I. INTRODUCTION

Introduction

The effect of particle size on erosion has been investigated by researchers, but in most cases, erosion from relatively small particles has not been considered nearly as often as erosion from large particles. However, recent experimental studies by The University of Erosion/Corrosion Research Center (E/CRC) show that small, sharp particles can cause severe erosion in both gas and liquid systems. Experiments at E/CRC indicated that in a sudden expansion geometry 25 μm particles caused more erosion than 150 μm particles (E/CRC Annual Report 2004). This means that small particles could cause a failure earlier than large particles for these conditions. Due to the fact that small particles are affected by turbulence more than larger particles, they can cause severe erosion in regions with high turbulence and locations where large particles do not.

Small particles can pass by acoustic sand detectors without being detected (Hedges et al., 2004). Small particles also can pass through sand screens or block a portion of the screen causing higher velocities in other sections resulting in erosion. This process makes the screen openings larger allowing larger particles to pass and erode the sand screen. Figure XIII-1 displays an eroded portion of a sand screen.

![Eroded Sand Screen](image)

Figure XIII-1. Eroded Sand Screen

To employ the E/CRC CFD-based comprehensive erosion model, particle impingement velocities and locations must be calculated. Previously, E/CRC employed CFX 4, and in some cases it was observed that the erosion pattern did not match experimental data. Some modifications were done for the sudden contraction/expansion geometry which improved the...
results but applicability to other geometries hasn’t been verified. Currently, E/CRC employs FLUENT 6 combined with User-Defined Functions (UDF) to predict erosion.

Despite previous work done with CFX, recently Zhang from E/CRC conducted an evaluation of erosion in a sudden contraction and expansion with Fluent. However, his CFD results significantly over-predict erosion from relatively small particles. The reason for this over-prediction is still unclear. As mentioned before, small particles are affected by turbulence more than larger particles. CFD modeling at E/CRC shows that small particles tend to stay in re-circulation regions; this causes non-physical impacts, which can result in exaggerated erosion predictions. Zhang, McLaury and Shirazi (2006) showed that additional physics were needed to predict small particle behavior in the near wall region.

Modeling the behavior of small particles near a wall is difficult, since the physics of small particle behavior near the wall isn't fully understood. To impact the wall, small particles must penetrate a viscous sub-layer region near the wall. Sometimes the small particles become trapped near the wall in computations causing more erosion. Modeling small particle erosion is being done at E/CRC due to the fact that they can cause severe erosion in many geometries. To develop an accurate erosion model, a better understanding of small particle behavior near the wall must be obtained. To gain that knowledge, experimental tests and numerical simulations must be done.

**Background**

In this section, a review of some of the previous studies on small particle erosion which were conducted at E/CRC is presented. Experimental and numerical studies on small particle erosion in a sudden contraction and expansion were done by Zhang at E/CRC. This project was supported by TUCoRE (Chevron), and a partial review of the findings is presented here.

As mentioned before, small particles are more affected by turbulence. Therefore, in regions with high turbulent kinetic energy and re-circulation, they could cause more erosion than larger particles. One of the geometries which has high turbulence regions is a sudden contraction/expansion geometry. CFD contour maps of velocity and turbulent kinetic energy are shown in Figures XIII-2 and XIII-3, respectively. A high turbulent kinetic energy region is clearly observed downstream of the throat which makes this geometry perfect to study small particle erosion.

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**Figure XIII-2. Contour of Velocity**

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Zhang at E/CRC conducted research examining the accuracy of CFD-based small particle erosion predictions in sudden contraction/expansion geometries. In this report, only results for one of the geometries are presented (Figure XIII-4). This work is very important because data that was generated in this study can be used to evaluate computational studies that will be done in this work. Thus, a description of the data collected will be given in this section of the report.

Sand

Silica flour was used in the previous work by Zhang with an average diameter of 25 μm. An SEM image of the silica flour used in the erosion tests is shown in Figure XIII-5, and the size distribution is shown in Figure XIII-6.
Figure XIII-5. SEM Image of Silica Flour (25 μm Average)

Figure XIII-6. Size Distribution of Silica Flour (25 μm Average)

Experimental Facilities

Figure XIII-7 shows the schematic of experimental facilities used by Zhang. The air-operated pump can deliver about 12 GPM (gallons per minute) of the water/sand mixture.
The maximum flow rate provided by the motor-driven pump is about 26 GPM. Sand and water were mixed in the mixing tank, and the mixer keeps the sand and water slurry homogeneous. The pump draws the water-sand mixture from the bottom of the mixing tank and delivers it to the test section. The water-sand mixture then flows back to the mixing tank. The actual flow rate was measured using a stopwatch to time the volume captured in a separate tank placed at the exit of the test section. To monitor sand concentration, samples were also taken from the exit.

**Testing Geometry**

More than one hundred wafers made of Aluminum (6061-T6) were used to form the test geometries placed inside the test section. Figure XIII-8 shows individual wafers with different inner diameters, and Figure XIII-9 shows the entire test geometry where wafers are held together using five long metal rods.
The wafers have a thickness of 0.25”. The center hole is the inner diameter exposed to the flow, and the other 5 smaller holes are used to hold the wafers together. By measuring the weight of each wafer before and after experiments, the local weight lost due to erosion is measured.
Experimental Results

The key parameters of Test 1 with Geometry 1 are listed below.

- $D_1 = 1.5\"$, $D_2 = 0.375\"$, $D_1/D_2 = 4.0$
- Fluid: Water
- Flow rate: 12 GPM (gallons per minute), average velocity is 0.66 m/s at inlet and 10.6 m/s in the throat
- Testing Time: 294 hours
- Sand: Silica flour, average size = 25 $\mu$m, weight concentration = 3% (about 0.227 kg/s sand flow rate)

Because the flow velocity is low, a long testing time was required to achieve measurable erosion. Figure XIII-10 shows erosion rate along the axis of Geometry 1 in units of mils/kg, which is the thickness loss of a wafer per amount of sand passing through the geometry. It is obvious that erosion of the throat region is much higher due to the higher velocity. Also because of the high turbulence which is caused by the sudden contraction at the entrance to the throat, the erosion at this location has the highest magnitude. Figure XIII-11 shows an expanded view of the erosion in the upstream and downstream sections of Geometry 1. In the upstream section, the erosion rate is nearly constant except near the sudden contraction where it decreases due to the stagnant region near the sudden contraction. Just after the throat, the erosion rate is low but reaches its highest local rate 4 inches after the throat near the reattachment point. High turbulence in the expansion promotes erosion at this location. After the local maximum, the erosion rate decreases until approximately 8 inches from the sudden expansion where it becomes relatively constant.
Figure XIII -10. Erosion Rate Measured in Test 1 with Geometry 1

Figure XIII -11. Erosion Rate Measured in Test 1 with Geometry 1 (Expanded View)
CFD Studies

A typical CFD-based erosion prediction procedure consists of three main steps: flow modeling, particle tracking, and applying erosion equations. FLUENT 6 (commercial CFD software) was used to predict the flow fields. Flow modeling is the basis of the CFD-based erosion prediction, any non-physical behavior affects the final erosion results. The predicted flow field is used as input for particle tracking to calculate particle trajectories. Particles cause erosion by crossing fluid streamlines and impacting the wall. To predict a statistically accurate erosion distribution on the geometry surface, a relatively large number of particles must be simulated with separate trajectories predicted for each particle. If a particle hits a wall, the corresponding impingement information is saved and used to calculate erosion. Erosion equations relate particle impingement information, particle physical characteristics (particle shape, sharpness, size and density) and wall material characteristics (hardness, yield strength, density, and surface roughness) to the mass loss of the wall.

Comparison of Erosion Predictions with Experimental Data

In this section, results from the CFD-based erosion predictions are compared with experimental data. Figures XIII-12 and XIII-13 show comparisons of results for Test 1. The CFD-based erosion prediction rate trend agrees very well with experimental data but the magnitude is over-predicted by a factor of 20. The trend of the predictions in the upstream section does not agree with experimental results since the flow is not fully developed at the beginning of the geometry. After 4 inches, the CFD procedure predicts the trend better including the decrease before the throat. In the downstream section, CFD results correctly predict the location of maximum erosion, but the magnitude is over-predicted by a factor of 40.
It is suggested that the over-prediction in erosion rate in the throat is due to the fact that current E/CRC erosion equation may not be applicable to aluminum, since re-circulation
and non-physical impacts are not a problem in the throat. Also, the over-prediction in the downstream section is higher than the throat and upstream sections. This may be a result of the erosion equation as well as re-circulation and non-physical impacts.

**Conclusions from Previous Work**

It is obvious that small particles can cause severe erosion in geometries with high turbulence and re-circulation regions. Also, they are capable of causing measurable erosion even in simple geometries like direct impingement. As mentioned before, CFD has not been successful in predicting small particle erosion, and the results from CFD over predict small particle erosion for the liquid cases examined. Some specific CFD particle tracking studies revealed that in CFD particle tracking many non-physical impacts occur and small particles tend to stay in re-circulation areas and repeatedly impact walls. This behavior causes non-physical erosion and results in over-prediction. Although non-physical impacts could be a cause for erosion over-prediction, this over-prediction has been seen in regions without re-circulation areas like in the throat of a sudden contraction/expansion. This means that the over-prediction is not just resulting from non-physical impacts but also other reasons which are still unknown.

**OBJECTIVE**

The main objective of this work is to develop an accurate CFD-based erosion model for small particle erosion. The model will be compared to existing, experimental data as well as data that is generated during this investigation.

To reach this goal several tasks must be performed. Preliminary erosion modeling over predicts the magnitude of erosion rate as compared to experimental data especially for smaller particles. The first important task is to select a geometry in which small particles cause measurable erosion, and the geometry should be simple enough to provide the opportunity to understand small particle behavior and the resulting erosion. Sudden contraction/expansion and direct impingement geometries are selected due to high erosion rates caused by small particles in these geometries. Also, these geometries are simple geometries which makes the study of small particle behavior easier. The next task is to examine small particle behavior near walls. Further study shows that commercial CFD codes predict small particles enter the viscous sub-layer and tend to stay there. These trapped particles hit the wall over and over in a really small area with almost the same impact.
velocity. This is one of the reasons for over-predicting erosion magnitude. Another task is to examine the difference between the near wall behavior of small particles as compared to larger particles. To understand the difference between small and large particles, experimental studies and CFD simulations should be conducted for both small and large particles in the same geometry. The commercial software (FLUENT) has been used to obtain flow solutions and particle tracking for this study. When particles hit the wall, impact information is saved and used to calculate erosion using erosion ratio equations. More study revealed that although FLUENT is successful predicting flow pattern it has some limitations in particle tracking and predicts non-physical particle behavior close to the wall. Since it is impossible to overwrite these limitations, a separate particle tracking code needs to be developed. This information can be used to modify current SPPS and CFD-based erosion models for small particles.

**APPROACH**

The approach to develop an accurate CFD-based erosion model for small particles has different aspects. The first step is developing an erosion equation for smaller particles (average size of 25 μm). Since current erosion equations were developed for larger particles, developing an erosion equation for small particles is necessary. Having an appropriate erosion equation for small particles is important in predicting erosion magnitude but does not affect the trend of erosion. The erosion prediction trend is affected by particle tracking. Detailed study of particle behavior needs to be performed to determine the capabilities of a commercial CFD software to predict small particle erosion. A Reynolds Stress Model (RSM) is employed for the flow field solution. For particle tracking, one-way coupling is assumed due to the low volume concentration of particles. Also to predict particle trajectories, a stochastic tracking technique is employed, so characteristic eddy lifetimes have some randomness. A relatively large number of particles must be released and modeled to obtain a statistically accurate distribution of erosion. Particle trajectories are investigated in detail especially close to the wall. All impact information is studied to gain a better understanding of the commercial CFD code capabilities. This study shows that current commercial CFD codes have deficiencies in particle eddy interaction modeling. To overcome commercial CFD code problems, a separate particle tracking code needs to be developed.
Erosion Equation For Small Particles

Experimental erosion results with small particles (less than 25 \( \mu m \)) in gas are limited due to the difficulties in filtering sand preventing them from spreading into air. Preventing small sand from polluting the environment and safety concerns for researchers always have been obstacles. Experimental data was obtained to help develop erosion equations for small particles. Silica flour was used for these experiments. It has an average diameter of 25 \( \mu m \) and has sharp edges.

Experimental Results and Determining Erosion Ratio Equation

Figure XIII-14 shows small particle erosion measurements in gas at different impact angles for aluminum. The data follows a typical erosion trend for ductile material. In Figure XIII-15, experimental data from small particles are compared with erosion data for large particles (150 \( \mu m \)). It is interesting that erosion from small particles are comparable with larger particles.

Figure XIII-14. Erosion Rate vs Impact Angle, Silica Flour (20 \( \mu m \)), Particle Impact Velocity = 28, 42 and 56 m/s
The E/CRC erosion equation is

\[ ER = C \times F_s \times V_p^{2.41} \times F(\theta) \]  \hspace{1cm} (1)

\[ F(\theta) = (\sin\theta)^{n_1} \times (n_2 + HV^{n_3}(1 - \sin\theta))^{n_4} \]  \hspace{1cm} (2)

Where:
- \( V_p \) = Representative particle impact velocity m/s
- \( F_s \) = Sharpness factor
- \( C \) = Constant
- \( HV \) = Vickers hardness of the wall material
- \( n_1 - n_4 \) = Constants which change for different wall materials and sand sizes

Using experimental data, \( C \) and \( n_1 - n_4 \) were determined and placed in Table 1.

<table>
<thead>
<tr>
<th>C</th>
<th>n_1</th>
<th>n_2</th>
<th>n_3</th>
<th>n_4</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.55</td>
<td>1.3</td>
<td>3.2</td>
<td>2.5</td>
</tr>
</tbody>
</table>
Figures XIII-16 to XIII-18 show comparisons between experimental data and the erosion ratio equation.

**Figure XIII-16.** Comparing Experimental Erosion Rate with E/CRC Erosion Equation for Silica Flour (20 \(\mu\)m), Impact Velocity = 28 m/s

**Figure XIII-17.** Comparing Experimental Erosion Rate with E/CRC Erosion Equation for Silica Flour (20 \(\mu\)m), Impact Velocity = 42 m/s
Implementing New Erosion Ratio Equation for Small Particles into CFD

Figures XIII-19 and XIII-20 compare erosion prediction results using two different erosion ratio equations which were developed for two different particle sizes: small particles with an average size of 25 μm and larger particles with average size of 150 μm. The sudden contraction/expansion geometry was selected to compare the effect of erosion ratio equation on predicting erosion. Results are shown in the throat and the expansion in Figures XIII-19 and XIII-20, respectively. Figure XIII-21 provides the experimental results in the expansion region separately for a better display of trend. These two different erosion ratio equations have the same form but different constants. Using the erosion ratio equation that was developed for the larger particles to predict erosion rate caused by small particles results in an over prediction of erosion. The predicted trends for both equations are similar since the particle impact information remains unchanged.
Figure XIII-19. Comparing Erosion Rate Predicted at Throat Using Fine Mesh and Coarse Mesh, Inlet Velocity = 0.66 m/s, Water, Sand Size= 25 um, Sand Rate 0.22 kg/s, Expansion Ratio = 4

Figure XIII-20. Comparing Erosion Rate Predicted at Sudden Expansion Using Fine Mesh and Coarse Mesh, Inlet Velocity = 0.66 m/s, Water, Sand Size= 25 um, Sand Rate 0.22 kg/s, Expansion Ratio = 4
Figure XIII-21. Erosion Rate Results From Experiment at Sudden, Inlet Velocity = 0.66 m/s, Water, Sand Size= 25 um, Sand Rate 0.22 kg/s, Expansion Ratio = 4
Predicting erosion has three steps; flow solution, particle tracking and erosion prediction. The particle tracking section of the CFD-based erosion modeling is also essential in erosion modeling. Particle tracking for small particles can be challenging due to the fact that small particles are affected by turbulence and interact with the viscous sub-layer next to the wall more than large particles. Currently at E/CRC, FLUENT is used for flow solution and particle tracking. But, FLUENT has some limitations in particle tracking. First of all in FLUENT, the eddy size is limited by cell size. So for larger cell sizes, FLUENT predicts bigger eddies compared to smaller cell sizes. This can have a dramatic effect on small particle behavior since these small particles are affected more than larger particles by turbulence. Another problem is predicting particle behavior close to the wall. FLUENT predicts particles which hit the wall come back and hit the wall again with a nonphysical impact velocity in a very small area. This behavior is one of the reasons for over prediction of erosion by CFD.

**Effect of Cell Size in Particle Behavior Prediction**

In this section, particle behavior predictions for two different cell sizes are compared. The sudden contraction/expansion geometry which was chosen for this study is based on previous experiments at E/CRC. The expansion ratio (ratio of the diameter after sudden expansion to throat) is 4. The inlet diameter is 1.5 inches, and the diameter of throat is 0.375 inches. The inlet flow velocity is 0.66 m/s and sand rate is 0.22 kg/s. Two different meshes were chosen for this geometry. The finer mesh has over 1,480,000 cells, and the coarser mesh has over 59,000 cells. Both meshes have square cells (dx=dy). The ratio of dx for the coarse mesh to the fine mesh is 5. Figures XIII-22 and XIII-23 demonstrate that the mesh size has a huge effect on particle tracking and erosion predictions. The experimental results in Figure XIII-23 are the same as shown in Figure XIII-21.
Figure XIII-22. Erosion Rate Predicted at Throat Using Fine Mesh and Coarse Mesh, Inlet Velocity = 0.66 m/s, Water, Sand Size = 25 um, Sand Rate 0.22 kg/s, Expansion Ratio = 4

Figure XIII-23. Erosion Rate Predicted at Sudden Expansion Using Fine Mesh and Coarse Mesh, Inlet Velocity = 0.66 m/s, Water, Sand Size = 25 um, Sand Rate 0.22 kg/s, Expansion Ratio = 4
Comparing flow solutions obtained from these two meshes shows similarities in trend and magnitude. Figures XIII-24 to XIII-26 show turbulent kinetic energy (TKE), dissipation rate, and velocity magnitude, respectively.

Figure XIII-24. Comparing Turbulent Kinetic Energy Using Fine and Coarse Meshes, 0.06 m from Sudden Expansion, Inlet Velocity = 0.66 m/s, Water, Sand Size= 25 um, Sand Rate 0.22 kg/s, Expansion Ratio = 4

Figure XIII-25. Comparing Dissipation Using Fine and Coarse Meshes, 0.06 m from Sudden Expansion, Inlet Velocity = 0.66 m/s, Water, Sand Size= 25 um, Sand Rate 0.22 kg/s, Expansion Ratio = 4
Figure XIII-26. Comparing Velocity Magnitude Using Fine and Coarse Meshes, 0.06 m from Sudden Expansion, Inlet Velocity = 0.66 m/s, Water, Sand Size= 25 um, Sand Rate 0.22 kg/s, Expansion Ratio = 4

Figure XIII-27. Comparing Eddy Length Using Fine and Coarse Meshes, Location: 2.5” from Sudden Expansion, Inlet Velocity = 0.66 m/s, Water, Sand Size= 25 um, Sand Rate 0.22 kg/s, Expansion Ratio = 4
Although calculated eddy length scale magnitudes are similar for both meshes (Figure XIII-27), FLUENT samples eddies 5 times more frequently for the finer mesh than the coarser mesh. So practically, eddies are 5 times smaller for the finer mesh than the coarser mesh, which affects the particle behavior. For example, the average particle motion in the positive radial direction for the course mesh is about five times higher than for 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. This may be one of the reasons for inaccuracies in predictions of erosion magnitude. So it can be seen that in FLUENT the mesh size affects particle behavior and as a result the erosion prediction.

Non-physical Particle Behavior Close to the Wall

It has been observed that in FLUENT most of the particles tend to impact the wall many times with non-physical impact speeds over a small area. This effect causes over predictions in erosion magnitude. Using a really fine mesh reduces this effect but does not prevent it completely. Figure XIII-28 shows a particle path in a sudden contraction/expansion geometry.

Figure XIII-28. Particle Path Using Coarse Meshes, Inlet Velocity = 0.66 m/s, Water, Sand Size = 25 um, Sand Rate 0.22 kg/s, Expansion Ratio = 4

Closer View
By having a closer view of the area where the particle hits the wall after the sudden expansion, non-physical particle behavior can be seen.

Figure XIII-29. Particle Impact Location Using Coarse Meshes,  
Inlet Velocity = 0.66 m/s, Water, Sand Size= 25 um, Sand Rate 0.22 kg/s,  
Expansion Ratio = 4

Figure XIII-30. Particle Impact Velocity Using Coarse Meshes, 
Inlet Velocity = 0.66 m/s, Water, Sand Size= 25 um, Sand Rate 0.22 kg/s,  
Expansion Ratio = 4
Figures XIII-29 and XIII-30 show that particles enter the viscous sublayer and demonstrate nonphysical behavior. Particles hit the wall with almost the same impact velocity over and over in a small area. This unphysical behavior is one of the reason that causes over prediction in CFD-based erosion modeling for small particles.

From the above study, it is obvious that in FLUENT, mesh size has an important role in predicting particle behavior and as a result simulating erosion. In the commercial CFD code, eddy size is limited by cell size. Having bigger cells results in bigger eddies. Also when a small particle enters the viscous sublayer, it tends to stay there and hits the wall over and over in a really small area with almost same particle impact velocity. In the current commercial CFD code, cell size close to the wall dominates particle impact speed. Using smaller cell size results in smaller impact velocities of particles and smaller erosion magnitude predication.

**Developing Stand Alone Particle Tracking Code**

It is apparent that modifications are necessary to the commercial particle tracking code to overcome deficiencies in predicting particle behavior. The commercial CFD code allows the user to interact with certain parts of the code through user defined functions (UDFs). However, the issues discussed in this work cannot be overcome with UDFs. A stand alone particle tracking code is needed to predict more accurate particle trajectories and as a result more accurate erosion. Fluent is successful in predicting flow pattern, so the flow solution obtained from FLUENT and exported to the particle tracking code. Particle trajectories and resulting erosion are then calculated separately.

Figures XIII-31 to XIII-34 compare predicted particle trajectories from FLUENT and the preliminary E/CRC particle tracking code. Three particles are released at three different locations in a direct impingement geometry. Both FLUENT and the preliminary E/CRC particle tracking code predict the same particle trajectories in Figures XIII-31 to XIII-32. However in Figure XIII-33, FLUENT predicts that the particle travels very close to the wall without impacting, but the preliminary E/CRC particle tracking code predicts that the particle hits the wall. In the E/CRC particle tracking code, impact with the wall occurs when the particle is less than a particle radius from the wall. In Figure XIII-34, predicted particle trajectories with rebound from FLUENT and the preliminary E/CRC particle tracking code are compared. Both FLUENT and the E/CRC code predict the same particle path. These preliminary results were obtained without accounting for turbulent effects on particles.
Figure XIII-31. Comparing Predicted Particle Trajectories From FLUENT with Preliminary E/CRC particle tracking code. Inlet Velocity = 10 m/s, Water, Sand Size=200 μm, Sand Density = 2600 kg/m$^3$, Initial Particle Velocities = 0.0 m/s

Figure XIII-32. Comparing Predicted Particle Trajectories From FLUENT with Preliminary E/CRC particle tracking code. Inlet Velocity = 0.1 m/s, Water, Sand Size=20 μm, Sand Density = 2600 kg/m$^3$, Initial Particle Velocities = 0.0 m/s, Particle Released at 0.001 m from the Nozzle Wall
Figure XIII-33. Comparing Predicted Particle Trajectories From FLUENT with Preliminary E/CRC particle tracking code. Inlet Velocity = 0.1 m/s, Water, Sand Size = 20 μm, Sand Density = 2600 kg/m³, Initial Particle Velocities = 0.0 m/s, Particle Released at 0.003 m from the Nozzle Wall.

Figure XIII-34. Comparing Predicted Particle Trajectories From FLUENT with Preliminary E/CRC particle tracking code. Inlet Velocity = 0.1 m/s, Water, Sand Size = 200 μm, Sand Density = 2600 kg/m³, Initial Particle Velocities = 0.0 m/s, Particle Released at 0.003 m from the Nozzle Wall. Elastic Rebound at the Wall.

Figures XIII-35 to XIII-38 compare predicted first impact locations for 1000 particles from FLUENT and the preliminary E/CRC particle tracking code. Figures XIII-36 and XIII-38
show closer view of Figures XIII-35 and XIII-37, respectively. The results shown in these figures account for turbulent dispersion of particles.

**Figure XIII-35.** Comparing Predicted First Particle Impact Location From FLUENT with Preliminary E/CRC particle tracking code. Inlet Velocity = 15 m/s, Air, Sand Size = 20 μm, Sand Density = 2600 kg/m³, Initial Particle Velocities = 0.0 m/s, 1000 Particles Released at 0.003 m from the Nozzle Wall

**Figure XIII-36.** Comparing Predicted First Particle Impact Location From FLUENT with Preliminary E/CRC particle tracking code. Inlet Velocity = 15 m/s, Air, Sand Size = 20 μm, Sand Density = 2600 kg/m³, Initial Particle Velocities = 0.0 m/s, 1000 Particles Released at 0.003 m from the Nozzle Wall
Figure XIII-37. Comparing Predicted First Particle Impact Location From FLUENT with Preliminary E/CRC particle tracking code. Inlet Velocity = 15 m/s, Air, Sand Size = 200 μm, Sand Density = 2600 kg/m³, Initial Particle Velocities = 0.0 m/s, 1000 Particles Released at 0.003 m from the Nozzle Wall.

Figure XIII-38. Comparing Predicted First Particle Impact Location From FLUENT with Preliminary E/CRC particle tracking code. Inlet Velocity = 15 m/s, Air, Sand Size = 200 μm, Sand Density = 2600 kg/m³, Initial Particle Velocities = 0.0 m/s, 1000 Particles Released at 0.003 m from the Nozzle Wall.
In Figures XIII-35 to XIII-38, particles are not allowed to rebound from the wall, so only first impacts are examined. Also, the effect of turbulence on particles is more prominent for smaller particles.

**Summary and Conclusion**

It is obvious that small particles cause severe erosion in geometries with high turbulence and recirculation areas. So developing accurate erosion models which can be applied for small particles is necessary. In this study, erosion in two geometries were investigated: direct impingement and sudden contraction/expansions. An erosion ratio equation for small particles (25 μm) was generated from experimental data. Using the erosion ratio equation for small particles improved the predicted erosion magnitude.

Currently, FLUENT is used at E/CRC to perform flow simulation and particle tracking but it has limitations. In FLUENT, eddy size is limited by cell size. As a result particle behavior prediction is different for different meshes. Also when small particles enter viscous sublayer, they tend to stay in the sublayer and impact the wall over and over with almost the same impact velocity, which is not physical. This behavior changes by changing cell size. It the commercial CFD code, 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**

Due to the limitations of current commercial software that is used at E/CRC, particles show unphysical behavior which affects erosion predictions. So developing a particle tracking program which does not have these limitations is necessary. This particle tracking program allows researchers at E/CRC to predict particle behavior more accurately, especially close to the wall which results in more accurate erosion predictions. A preliminary E/CRC particle tracking code predicts particle trajectories in direct impingement geometry that are similar to FLUENT predictions without considering turbulent dispersion. Additional work is necessary for appropriate implementation of turbulent dispersion in the new particle tracking code. Once modifications are made and shown to improve erosion predictions, similar modifications can be made SPPS.
References