot-scale filtration tests to determine filtration equipment size and to investigate the impact of operating parameters on filter flux

Pilot-Scale Filtration Studies

- Mott Crossflow filter
- Sintered stainless steel
- 7 filter tubes
- 5/8" ID
- 10 ft length
- 0.5 μ pore size
- Located at University of South Carolina

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Test Procedure

- Prepared 150 gallons 5.6 M sodium salt solution
- Added solids to produce nominal 0.6 g/L insoluble solids
  - ~ 1:1 ratio of sludge/MST
- Varied axial velocity and transmembrane pressure (TMP) in a statistically designed manner
- Measured filter flux as function of operating parameters
- Added additional solids to achieve nominal 2.9 g/L insoluble solids
  - ~ 1:1 ratio of sludge/MST
- Varied axial velocity and TMP – measured filter flux
- Added additional solids to achieve nominal 12.9 g/L insoluble solids
  - ~ 1:1 ratio of sludge/MST
- Varied axial velocity and TMP – measured filter flux
- Added additional solids to achieve nominal 60 g/L insoluble solids
  - ~ 1:1 ratio of sludge/MST
- Varied axial velocity and TMP – measured filter flux
- Conducted additional test with sludge only feed
- Fit data with filtration models

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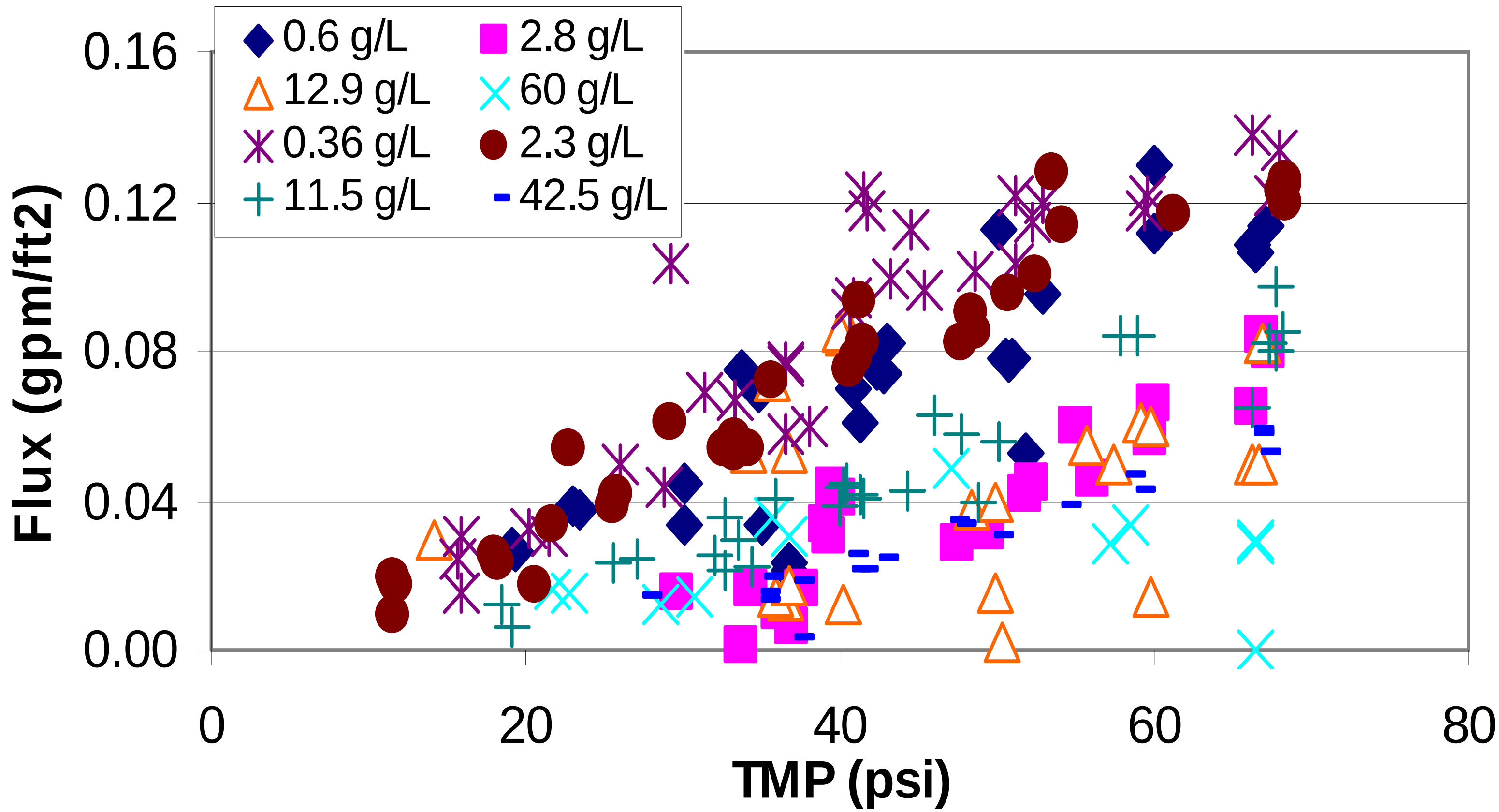
Test Results



Data suggest a correlation between TMP and filter flux
Data suggest correlation between solids concentration and flux

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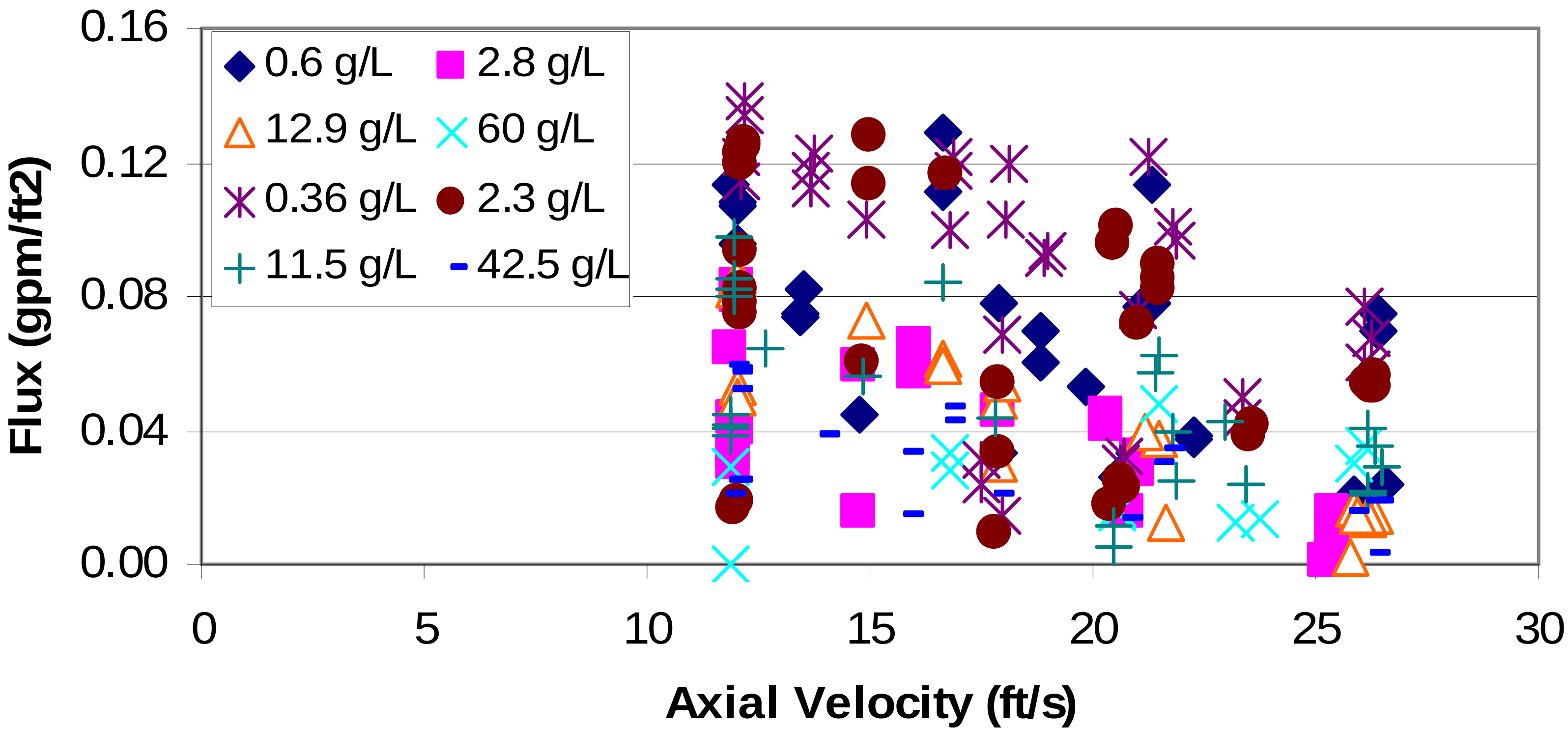
Test Results



Data does not indicate a correlation between axial velocity and filter flux

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Filtration Models

Modified Hagen-Poiseuille

$$J = \frac{\varepsilon d^2 \Delta P}{32 \mu L} = A_1 \Delta P$$

Kozeny-Carmen

$$J = \frac{\Delta P d_p^{\,2} \varepsilon^3}{180 L \mu (1-\varepsilon)^2} = A_6 \Delta P$$

Brownian Diffusion

$$J = 1.31 \left[\frac{\tau_w D_{Bl} \phi_w}{\mu L \phi_b} \right]^{1/3} = A_2 \frac{\tau^{\,1/3}}{\phi_b^{\,1/3}} = A_2 \frac{v^{.583}}{\phi^{\,1/3}}$$

Shear Induced Diffusion

$$J = 0.072 \frac{\tau_w}{\mu} \left[\frac{\phi_w r^4}{\phi_b L} \right]^{1/3} = A_3 \frac{\tau_w}{\phi_b^{\,1/3}} = A_3 \frac{v^{1.75}}{\phi_b^{\,1/3}}$$

Inertial Lift

$$J = 0.036 \rho r^3 \frac{\tau_w^{\,2}}{\mu^3} = A_4 \tau_w^{\,2} = A_4 v^{3.5}$$

Surface Transport Model

$$J = 2.4 r \frac{\tau_w}{\mu} \frac{(r^2 R_c)^{2/5}}{\tan\theta} = A_5 \tau_w = A_5 v^{1.75}$$

$$R_c = 45 \frac{\phi_w^{\,2}}{r^2 (1-\phi_w)^3}$$

Lift Velocity

$$J = 0.34 \frac{\tau_w^{\,1.5} d_p^{\,2}}{\lambda v^{1/2}} = A_7 \tau_w^{\,1.5} = A_7 v^{2.625}$$

Boundary Layer

$$J = 0.078 \left(\frac{d_p^{\,4}}{L} \right)^{1/3} \tau_w \ln\left(\frac{C_w}{C_b} \right) = A_8 \tau \ln\left(\frac{1}{C_b} \right) = A_8 v^{1.75} \ln\left(\frac{1}{C_b} \right)$$

Murkes and Carlsson Model

$$J = \frac{a_1 \Delta P v^{1.5}}{a_2 \Delta P C^{2/3} + v^{1.5}}$$

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Filter Flux Modeling

- Researchers used JMP® Statistical Software to fit the filtration data with models described on previous slide
- Determined F-ratio (variance from model/variance from error)
- Parameters investigated
  - TMP, axial velocity, concentration
- Constant parameters
  - Viscosity, density, pipe diameter, cake porosity, diffusivity
- Difference in median particle size between feeds ~ 10%
  - Assumed constant

Initial Model Results

Model	F-ratio	Prob > F
Modified Hagen-Poiseuille Kozeny-Carmen	82	< 0.0001
Brownian Diffusion	26	< 0.0001
Shear Induced Diffusion	1.5	0.23
Inertial Lift	42	< 0.0001
Surface Transport Model	43	< 0.0001
Lift Velocity	43	< 0.0001
Boundary Layer	2	0.21
Modified Murkes-Carlsson	217	< 0.0001

Modified Murkes-Carlsson, Modified Hagen-Poiseuille, and Kozeny-Carmen models describe data best

Models show TMP, axial velocity, and solids concentration affect filter flux – TMP strongest effect

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Murkes and Carlsson Model

$$J = \frac{0.00174\ \Delta P v^{1.5}}{0.120\ \Delta P C^{2/3} + v^{1.5}}$$

$$\lim_{v \to \infty} J = 0.00174 \Delta P$$

$$\lim_{\Delta P \to \infty} J = 0.0145 \frac{v^{1.5}}{C^{2/3}}$$

- At large velocity, model predicts flux is a strong function of TMP
  - Velocity high during tests
  - Observed in plots
- At large TMP and high solids loading, model predicts flux is a strong function of axial velocity
  - TMP moderate during tests
  - Solids loading varied 2 orders of magnitude
  - Correlation not observed in plots

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Conclusions

- Strong correlation between filter flux and TMP – likely caused by high axial velocity
- Models with TMP dependence provide better agreement with the data than models with axial velocity and concentration dependence
- Murkes-Carlsson model provides best fit with data

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