Small Particle Erosion Testing and Modeling

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November 2012
Outline

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Introduction

• Experimental studies at the University of Tulsa’s Erosion/Corrosion Research Center (E/CRC) show that small, sharp particles cause severe erosion in both gas and liquid systems.

• Small particles can pass through fine gravel packs and sand screens.

• Even though acoustic sand monitors may not be able to detect small sand, this sand may cause erosion.
Background
Background

• Previously, it was commonly thought that small sand (less than 40 µm) could not cause significant erosion
• However, measurable erosion has been observed for small sand at E/CRC
Flow Geometry Considered in the Current Work

- Zhang at E/CRC conducted a research project (2009), studying erosion caused by small particles in sudden contraction/expansion geometries.
- Project was supported by TUCoRE (Chevron)
Background (Zhang 2009)

Water, \( V_{\text{inlet}} = 0.66 \text{ m/s}, V_{\text{throat}} = 10.64 \text{ m/s}, \) Testing time: 294 hours
Sand: Silica flour, average size = 25 \( \mu \text{m}, \) weight concentration = 3%
Background (Zhang 2009)

Water, $V_{\text{inlet}} = 0.66 \text{ m/s}$, $V_{\text{throat}} = 10.64 \text{ m/s}$, Testing time: 294 hours
Sand: Silica flour, average size = 25 µm, weight concentration = 3%

Closer View

$\frac{d_1}{d_2} = 4$
$d_1 = 1.5''$
Background

- E/CRC has been studying erosion results from small particles (silica flour)

- Experiments (direct impingement, sudden contraction/expansion, slug flow)

- CFD Simulations

- Generally, CFD simulations are not successful in predicting small particle erosion due to the fact that the physics of small particle behavior near the wall are not fully understood
Background (Zhang 2009)

Water, $V_{\text{inlet}} = 0.66 \text{ m/s}$, $V_{\text{throat}} = 10.64 \text{ m/s}$, Testing time: 294 hours
Sand: Silica flour, average size = 25 $\mu$m, weight concentration = 3%

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Background (Zhang 2009)

Water, $V_{\text{inlet}} = 0.66 \text{ m/s}$, $V_{\text{throat}} = 10.64 \text{ m/s}$, Testing time: 300 hours
Sand: Silica flour, average size = 25 $\mu$m, weight concentration = 3%

Closer View Graph

Closer View Graph

Experimental Data
CFD Prediction (x0.05)

$d_1/d_2 = 4$
$d_1 = 1.5''$
Objectives

• Develop a modeling approach to accurately predict erosion resulting from small particles

• Use findings from improved erosion model for small particles to improve erosion prediction in SPPS
Approach

- In order to develop accurate erosion model for small particles several steps must be taken
  - Develop erosion ratio equation for small particles
  - Perform erosion CFD simulations using commercial CFD code
  - Find and improve deficiencies in commercial code
  - Develop stand alone particle tracking code to overcome deficiencies
  - Use findings from new model to improve SPPS
Developing Erosion Ratio Equation For Small Particles
Small Particle Erosion Ratio Equation

Al 6061-T6, Impact Angle: 60 degrees, Sand Size: 25 µm, Particle impact velocity: 42 m/s, Air

![Diagram showing cumulative material loss vs. sand weight with the equation y = 0.0085x and indicating Test 1 and Test 2 results.](image)

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Small Particle Erosion Ratio Equation

Al 6061-T6, Sand: Silica Flour (25 µm), Air

Erosion Ratio (g/g)

Impact Angle (degree)
Measuring Particle Velocity

Particle Velocity vs. Fluid Velocity for Air (Okita, E/CRC)

![Graph showing the relationship between particle velocity and fluid velocity for different particle sizes. The graph includes data points for 350 microns, 150 microns, and linear fits for each size. The correlation coefficients R² for 350 microns and 150 microns are 0.9909 and 0.9847 respectively.](image)
Comparing Erosion Ratios for Silica Flour (25 µm) and OK#1 (150 µm)
Particle impact velocity=42 m/s, Al Alloy 6061

\[
ER = C \times F_s \times V^{2.41} \times f(\theta)
\]

- Silica flour (25 um)
- OK#1 (150 um)
Applying Erosion Ratio Equation for Small Particles In Commercial Code
Erosion Prediction in Throat

Throat Velocity= 10.64 m/s, Water, Sand Size= 25 µm, Sand Rate 0.22 kg/s, Expansion Ratio= 4

![Graph showing erosion prediction](image)

- Erosion Ratio Equation Developed for Small Particles
- Erosion Ratio Equation Developed for Larger Particles
- Experiment

Axial Distance, Measured from Throat Inlet (m)
Erosion Prediction in Throat

Throat Velocity = 10.64 m/s, Water, Sand Size = 25 µm, Sand Rate 0.22 kg/s, Expansion Ratio = 4
Erosion Prediction After Expansion

Throat Velocity = 10.64 m/s, Water, Sand Size = 25 µm, Sand Rate 0.22 kg/s, Expansion Ratio = 4
Commercial CFD Code Capabilities

- Detailed study of particle behavior using commercial CFD code was performed
  - Effect of cell size on particle behavior
  - Near wall particle behavior
Effect of CFD Cell Size on Particle Behavior
Erosion Prediction

Erosion Rate Predicted at Throat Using Coarse CFD Mesh (59,000 cells) and Fine CFD Mesh (1,480,000 cells), Throat Velocity = 10.64 m/s, Water, Sand Size = 25 \( \mu \)m, Sand Rate 0.22 kg/s, Expansion Ratio = 4

![Graph showing erosion rate over axial distance](image)

- Course Mesh Erosion Results
- Fine Mesh Erosion Results

Axial Distance, Measured from Throat Inlet (m)
Erosion Prediction

Erosion Rate Predicted at in Expansion Using Coarse CFD Mesh (59,000 cells) and Fine CFD Mesh (1,480,000 cells), Throat Velocity = 10.64 m/s, Water, Sand Size = 25 µm, Sand Rate 0.22 kg/s, Expansion Ratio = 4
Erosion Prediction

Erosion Rate Predicted at Throat Using Coarse CFD Mesh and Fine CFD Mesh, Throat Velocity $= 10.64 \, \text{m/s}$, Water, Sand Size $= 25 \, \mu\text{m}$, Sand Rate $0.22 \, \text{kg/s}$, Expansion Ratio $= 4$
Flow Simulation Results

Comparing Turbulent Kinetic Energy Using Fine and Coarse CFD Meshes, 0.063 m from Sudden Expansion, Throat Velocity= 10.64 m/s, Water, Expansion Ratio = 4
Flow Simulation Results

Comparing Velocity Magnitude Using Fine and Coarse CFD Meshes, 0.063 m from Sudden Expansion, Throat Velocity= 10.64 m/s, Water, Expansion Ratio = 4
Comparing Eddy Length Using Fine and Coarse CFD Meshes, Location: 2.5 inches from Sudden Expansion, Throat Velocity = 10.64 m/s, Water, Expansion Ratio = 4
Eddy Prediction

Particle Path, Throat Velocity = 10.64 m/s, Water, Sand Size = 25 µm, Expansion Ratio = 4
Eddy-Particle Interaction

• Although calculated eddy length scale magnitude is similar for both meshes, the average particle motion in the positive radial direction for the course mesh is about five times higher that of the fine mesh. This shows that having larger cells (and as a result having larger eddies) makes particles move more in the radial direction than for the fine mesh.

• Closer inspection found that the commercial CFD code used in this work samples a new eddy each time a particle enters a new cell.
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Near Wall Particle Behavior
Near Wall Particle Behavior

Particle Path, Throat Velocity = 10.64 m/s, Water, Sand Size = 25 µm, Expansion Ratio = 4

Closer View
Near Wall Particle Behavior

Particle Impact Location Using Coarse Mesh, Throat Velocity = 10.6 m/s, Water, Sand Size = 25 µm, Expansion Ratio = 4

Viscous Sublayer Region

Wall

Impacts

Closer View Graph

Y+ ≈ 5-10

d1/d2 = 4

1 mm

Particle Axial Location From the Inlet (m)

Radial Location (m)
Particle Impact Velocity Using Coarse Mesh, Throat Velocity = 10.6 m/s, Water, Sand Size = 25 µm, Expansion Ratio = 4

Near Wall Particle Behavior

Particle Axial Location From the Inlet (m)
Near Wall Particle Behavior

- Particle Distance From Wall
- Fine Mesh
- Coarse Mesh
- Velocity Profile Close to Wall
- First Cell from Wall

Distance From Wall vs. Flow Velocity

Coarse Mesh and Fine Mesh compared for different particle distances from the wall.
Developing Stand Alone Particle Tracking Code

- Flow solution is obtained in FLUENT and exported to E/CRC particle tracking code

- Particle trajectories and resulting erosion are then calculated
Verifying Particle Behavior without Turbulence

200 µm particle released at the inlet, water, velocity = 10 m/s, laminar, particle released without initial velocity, particle density = 2600 kg/m³
Verifying Particle Behavior without Turbulence

20 µm particle released at the inlet, water, velocity at inlet = 0.1 m/s, laminar, particle released without initial velocity, particle density = 2600 kg/m$^3$, Particle released 0.0031 m from the nozzle wall.

Both FLUENT and E/CRC code predict the same particle path.
Verifying Particle Behavior without Turbulence

20 µm particle released at the inlet, water, velocity at inlet = 0.1 m/s, laminar, particle released without initial velocity, particle density = 2600 kg/m³, Particle released 0.001 m from the center of nozzle.

Diameter of Nozzle = 0.008 m

E/CRC code predicts particle hits the wall
Verifying Particle Behavior without Turbulence

200 µm particle released at the inlet, air velocity at inlet = 0.1 m/s, laminar, particle released without initial velocity, particle density = 2600 kg/m³. Elastic rebound, particle released 0.001 m from the nozzle wall.

Both FLUENT and E/CRC code predict the same particle path.
Adding Turbulence
Comparing Particle Impact Locations in FLUENT with the Particle Tracking Code with Turbulence, Air, Inlet Velocity = 15 m/s, Particle Size = 20 µm

Diameter of Nozzle = 0.008 m

Fluent
CODE

Closer View
Comparing Particle Impact Locations in FLUENT with the Particle Tracking Code with Turbulence, Air, Inlet Velocity = 15 m/s, Particle Size = 20 µm
Adding Turbulence

Comparing Particle Impact Locations in FLUENT with the Particle Tracking Code with Turbulence, Air, Inlet Velocity = 15 m/s, Particle Size = 200 µm

Diameter of Nozzle = 0.008 m

FLUENT
CODE

Target Wall

Closer View

Erosion/Corrosion Research Center
Comparing Particle Impact Locations in FLUENT with the Particle Tracking Code with Turbulence, Air, Inlet Velocity = 15 m/s, Particle Size = 200 µm

Diameter of Nozzle = 0.008 m

200 µm

Radial Location (m)

Axial Location (m)

Target Wall

Closer View Graph

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Verifying Particle Tracking Code

Snyder and Lumley Experiment (J. Fluid Mech. (1971), vol. 48, part 1, pp. 41-71)

\[ Y \text{ Direction Dispersion} = \frac{\sum (\text{Particle Distance From Center Line in a Particular Time})^2}{\text{Number of Particles}} \]
Verifying Particle Tracking Code

Inlet

Outlet

Wall

Wall

Center Line

Particle Path

(Y-direction) dispersion

Wind Channel

x

y
Verifying Particle Tracking Code

Comparison of Predicted transverse (Y-direction) dispersion with experimental data, Hollow glass beads, Size=46.5 µm, Density = 260 kg/m³, Released Velocity = 6.55 m/s

Graph showing Y-direction dispersion (cm²) against Time (ms) with data points and trend lines for Snyder & Lumley Data (1971), G. Klose, et al Prediction (1981), and E/CRC Particle Tracking Code.
Conclusion

- Small particles can cause severe erosion in geometries with high turbulence and recirculation areas.

- New E/CRC erosion ratio equation for small particles predicts erosion magnitude closer to experimental data compared to previous erosion ratio equations.
Conclusion

• In commercial CFD code, eddy size is limited by cell size which affects turbulent dispersion of particles

• When small particles enter viscous sublayer, they tend to stay and impact the wall over and over in a small area

• Cell size close to the wall dominates particle impact speed

• To overcome commercial CFD code problems, a separate particle tracking code needs to be developed.
Future Work

- Modifying preliminary particle tracking code
  - Modifying particle behavior prediction especially close to the wall (better representation of fluid velocity used in particle tracking)
  - Modifying eddy-particle interaction time

- More study is needed to examine particle eddy interaction of the current preliminary particle tracking code

- Developments in CFD-based erosion modeling will be used to improve SPPS
THANK YOU