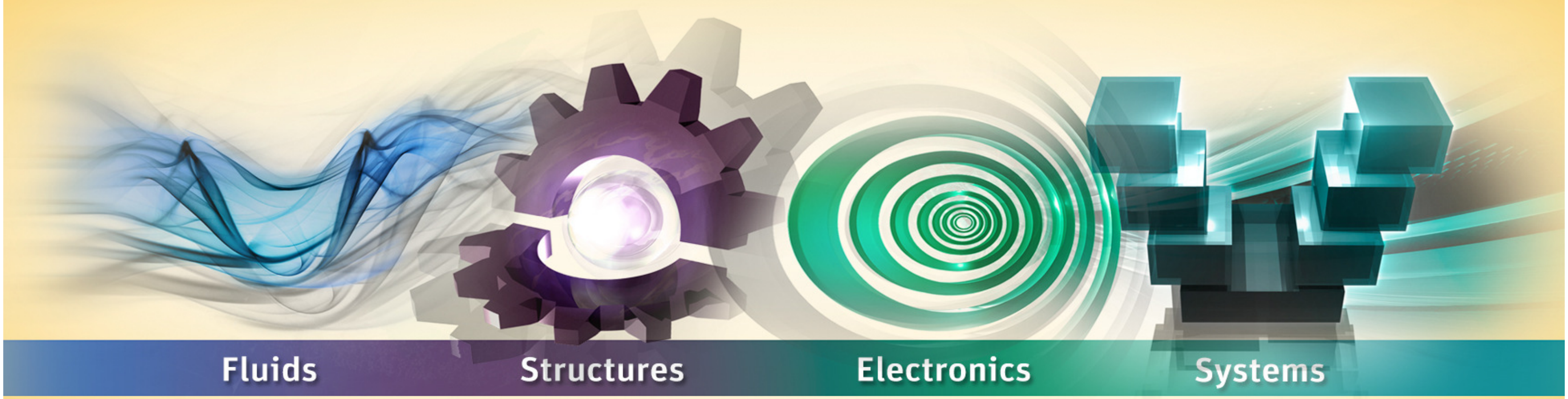
Realize Your Product Promise®

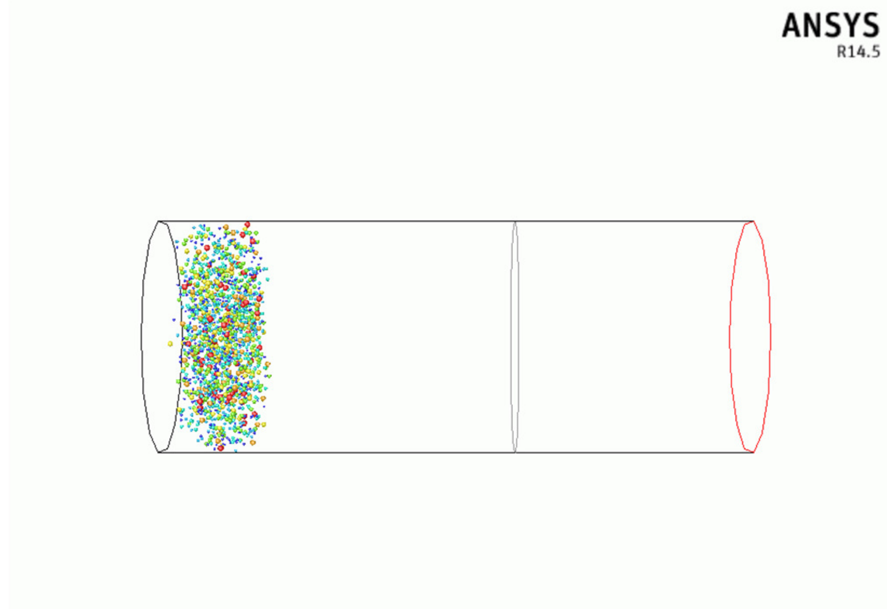
Simulating Erosion Using ANSYS Computational Fluid Dynamics

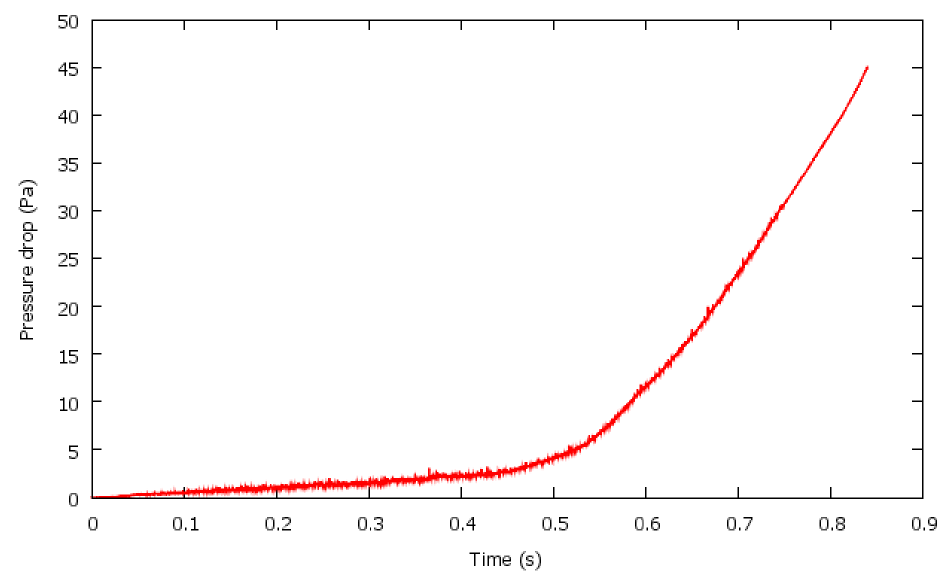


Vedanth Srinivasan, Ph. D.
Senior Technical Services Engineer

Outline

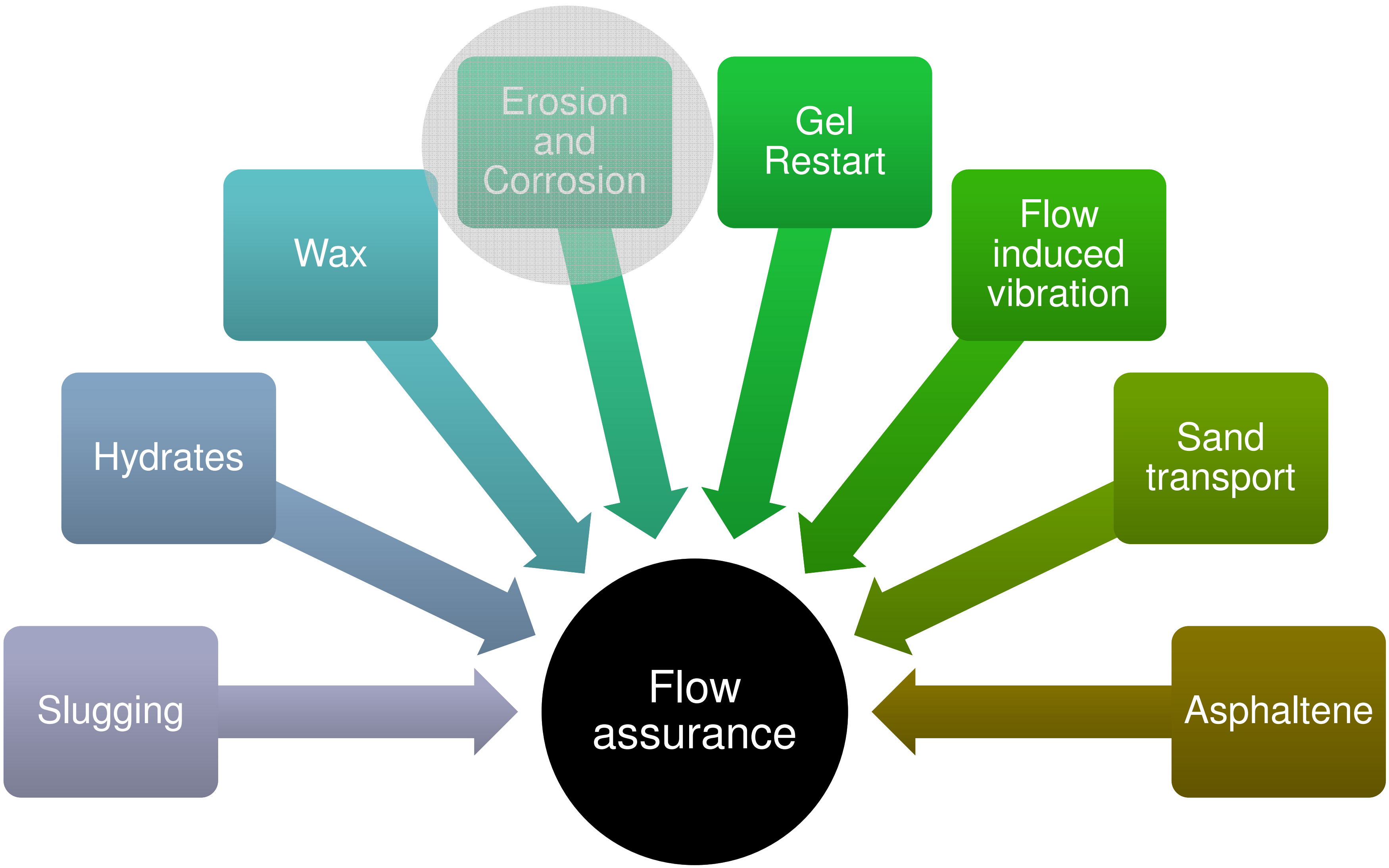
- Multiphase Advances in ANSYS CFD
  - Particulate modeling
  - Sand Management
  - Sand Transport in pipelines
- Erosion Modeling
  - Single Phase Erosion
  - Multiphase Erosion
  - Erosion Module
- Summary





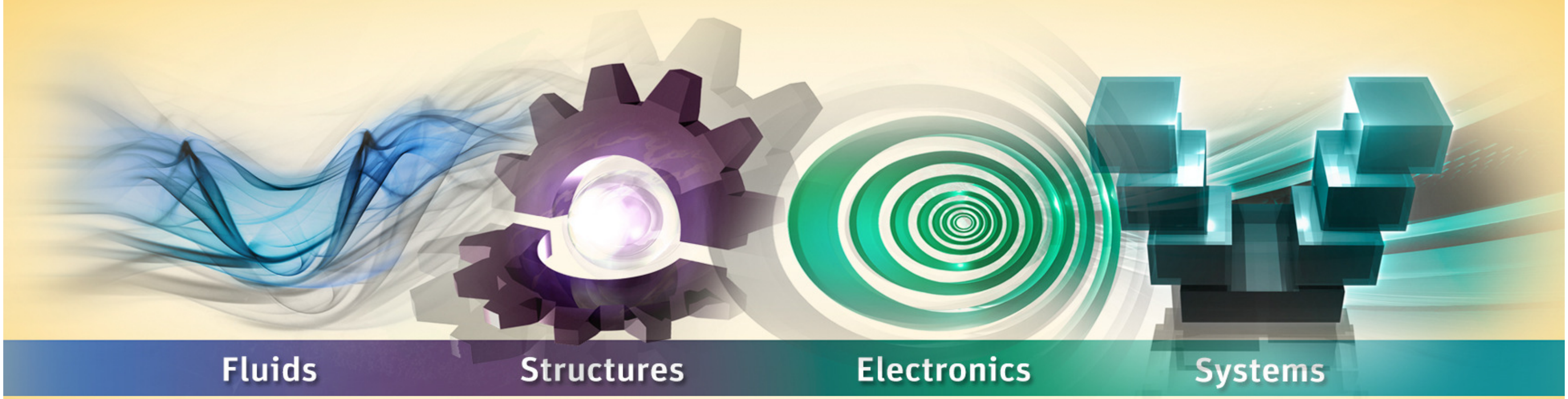
Sand Screen Modeling using CFD DEM

Leading Product Development Targeted to Application of ANSYS CFD to Flow Assurance



Realize Your Product Promise®

Predicting Particulate Erosion



ANSYS Erosion Process

- **Hydrocarbon wells produce a complex multiphase mixture of components including**
  - Hydrocarbon liquids – oil, condensate, bitumen
  - Hydrocarbon solids – waxes, hydrates
  - Hydrocarbon gases (natural gas)
  - Other gases – hydrogen sulphide, carbon dioxide, nitrogen
  - Water with dilute salts
  - Sand and proppant particles
- **Potential mechanisms that could cause significant erosion damage are:**
  - Particulate erosion
  - Liquid droplet erosion
  - Erosion-corrosion
  - Cavitation
  - It is generally accepted that particulates (sand and proppant) are the most common source of erosion problems in hydrocarbon systems

Sand and Particulate Erosion

- Sand Erosion of pipelines and equipment is a major problem
- Solids entrained in the fluid impinge the walls of piping and equipment causing in removal of wall material, reducing the service life.
- Erosion limits the expected life time of piping details, and is vital in risk management studies
- It is critical to predict the erosion damages in a flow system accurately

Eroded Tools

Failed Tool

Erosion & Flow Assurance

Sand Production & Flow Rate

- Gas systems work with high Velocities – more prone to erosion
- Particles in Wet gas systems can be trapped by liquid – severe erosion
- Slugging in pipelines generating periodic high velocities
- Unsteady production operation leads to sand accumulation

Particulate Flow

- Particulate erosion function of impact velocity (V^n – n upto 2-3 for steel surfaces)
- High density – high viscosity particles carried by flow than impact
- Low viscosity/low density fluids impact on walls very likely

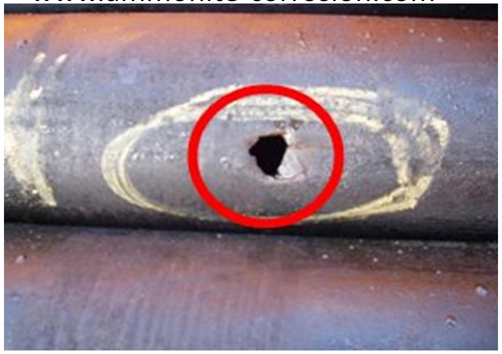
Particulate Property

- Small particles carried away by fluid than causing impact
- Large particle result in high bouncing off
- Hard particles create more erosion than soft particles
- Sharp particles create more damage than rounded particles

A Look at Modeling Benefits

- Overcome testing and measurement issues
- Understand flow behavior for effective mitigation and risk assessment
- Study and prepare for dynamic field variations
- Evaluate multiphase interactions and overall flow assurance
- Detailed account of pitting and estimate mechanical strength and material life


www.ammonite-corrosion.com


www.petroceram.com

Typical Example – Control and Delay Erosion

Problem

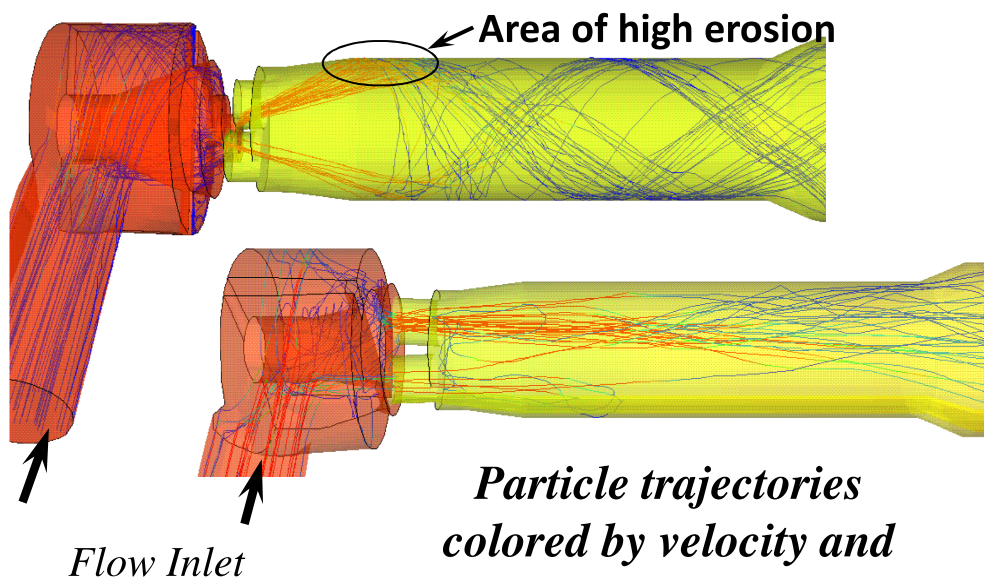
- Particle impact at the small area with high velocity causing excessive erosion

Solution

- Modify exit flow from choke without causing additional pressure drop.
- ANSYS multiphase flow solutions to understand and change particulate flow patterns

Result

- Modified choke geometry leads to flow streamlines parallel to exit pipe.
- Increase particle impact area while reducing particle impact velocity
- Reduce chock maintenance and replacement cost

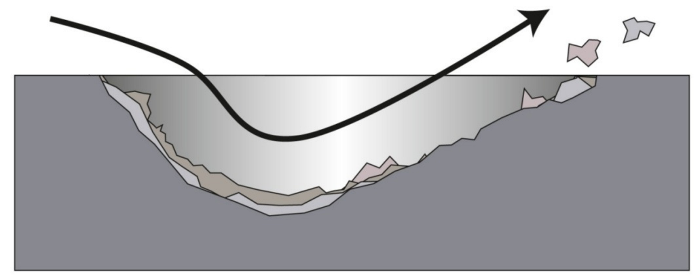


Particle trajectories colored by velocity and associated erosion area for two chokes

Courtesy of DNV

Challenges in Erosion Modeling

- Erosion is Complex Phenomena, depends on
  - Particle properties and particle tracks
  - Local Flow and turbulence field
  - Surface conditioning
  - Multiphase effects
    - Erosion shield due to solid accumulation
    - Damping effect due to liquid film
  - Effect of local cavities due to material removal



- Not possible to obtain a universal erosion model
  - Different models for different flow characteristics
  - Always need experimental data to tune model parameters

Erosion Modeling – Traditional approach

- Physical testing of new prototype designs
  - Time consuming
  - Degree of trial and error
- Semi-empirical models and correlations of erosive wear
  - Limited to predicting peak values of wear
  - Usually exist only for simple standard geometries
  - API RP 14E
    - Ad-hoc methods that are independent of the sand production rate
    - "erosional velocity"
      - Based on an empirical constant (C-factor) and the fluid mixture density

$$V = \frac{C}{\sqrt{\rho}}$$

Erosion Modeling – CFD approach

- CFD modeling provides the user with detailed information on the exact location and magnitude of the erosive wear.
- Single phase Computational Fluid Dynamics simulations
  - Applicable for dilute particle phase
  - Based on Eulerian-Lagrangian methodology
    - Single phase simulation + DPM
  - Lots of literature and many erosion models
  - Provides detailed information on the exact location and magnitude of the erosive wear
  - Potential to allow design to be optimized prior to testing

Erosion Modeling – CFD approach

- **Multiphase CFD Simulations**
  - More realistic for full particle loading from low, medium to high range
  - Based on Eulerian-Granular multi-fluid approach
  - Captures four-way couplings including fluid-particle, particle-fluid, particle-particle, and turbulence interactions
  - Capture particle shielding and liquid damping effects

CFD Modeling Complement Experimental testing for Erosion Predictions

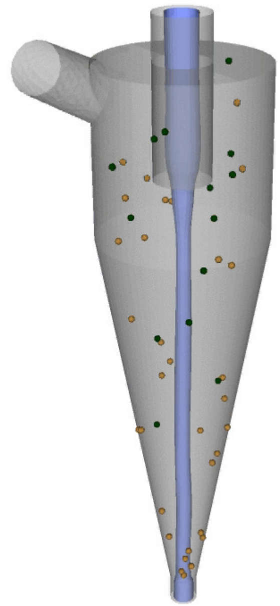
Erosion Modeling Considerations: Particle Transport

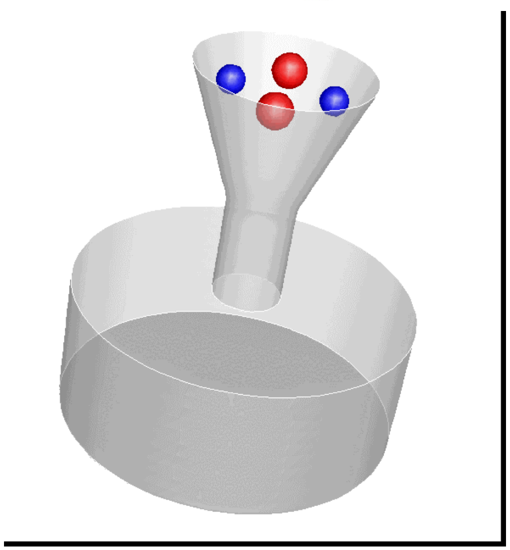
Multi-fluid Models

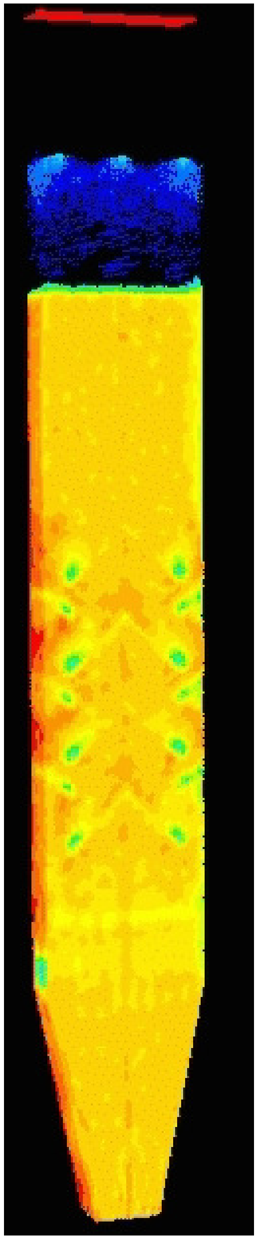
- Euler-Granular Models
- Drag laws calibrated
- Applies Kinetic Theory of Granular flow

Particle Models

- Discrete Phase Model (DPM) for dilute phase
- Particle tracking model with probabilistic collision model
- Dense DPM for dense flows with large size distributions
- Macroscopic Particle Model





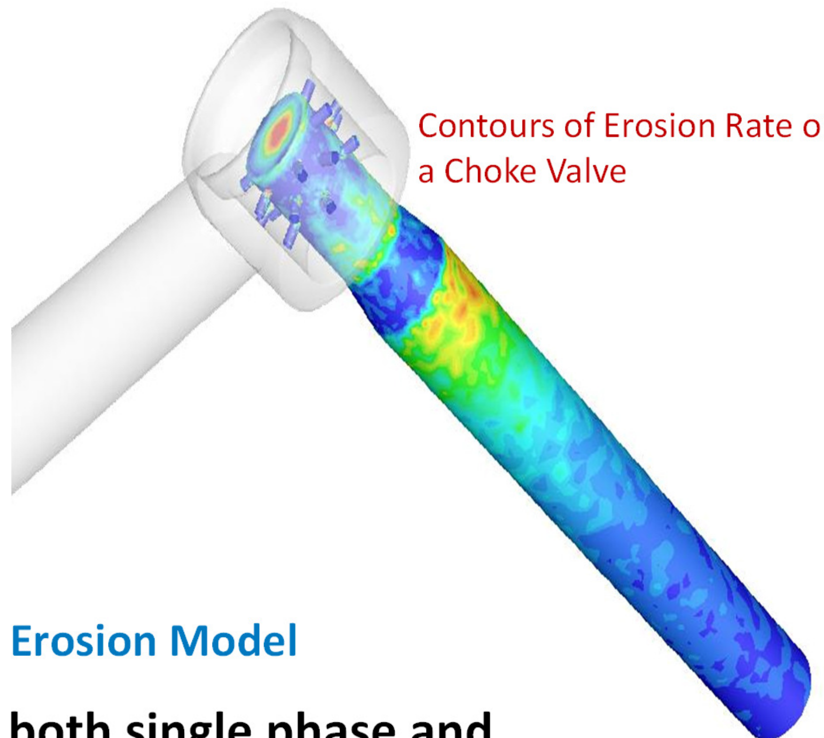


Components of Erosion Modeling

- Track Particulate Behavior in Dilute or Dense Systems
- Evaluate Fluid-Particulate interactions within single/multiple fluidic phases
- Assess Particle-Particle interactions (Collision models or dense systems)
- Particle-Wall Interactions
- Material Degradation & Flow Modulations

A Wide Array of Erosion Models Available

- **Industry accepted Erosion Models are built-in in Erosion Module**
  - FLUENT's Default Erosion Model
  - Mclaury et. Al Erosion Model
  - Salama & Venkatesh Erosion Model
  - Finnie Erosion Model
  - DNV Erosion Model
  - Oka Erosion Model
  - Zhang (ECRC) Erosion Model
  - Grant and Tabakoff Erosion Model
  - **Erosion Model based on Wall Shear Stress**
  - **Flexibility to incorporate any user-defined Erosion Model**



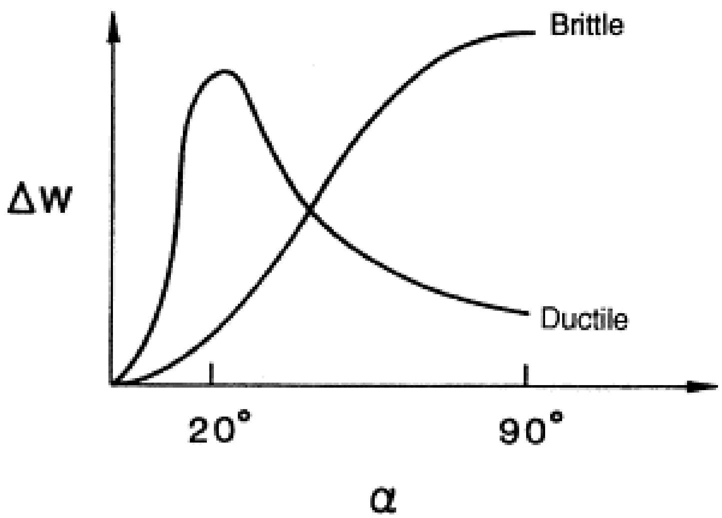
Contours of Erosion Rate on a Choke Valve

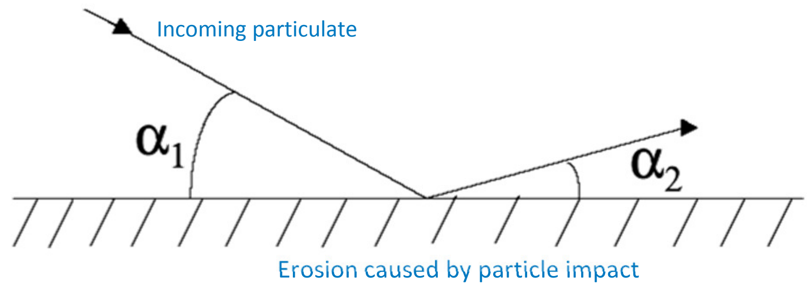
- **All these Erosion Models are available for both single phase and multiphase CFD simulations**
  - Eulerian-Eulerian, Eulerian-Granular, VOF, DPM, DDPM, DEM

ANSYS Solution for Erosion Modeling

- **Typical variables affecting Erosion rate**
  - **Angle of impingement**
  - **Impact velocity**
  - **Particle diameter**
  - **Particle mass**
  - **Collision frequency between particles and solid walls**
  - **Material properties for particle and solid surface**
  - **Coefficients of restitution for particle-wall collision**

$$R_{\text{erosion}} = \sum_{p=1}^{N_{\text{particles}}} \frac{\dot{m}_p C(d_p) f(\alpha) v^{b(v)}}{A_{\text{face}}}$$





m	:	Mass flow rate of the particles
f(a)	:	Impingement angle function
V	:	Particle impact velocity
b	:	Velocity exponent
$C(D_p)$	:	Particle diameter function

Erosion Model for Dense System

Dense DPM accounts for particle-particle interaction and solid volume effect on fluid phase

ABRASIVE EROSION: Erosive due to relative motion of solid particles moving nearly parallel to a solid surface

Erosion Model Based on Wall Shear Stress

$$ER_w = A \times V^n \times SS$$

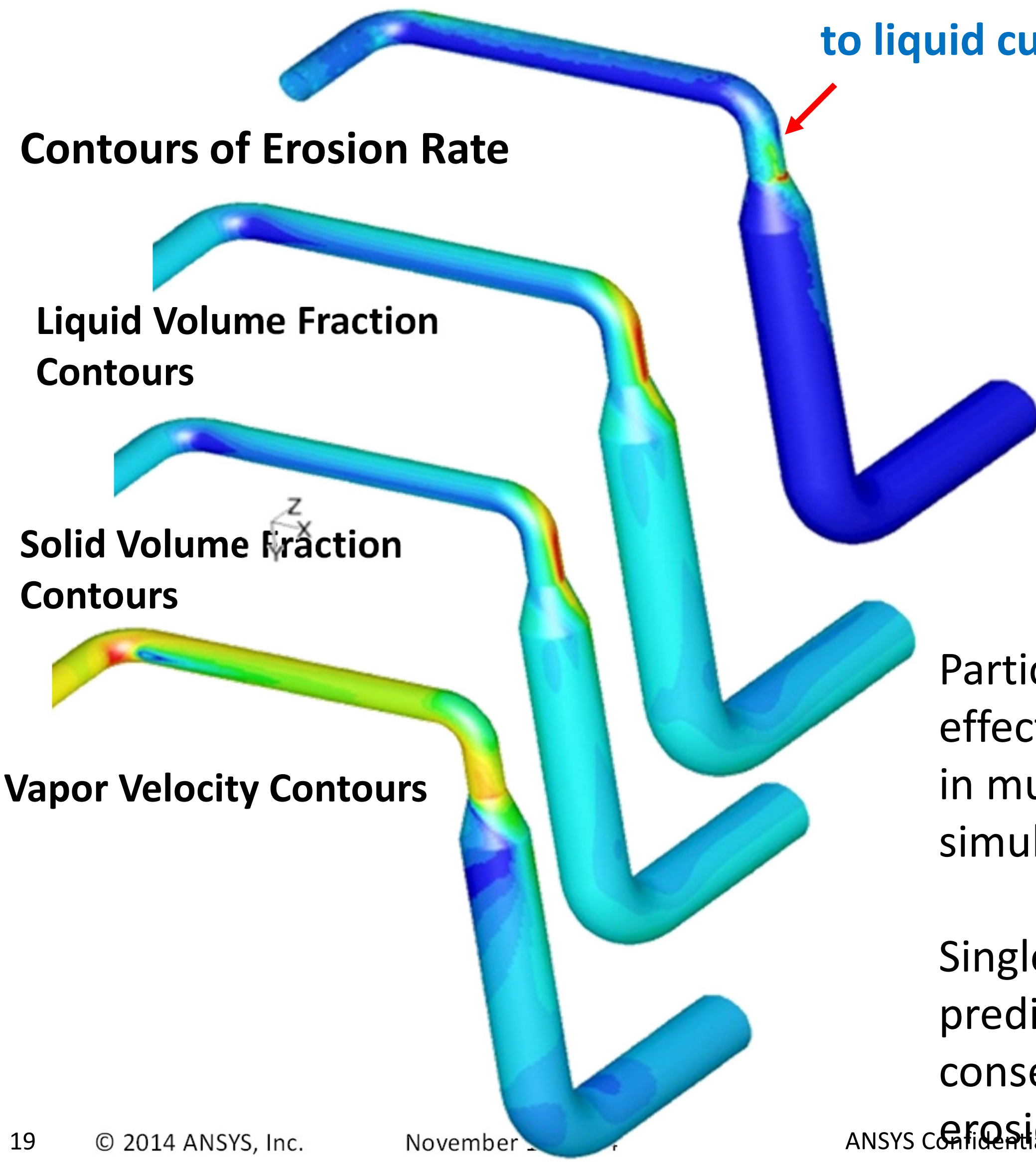
A = Constant (diameter function)
n = Velocity Exponent
SS = Wall Shear Stress

Overall Erosion Rate

$$ER = ER_{sp} + ER_w$$

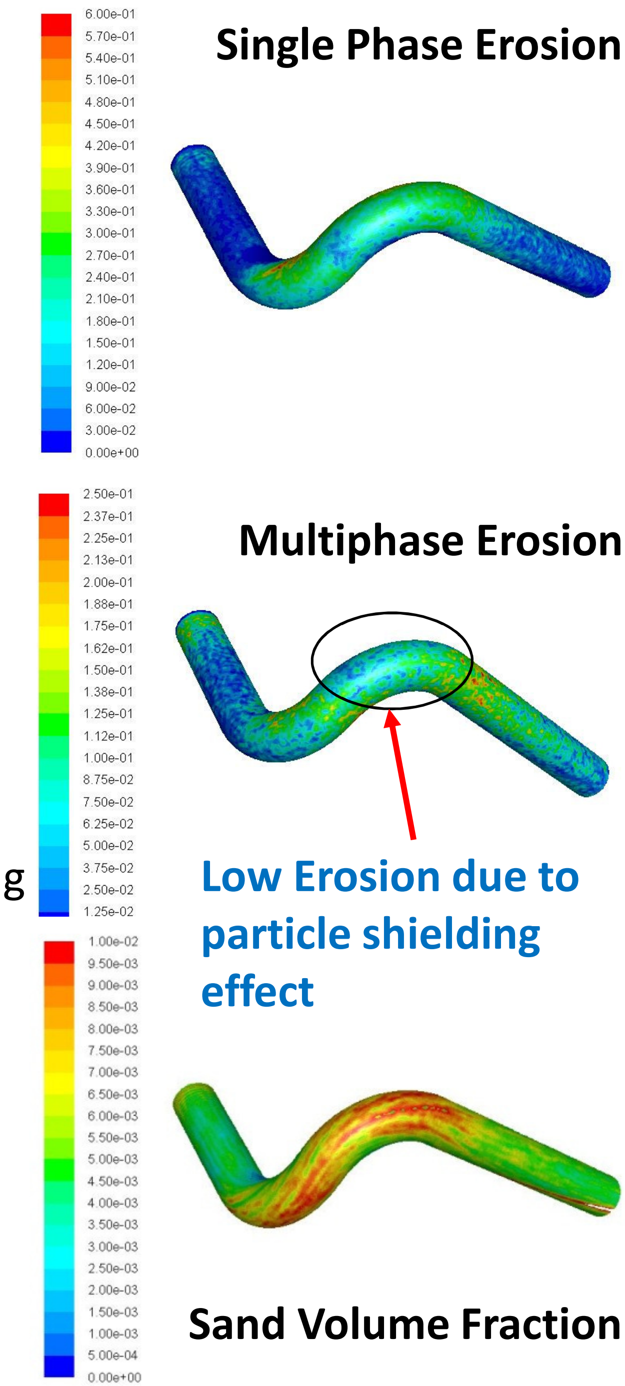
ANSYS Multiphase Erosion

Low Erosion due to liquid cushion



Particle shielding effect captured in multiphase simulation

Single phase predicts conservative erosion



Low Erosion due to particle shielding effect

ANSYS Coupling Erosion with MDM

- **Removal of solid surface material due to Erosion creates localized cavities which affect the flow field, particle tracking and hence the erosion.**
- **Such dynamically changing eroded curvature effect needs to be incorporated for more accurate erosion calculation**
- **ANSYS FLUENT has developed Erosion-MDM connectivity to dynamically deform the solid wall surface based on local erosion rate**

Erosion Modeling Workflow

- **Easy to use template based tool to perform an erosion simulation through a single GUI Panel**
  - User inputs drive the UDF and journal file in the background
  - Multiple Erosion Models to choose
  - Built-in defaults for DPM settings
  - Customized post processing for erosion rate
- **Ability to compare multiple erosion models by single click of button**
- **Complete Automation of Erosion-MDM coupled simulation**
  - Including post processing and animation
- **Allows for multiphase erosion simulations**
  - Choose secondary phase or mixture phase velocity field and fluid properties for particle tracking
  - Abrasive erosion model for flow of dense slurry

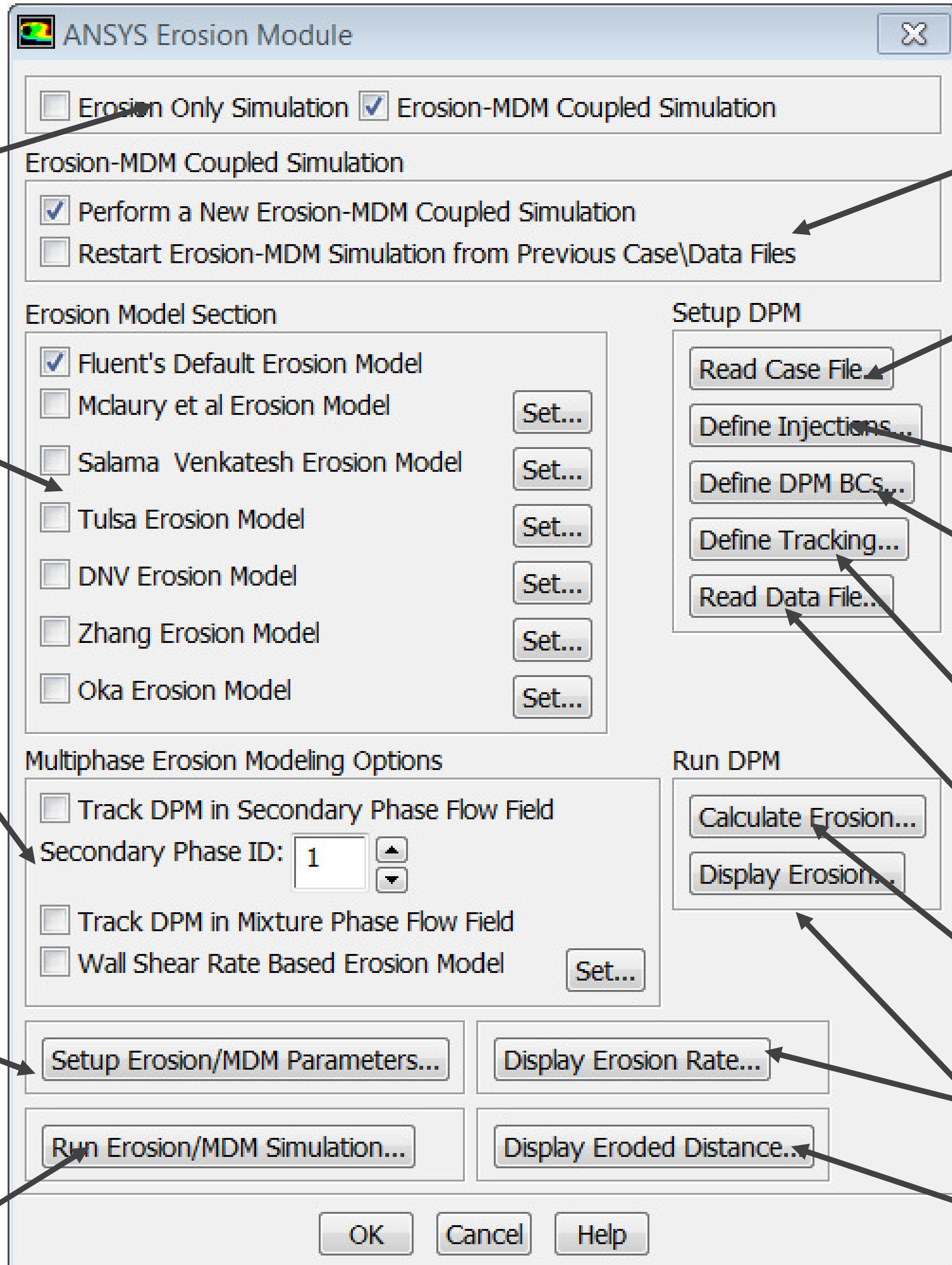
Option to run erosion-only or erosion-MDM coupled simulation

Various erosion models to choose from

Option to choose secondary phase or mixture phase flow field and properties for DPM particle tracking

Opens panel to define required parameters for Erosion-MDM coupling

Opens panel to start erosion-MDM simulation



Main Panel

Option to start a new Erosion-MDM simulation or restart from the existing data file at previous time interval

Opens Fluent's panel to read the case file for the flow field

Opens Fluent's DPM injection panel to define particle injections

Opens Fluent's boundary condition panel to set DPM BCs for wall zones

Opens Fluent's DPM panel to set parameters for particle tracking

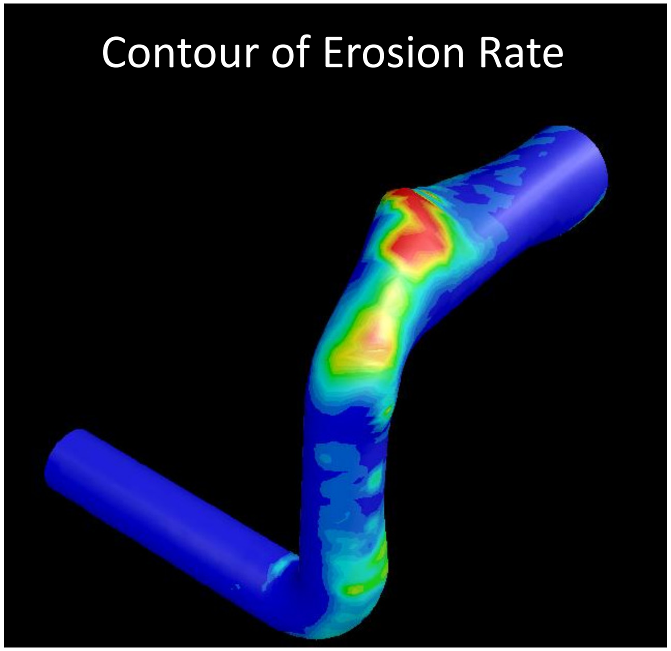
Opens Fluent's panel to read the data file for the flow field

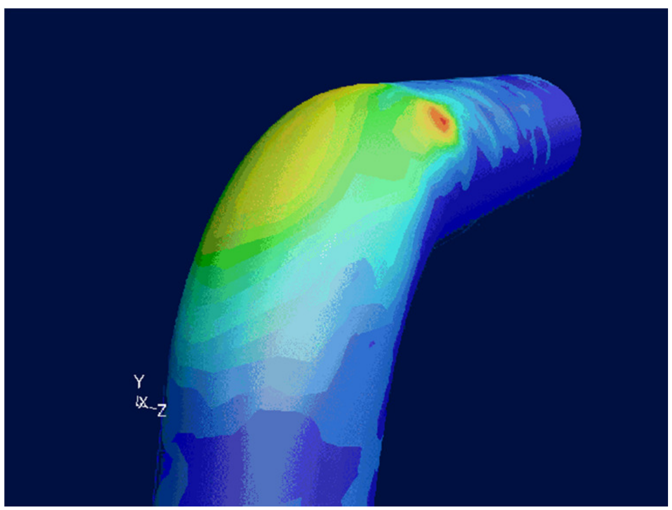
Opens Fluent's panel to start iterating for erosion-only analysis

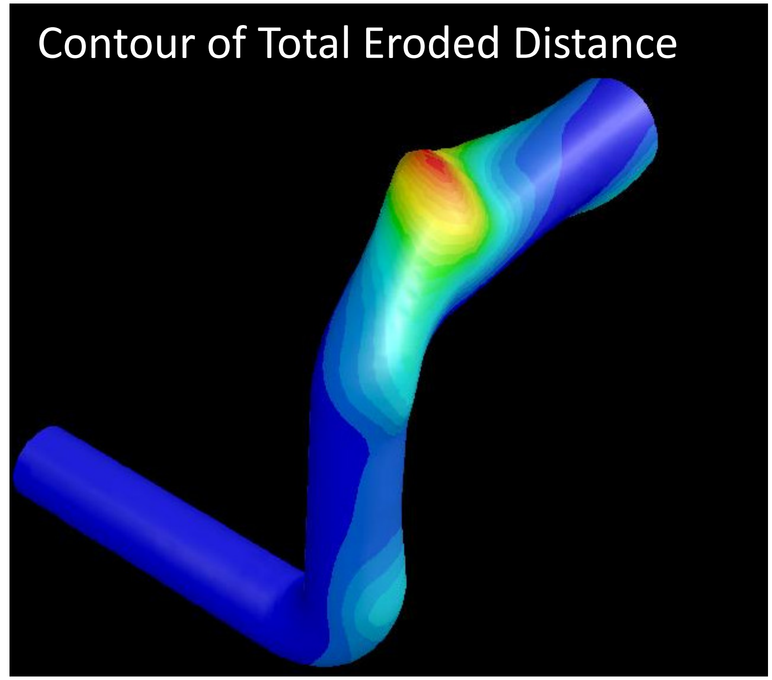
Display erosion rate on all wall zones

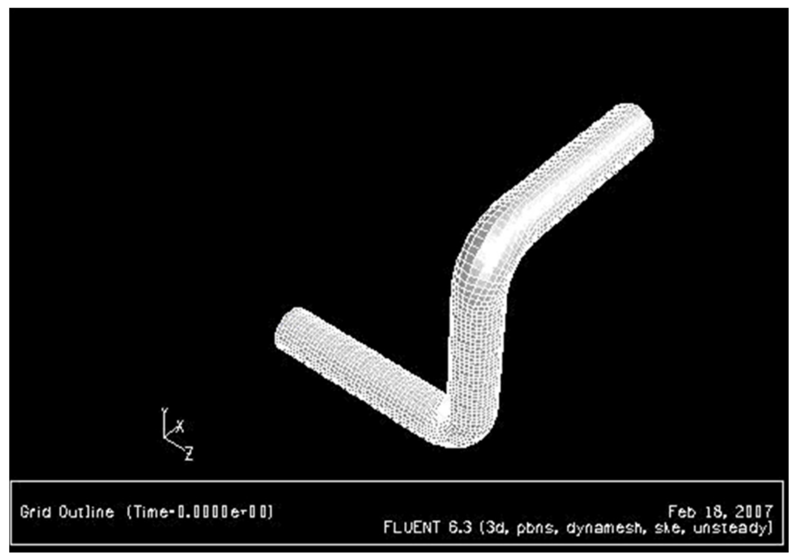
Display cumulative eroded distance at wall zones

Erosion - MDM


Contour of Erosion Rate



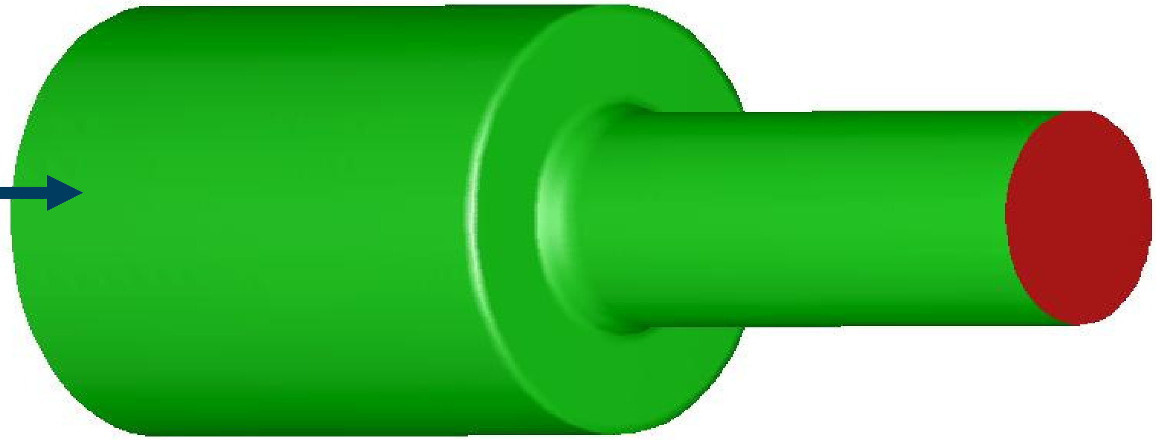

Contour of Total Eroded Distance



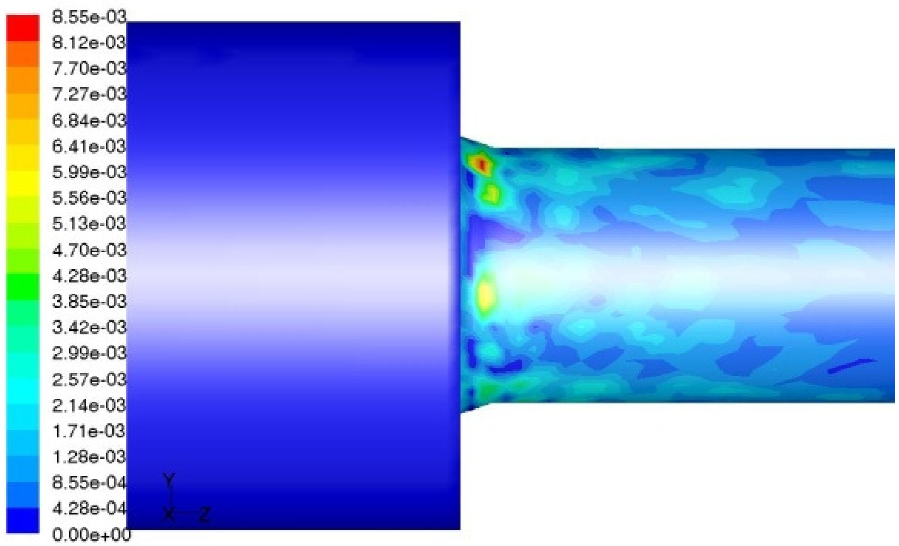
Erosion - MDM

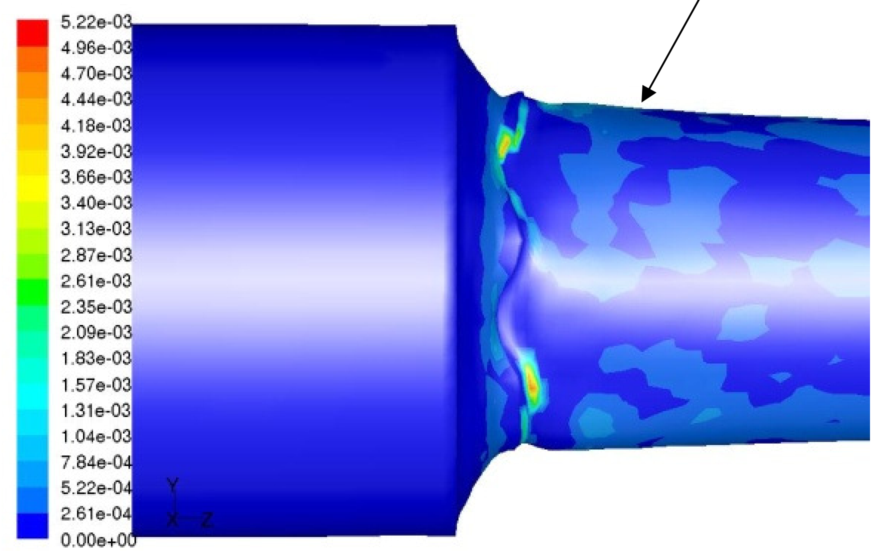
Eroded Material is Removed -> Better Material Thickness Prediction

FLOW



Larger ID
After 42 hr





Plots of erosion contours in a 4 inch test case

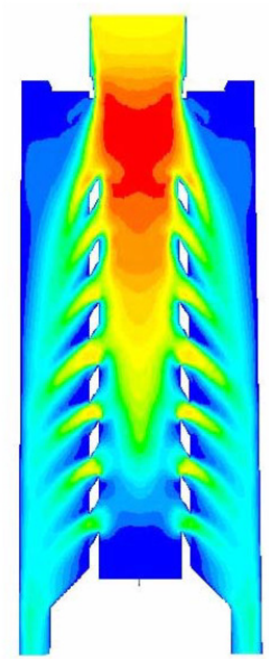
Case-Study Tool Erosion in Gravel Pack: (Erosion for Dense Slurry)

CFD Simulation to analyze flow field and erosion pattern in frac pack tools

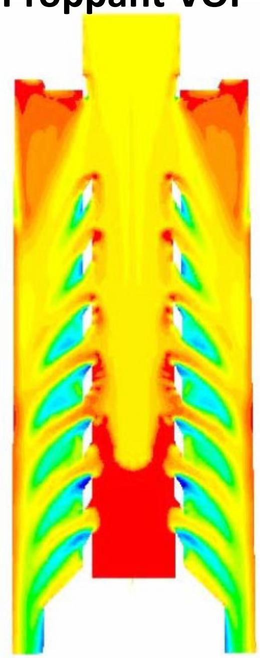
Calibration of erosion model based on lab tests and Erosion pattern compared with large scale tests.

Wall shear stress based erosion included

Fluid Velocity



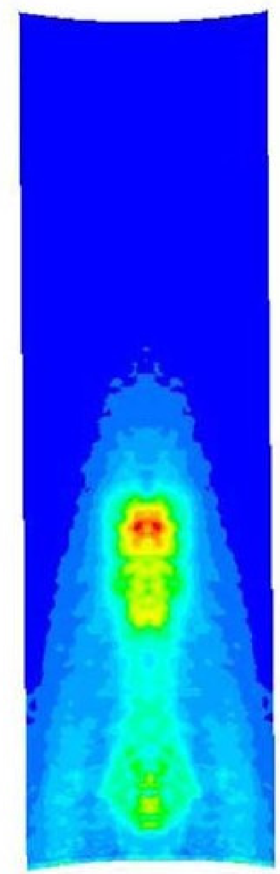
Proppant VOF



Turbulent Slurry flow with high proppant concentrations

Non-newtonian fluids

Calibration of Impact angle function



Erosion pattern on the inside surface of upper extension sleeve

OTC 17452 paper by Halliburton

Summary

- **ANSYS CFD provides platform for multi-physics, multi-scale and multi-components configurations of particulate flows**
  - **MPM, DPM, DDPM, DEM, Eulerian-Granular**
- **ANSYS CFD equipped with all required modeling needs for erosion predictions, including**
  - **Multiphase flow modeling for dense slurry**
  - **Erosion-MDM coupling**
- **Actively working with TUSMP and E/CRC**