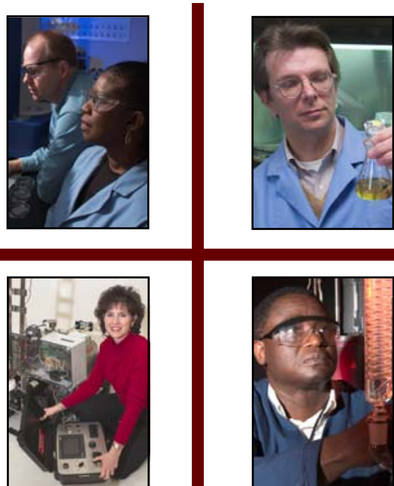
# Predicting Slurry Pump Performance in Nuclear Waste Storage Tanks



SAVANNAH RIVER NATIONAL LABORATORY

We Put Science To Work

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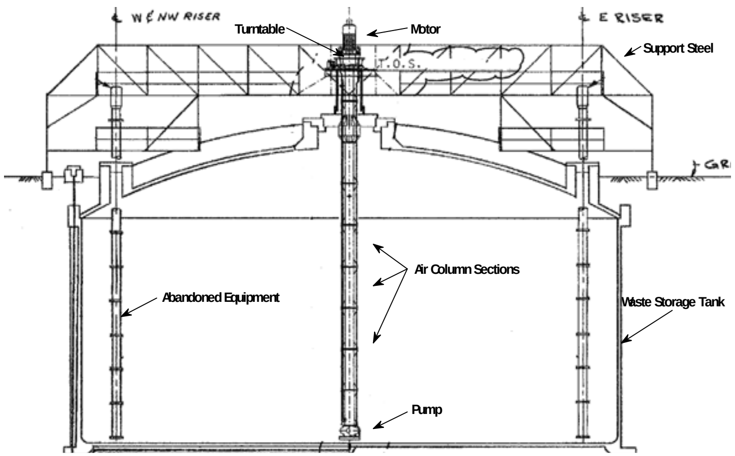
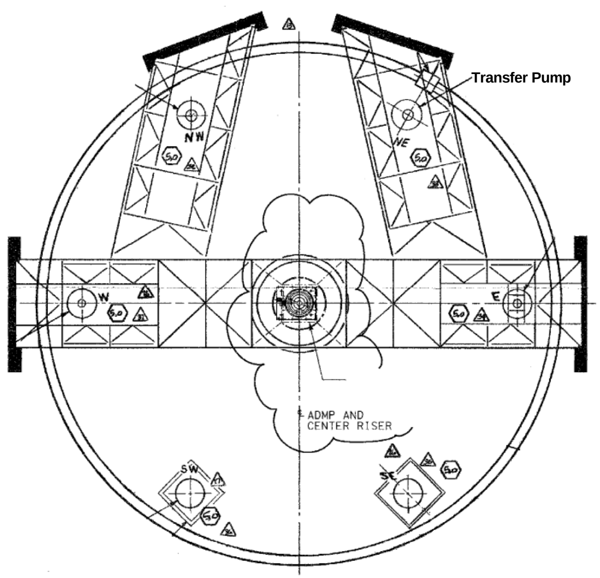
Process Engineering
1/18/08

# ABSTRACT

- **Residual radioactive waste was removed from a waste tank in the F-Area Tank Farm (FTF) at Savannah River Site (SRS), using the advanced design mixer pump (ADMP).**
- **Known as a slurry pump, the ADMP is a 55 foot long pump with an upper motor mounted to a steel super structure**, which spans the top of the waste tank. The motor is connected by a long vertical drive shaft to a centrifugal pump, which is submerged in waste near the tank bottom. The pump mixes, or slurries, the waste within the tank so that it may be transferred out of the tank.
- **The tank is a 1.3 million gallon, 85 foot diameter underground waste storage tank, which has no internal components such as cooling coils or structural supports. The tank contained a residual 47,000 gallons of nuclear waste, consisting of a gelatinous radioactive waste known as sludge and particulate zeolite.** The prediction of the ADMP success was based on nearly thirty years of research and the application of that research to slurry pump technology. Many personnel at SRS and Pacific Northwest National Laboratories (PNNL) have significantly contributed to these efforts.
- This presentation summarizes that research, which is pertinent to the ADMP performance. In particular, **a computational fluid dynamics (CFD) model was applied to predict the performance of the ADMP in a waste tank.**
- **Essentially, this presentation consists of a brief summary of several publications for the American Society of Mechanical Engineers, 2004, Fluids / Heat Transfer Conference.** Each of the papers, Parts I – IV, discuss modeling, testing, and the historical performance of slurry pumps, which were needed to predict the FTF results.
- **The CFD model results and the experimental validation of those results will be published in the January, 2008, ASME Journal of Fluids Engineering.**

# ADMP Tank Installation



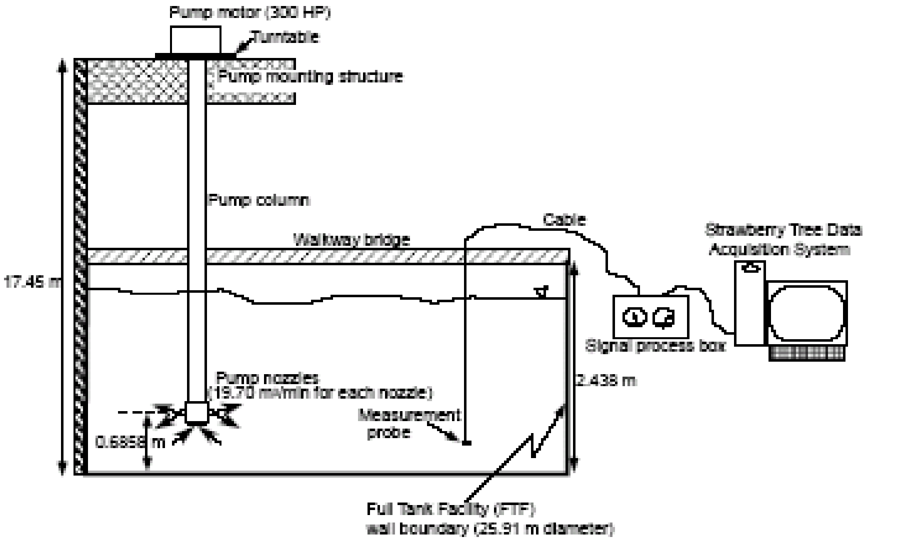




- Single pump installed in the center of an 85 feet diameter, 33 feet tall, underground waste storage tank.
- No internal tank obstructions

# ADMP, Advanced Design Mixing Pump

# Test Facility


- Pump installed off center in a full scale, 85 feet diameter, 8 feet deep tank.
- Rotating walkway permitted velocity measurements anywhere in the tank

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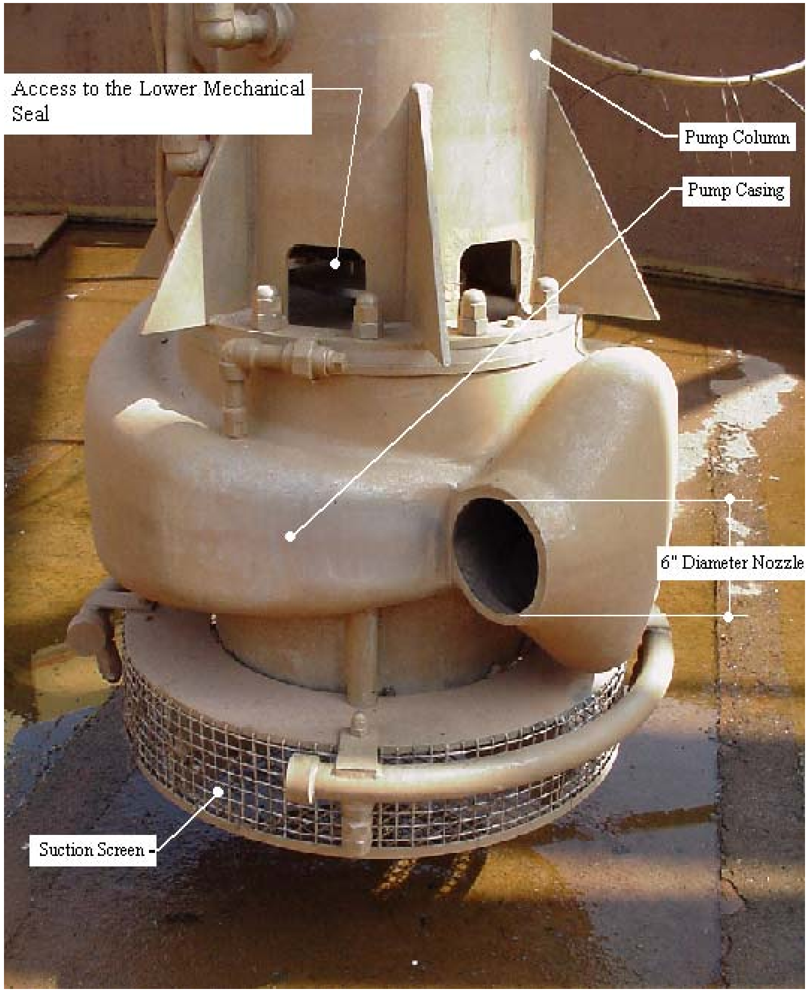
# ADMP Construction




- **ADMP = 10400 gpm pump**
- **Rotates at 1/5 – ½ rpm**
- **Other slurry / mixing pumps at SRS**
  - **Quads = 5200 gpm**
  - **Standards = 1200 gpm**

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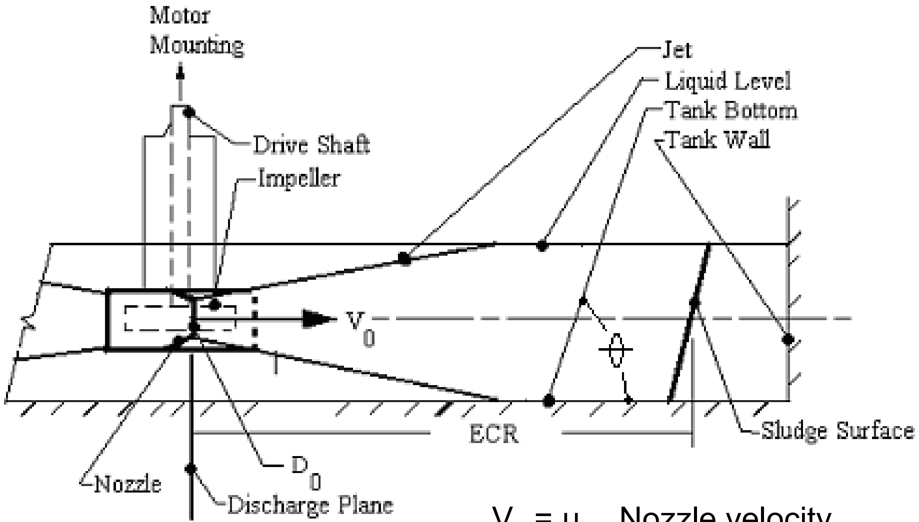
# Sludge mixing, Churnetski




$V_o = \mu_0$ Nozzle velocity
$D_0$ Nozzle diameter
$\rho$ Density
$\tau$ Yield stress

- **Predicted by the effective cleaning radius (ECR), which is derived from shear equations.**

$$\mathrm{ECR} = 0.40 \cdot D_0 \cdot V_0 \cdot \sqrt{\frac{\rho}{\tau}} \cdot \left(100 \frac{\mathrm{cm}}{\mathrm{m}}\right)$$

- **Additional erosion effects not modeled**
- **SRS "Rule of thumb"**
  - **3 ft/sec minimum velocity needed to suspend sludge**
  - **1 ft/sec average tank velocity needed to keep sludge suspended**

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# Tank Waste

- **Sludge:**
  - NaNO3, NaNO2, NaAlO2, Na2CO3, and Na2SO4
  - Radioactive and stable fission products (< 1% each)
  - Fe(OH)3, Al(OH)3, MnO2, CaCO3, Zeolite, and SiO2.
- **Zeolite**
  - Porous, granular alumino-silicate solid, which may have its interstitial voids filled with large unattached molecules or water

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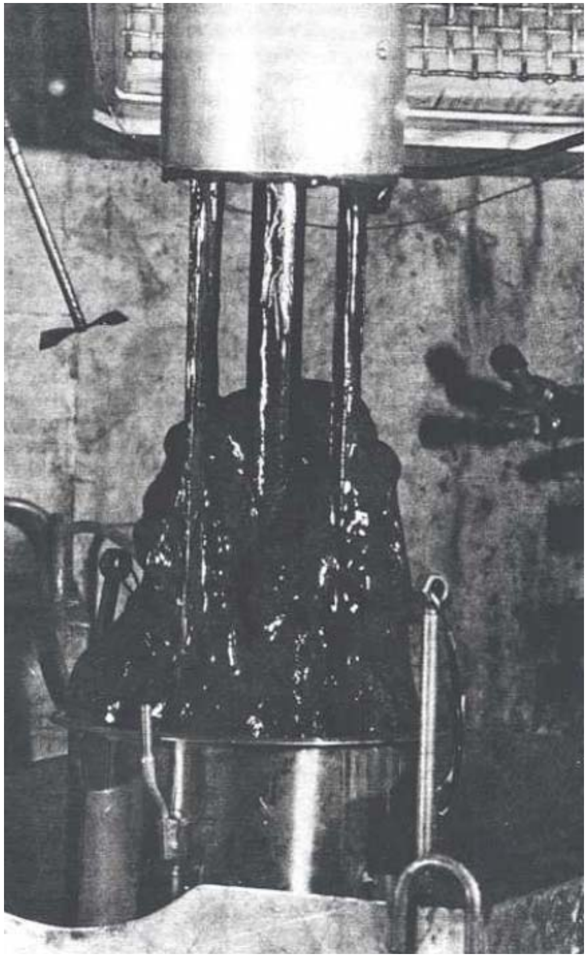
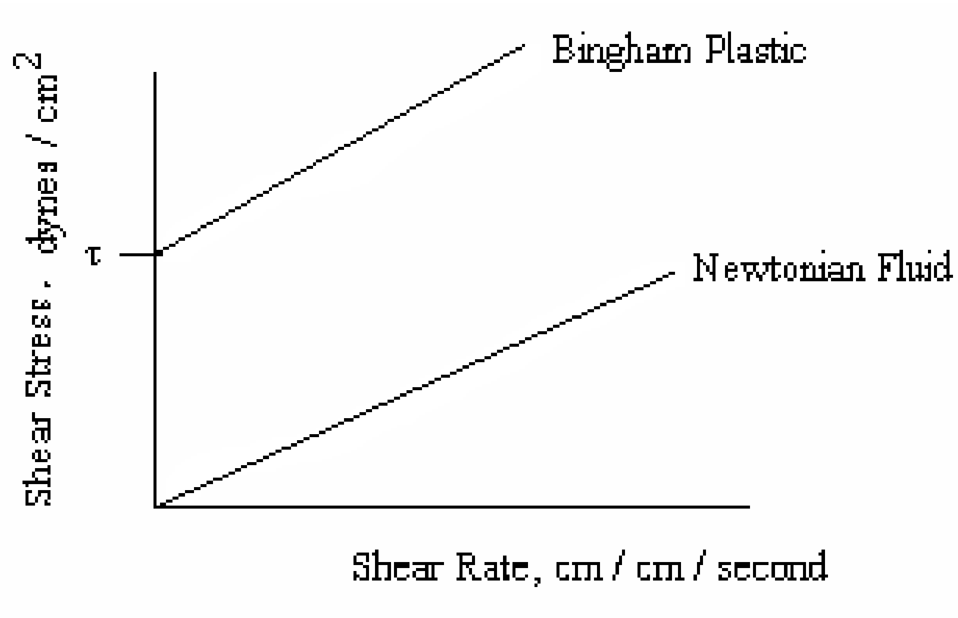
# Sludge / Bingham Plastic

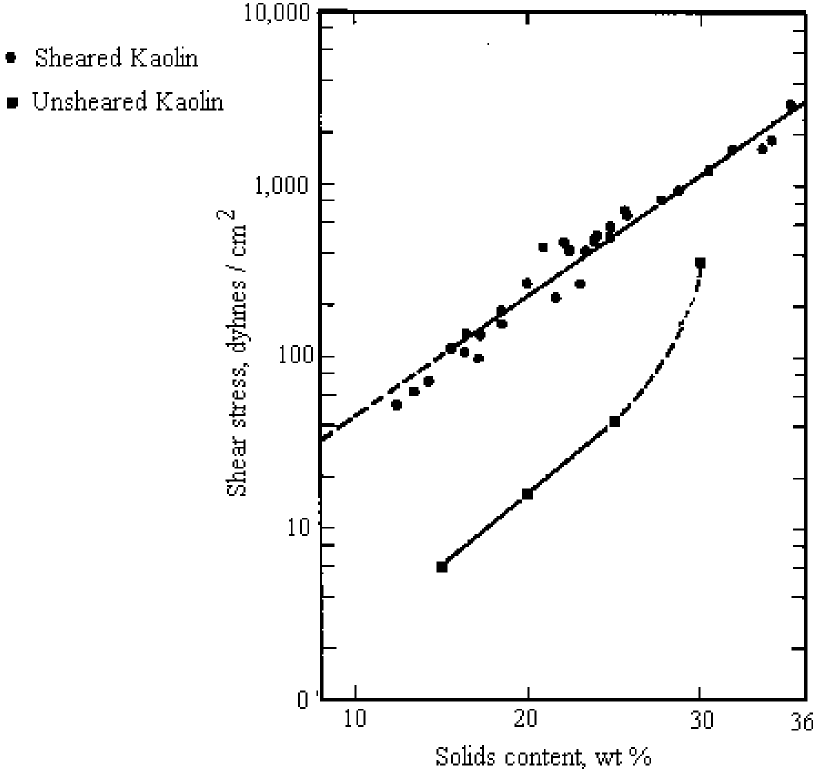


Stone



# Kaolin Modeling

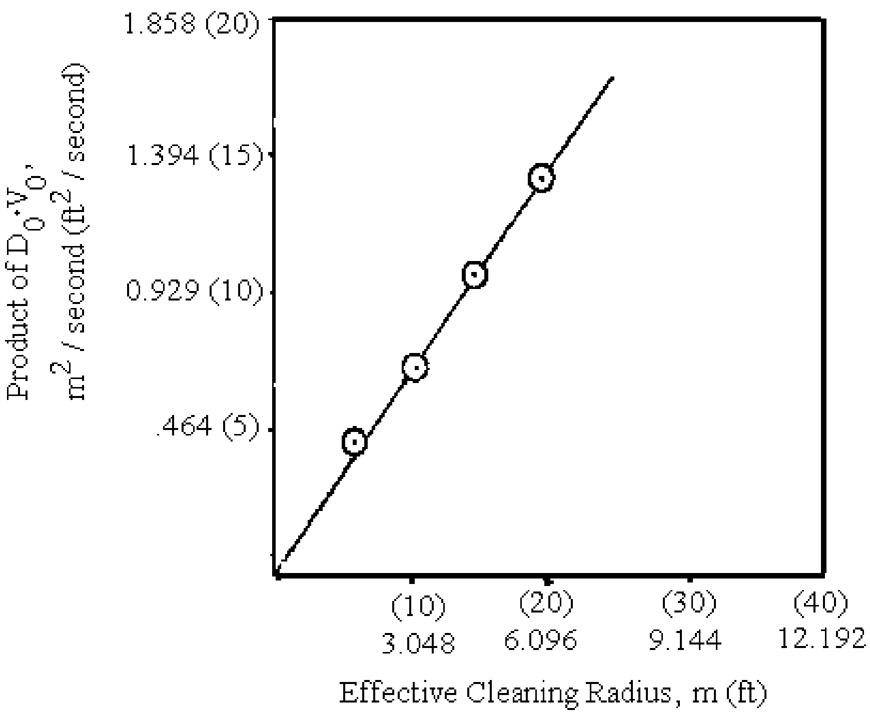
- Material properties similar to sludge
- Mixing breaks up the Kaolin platelets and increases the yield stress up to 30 hours of mixing
- Indexed pump increased the ECR by ≈ 3 % at the test facility for a free jet away from the wall




Selby


Hansen

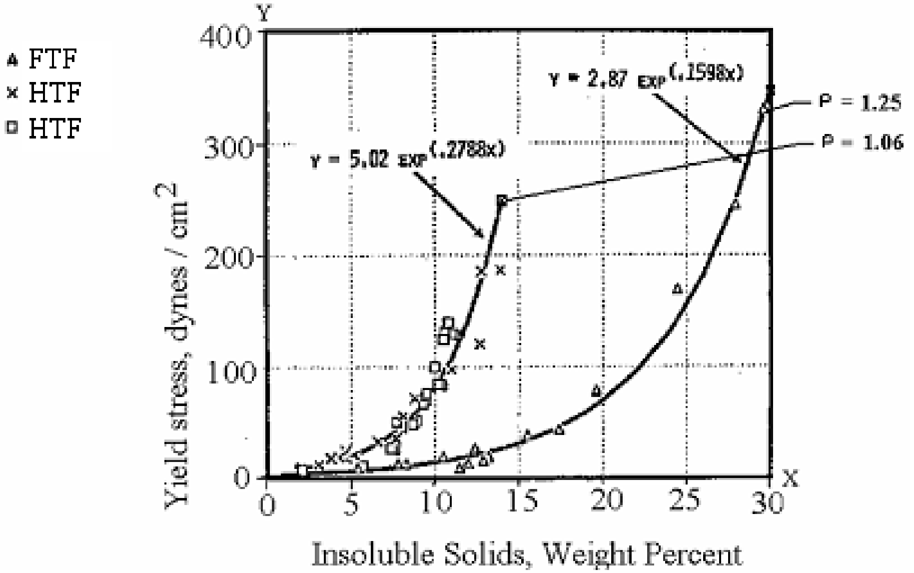
# Kaolin Test Results




Churnetski

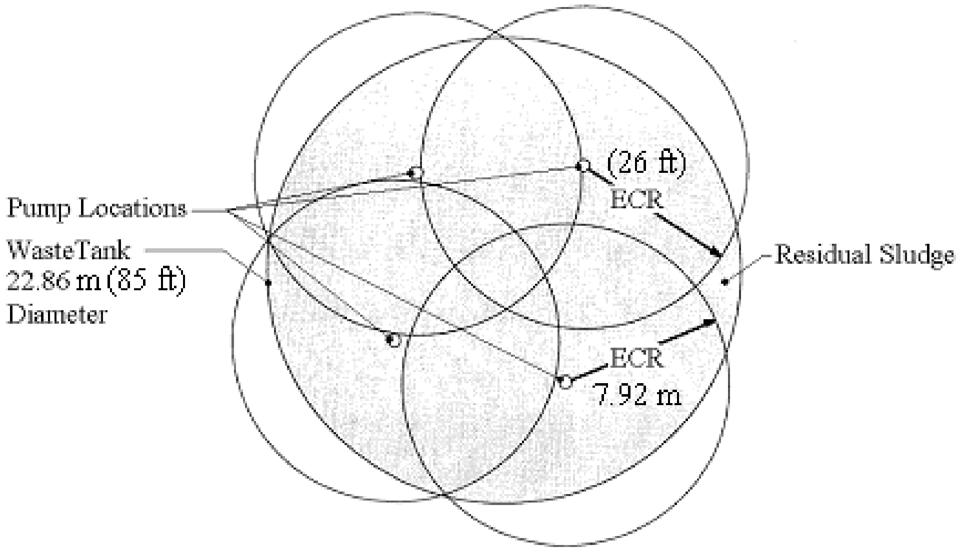
- **The effective cleaning radius is proportional to the pump discharge diameter and velocity**
- **Demonstrated with Kaolin tests**

# Sludge Properties, Hamm




- Worst case sludge properties assumed
- Bounding sample was allowed to settle for a year

# Historical Results




- Previous FTF facility results
  - ECR accurately predicted residual waste in a tank, which contained dried, solid, sludge and installed cooling coils
  - Indexing the pump removed additional waste
  - Historical rheological data available for the figure shown
  - Calculated a 2.27 feet / second minimum velocity to suspend waste
- Rheological data unavailable for the case considered here
  - Historical transfer data was similar for both cases
- Material properties assumed to be similar for use in the ECR equation



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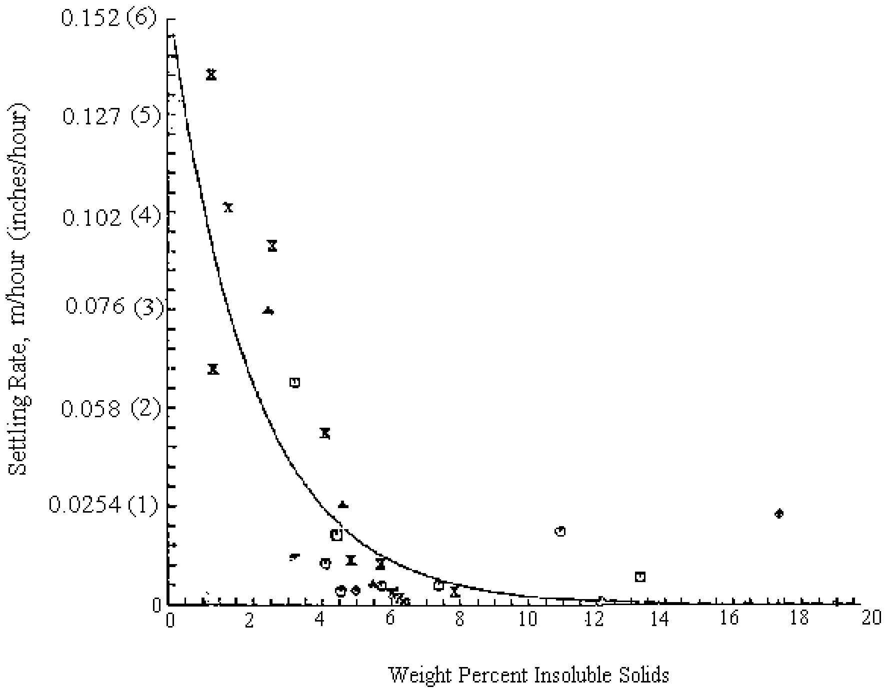
# Suspension



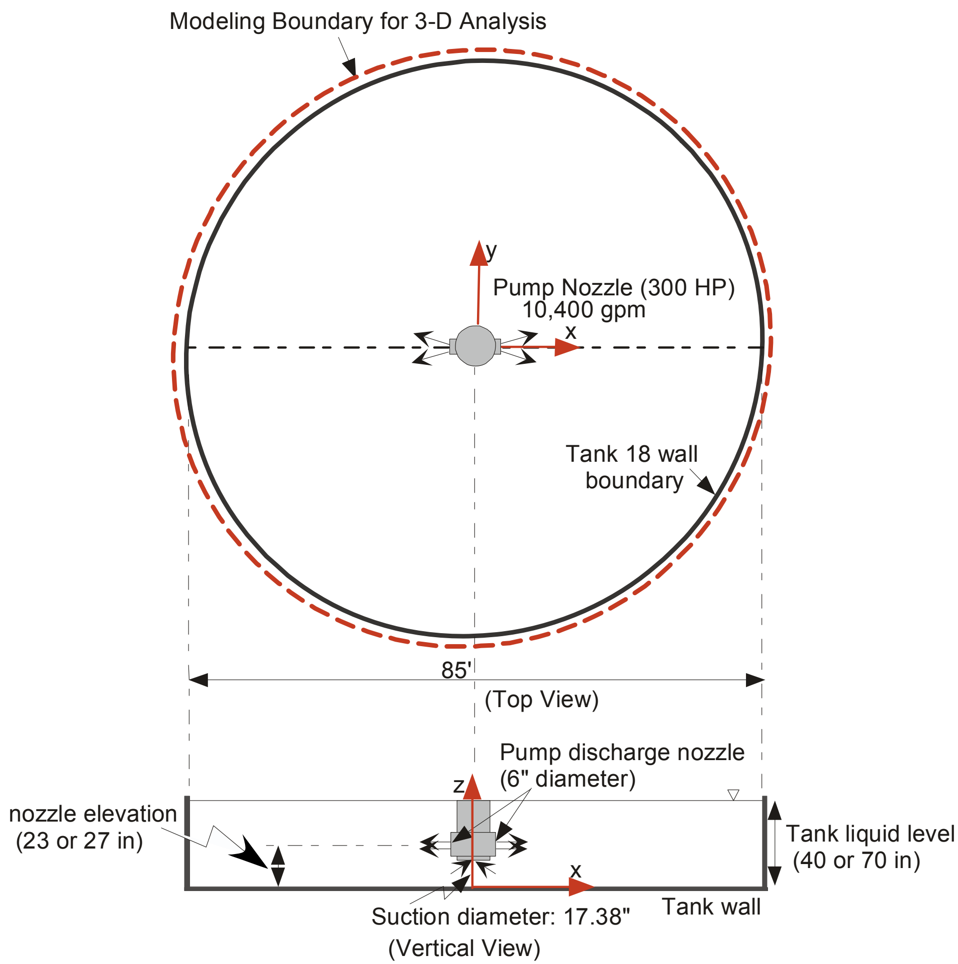

Motyka

- **Limited data on settling rates of sludge indicated effective mixing**

$$V_s \propto D_p \cdot g_c^2 \cdot \left( \frac{\rho_p - \rho_L}{18 \cdot \mu} \right)$$

- **Operations experience indicated that sludge settling was not expected to be a problem**

# CFD models




- **Fluent® models**
  - **Validated off-center pump model. Single phase fluid,**

    **SpG = 1.0**
  - **Final central pump model shown. SpG = 1.2**
- **260,000 elements were used in the CFD models**
- **Uniform flow at the nozzle exits**
  - **Previous research showed that tangential nozzles provide higher flow rates than radial nozzles for identical impellers**
  - **This work showed that smaller nozzles with equivalent $\mu_0$ D provided higher velocities along the nozzle discharge plane**
- **Selection of the κ-Є turbulence model provided better agreement with experiment**

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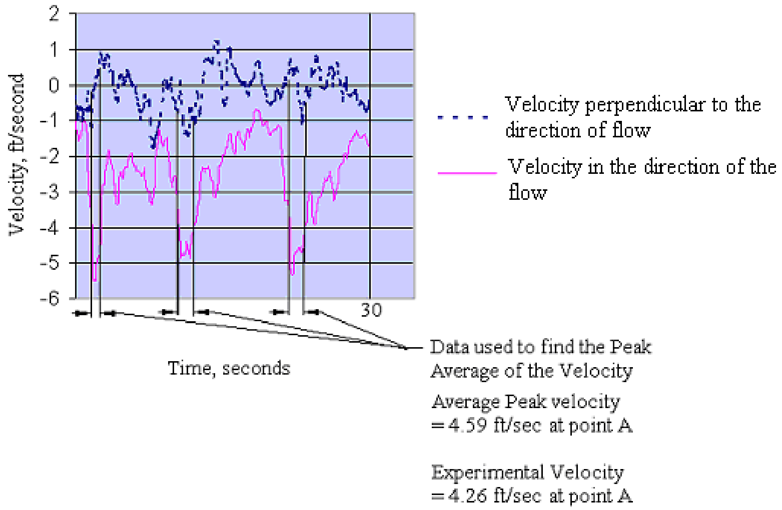
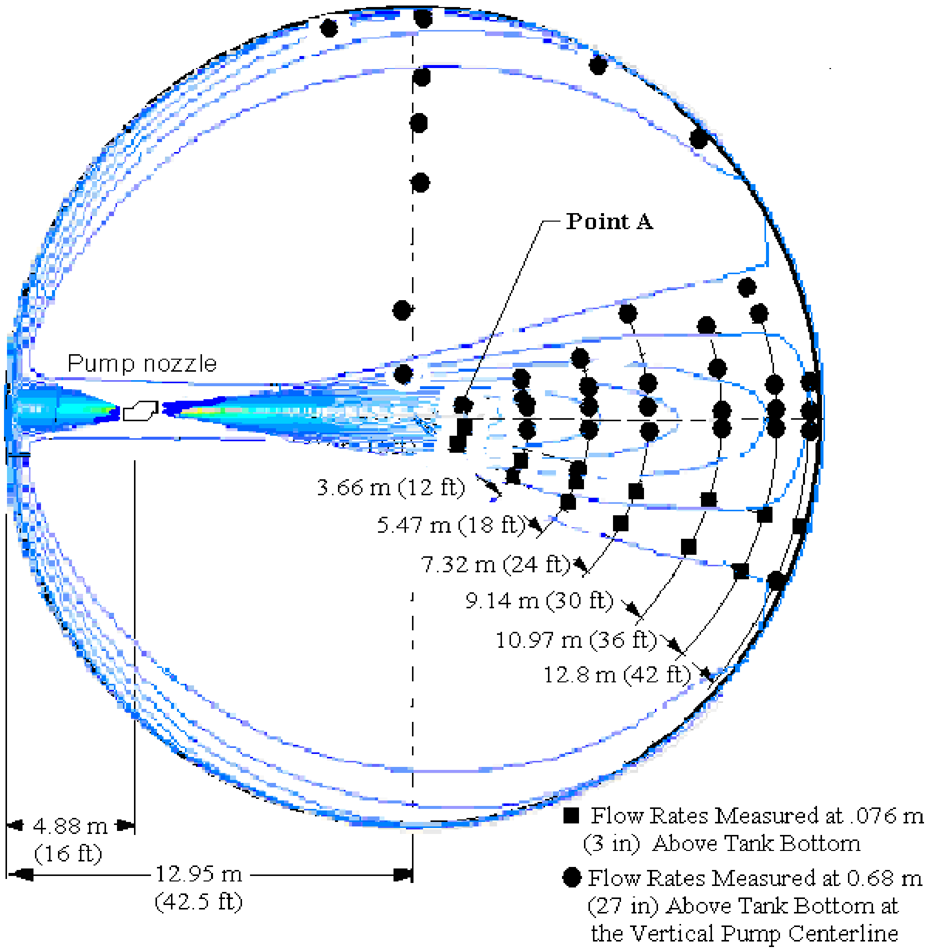
# Full Scale Testing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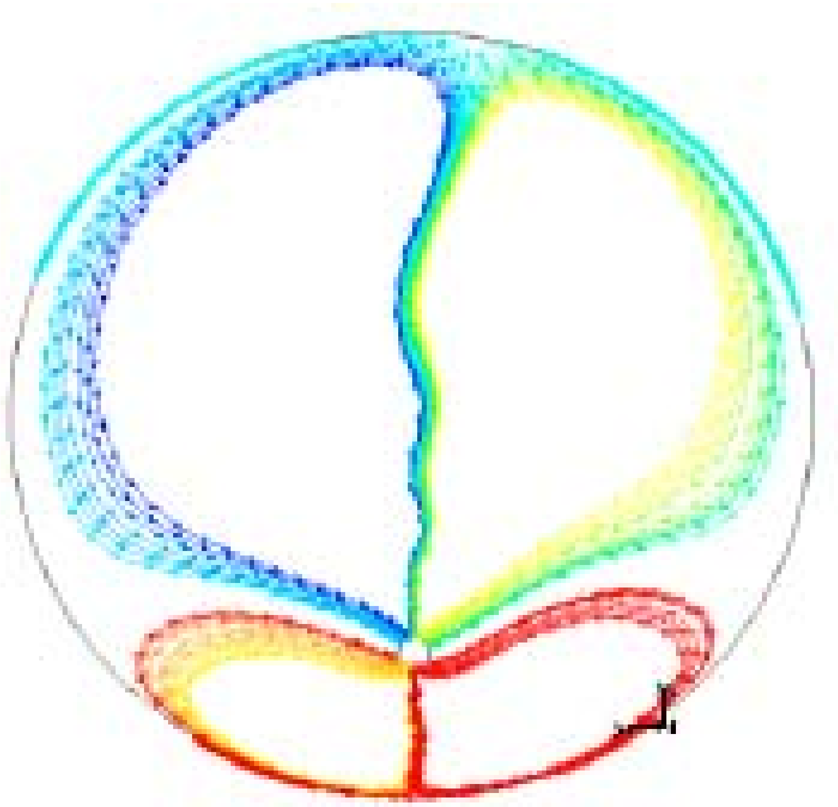
# Comparison of CFD to experimental results



- Plot shown is ten seconds after pump startup
- 2-D model was unacceptable
- 3-D model agreed with observations
- Flow field oscillated with respect to the pump

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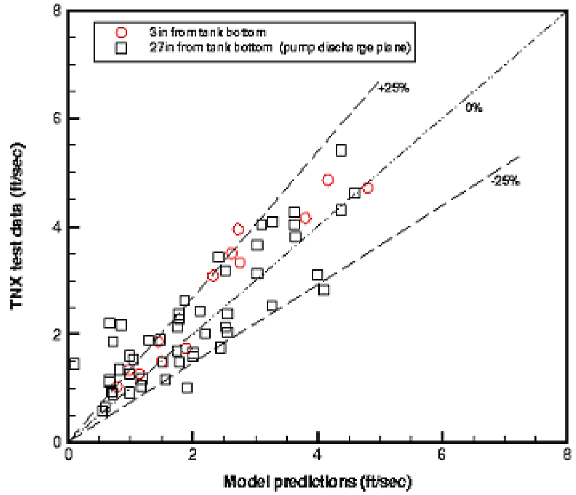
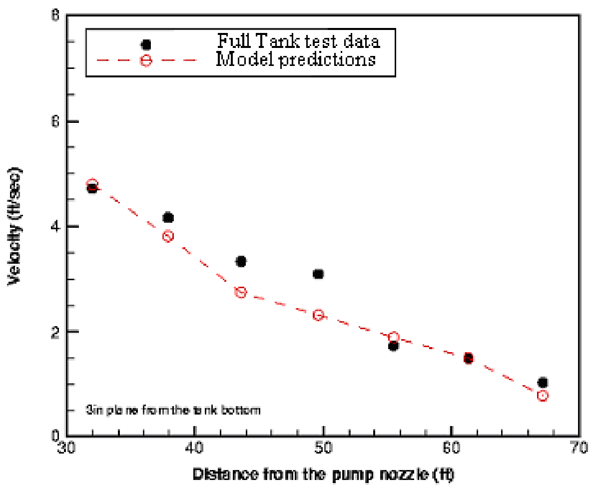
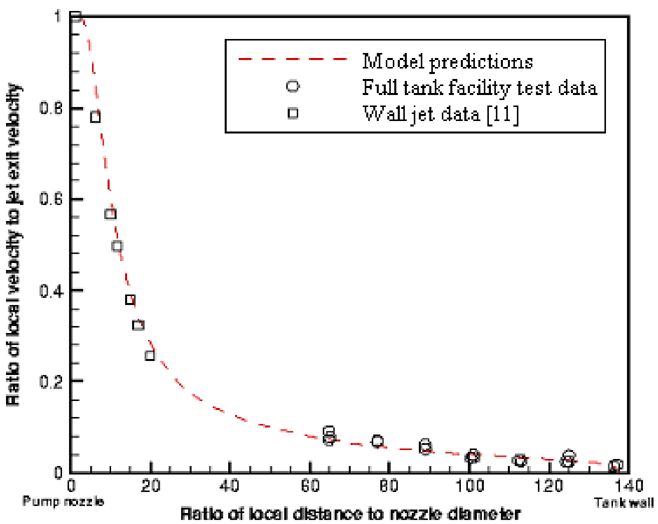
# Test Data for a Fixed Jet




- Experimental results are within 25 % of predictions for a fixed jet impinging on a wall.
- Previous CFD models in the literature were only within 100 – 200 % accuracy

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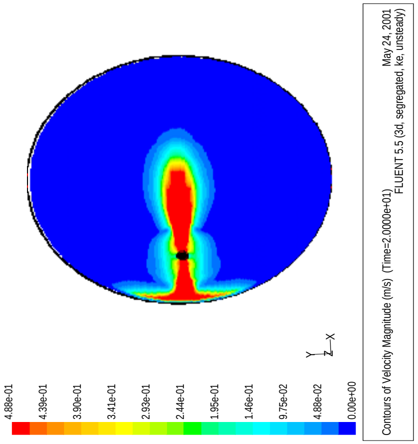
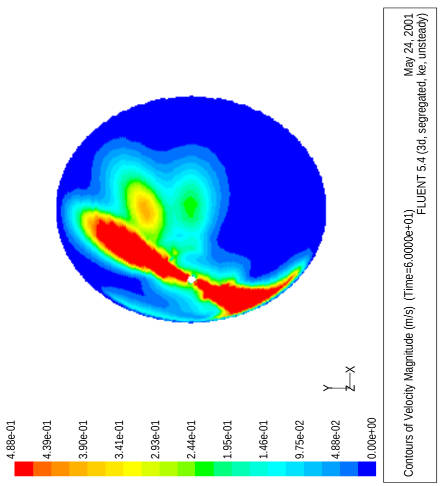
# Rotating jet

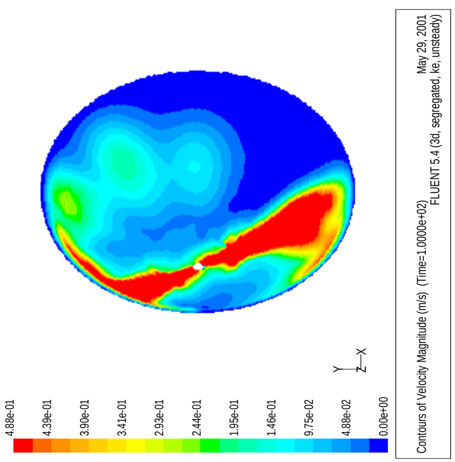
- 30 ° steps in rotation modeled ¼ rpm rotation
- Rotating jet data not measured
- Models look reasonable, qualitatively
- ECR slightly less for a rotating jet than for a fixed jet for a wall jet configuration



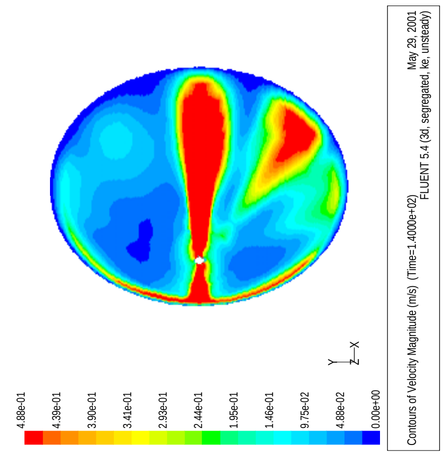

20 seconds




60 seconds

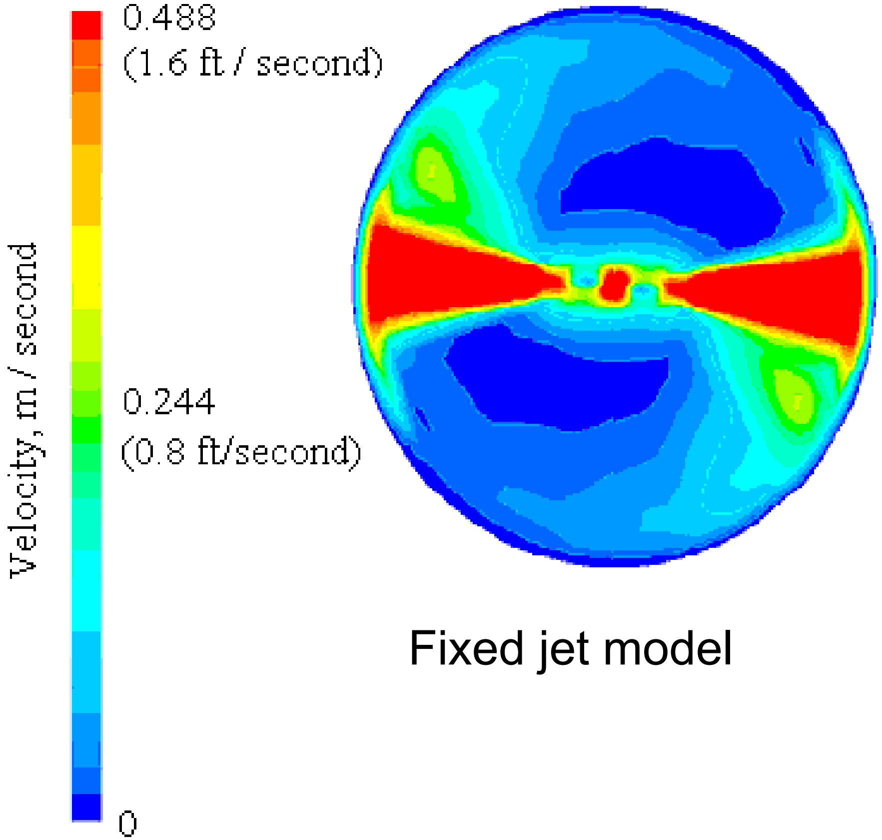



100 seconds




140 seconds

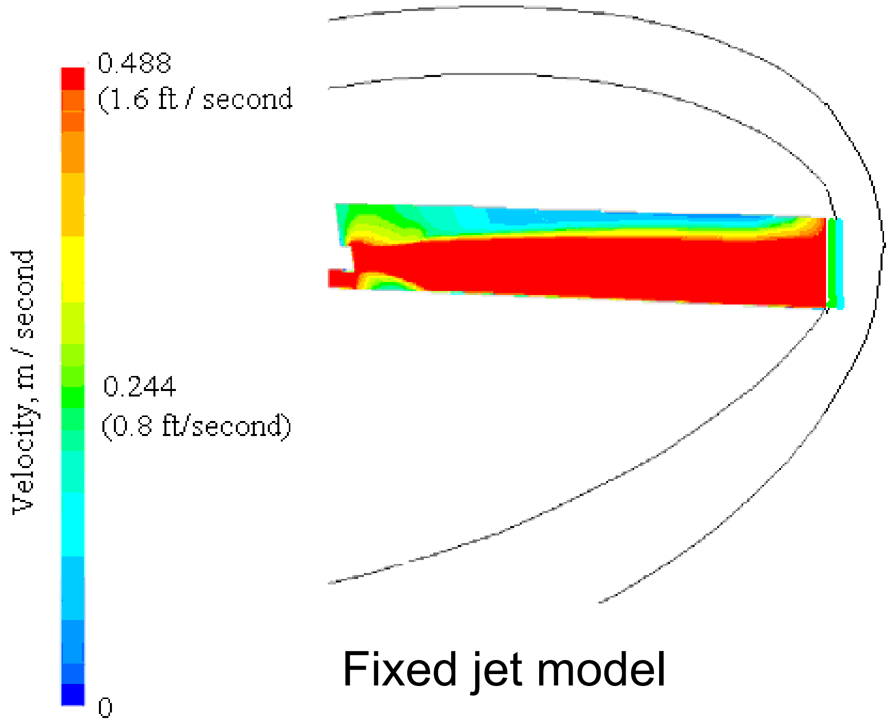
# ECR Prediction for Mixing, Leishear, Lee, Stefanko, Dimenna




Fixed jet model

- Validated single phase model used to approximate two phase flow.
- To predict where mixing would occur, the experimental minimum velocity predicted by the ECR equation was used (2.27 ft / second)
- The modeled location of this velocity near the tank wall was then assumed to be the final sludge interface

# Jet Cross Section




Fixed jet model

- CFD model predicts that some sludge will exist near the tank wall
- However, the actual tank geometry showed that some of the sludge should slide down into the higher velocity flow path
- 0-1400 gallons of residual waste was predicted depending on wall effects

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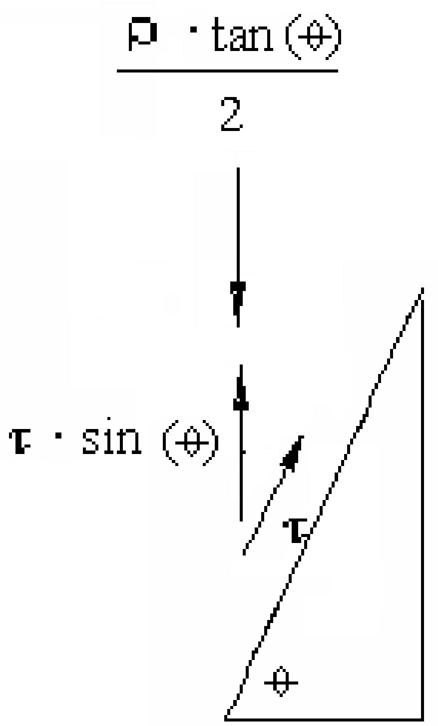
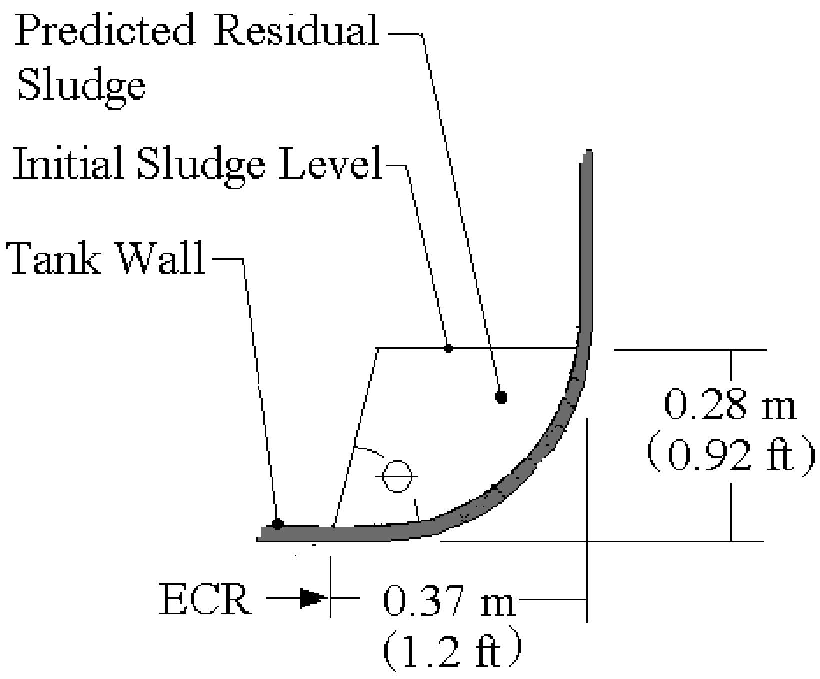
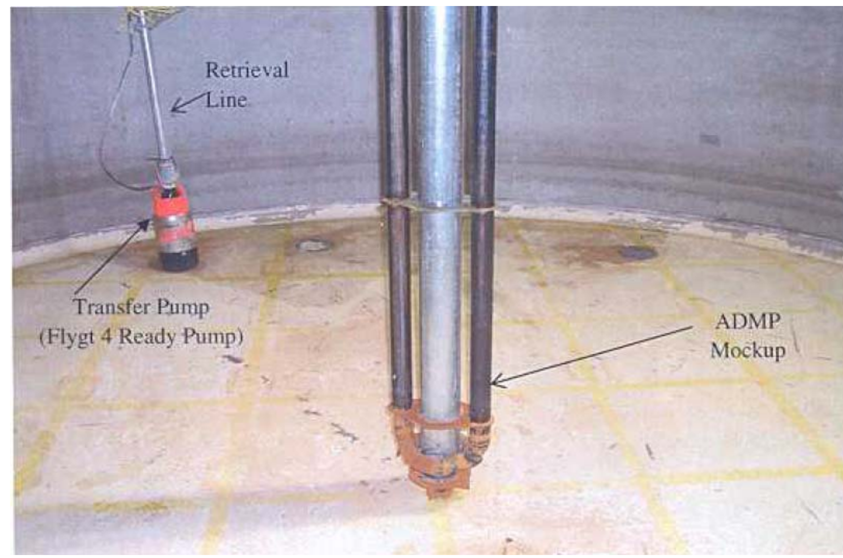
# Tank geometry effects on mixing at the wall




Angle of repose



# Quarter Scale Model, PNNL, Enderlin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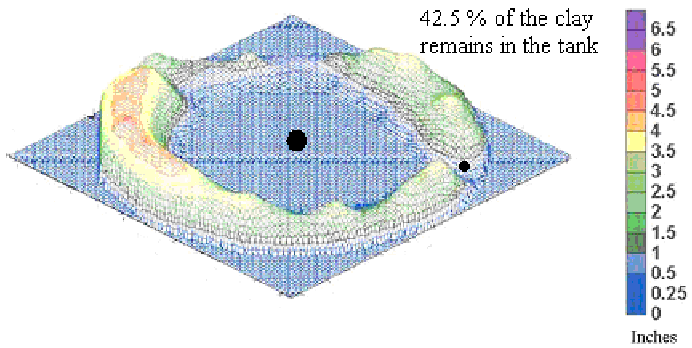
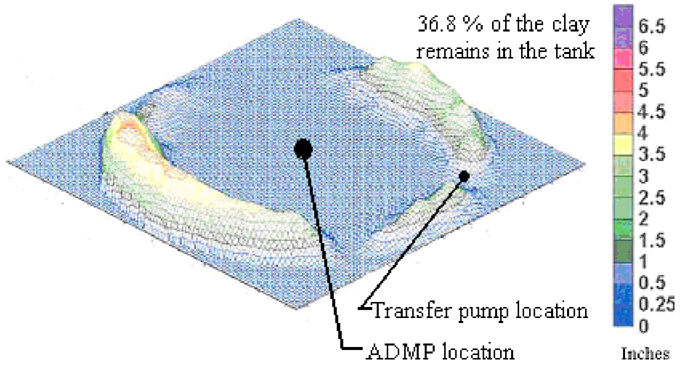
# Quarter Scale Kaolin Results

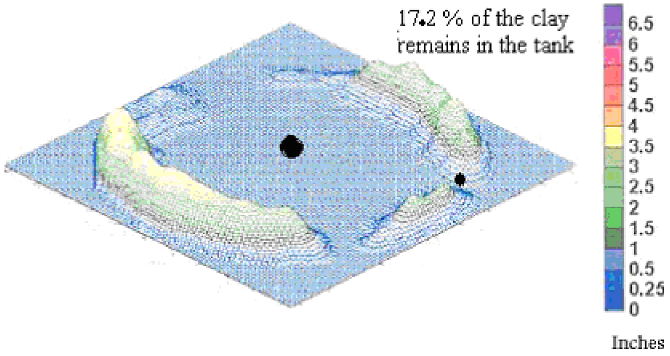
- 10° rotations at 5 minute intervals
- Effective mixing of sludge predicted, even though quarter scale mixing was non-uniform
- Four mixing cycles were predicted



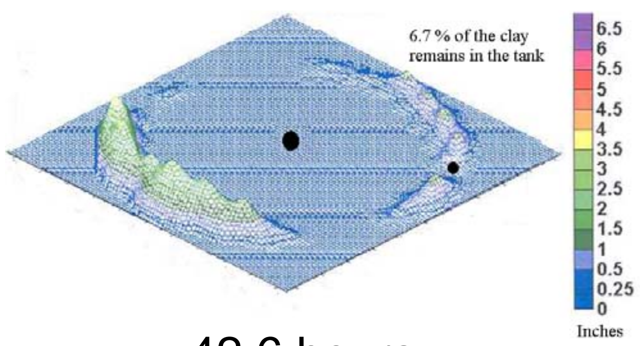

2.23 hours




9.81 hours




15.8 hours




42.6 hours

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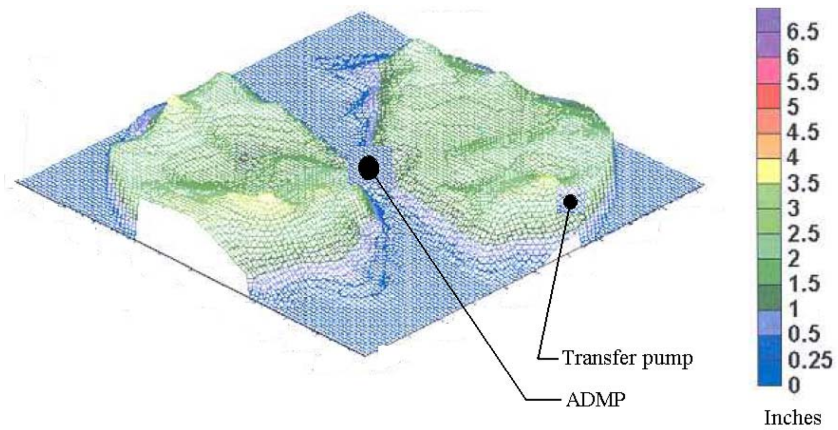
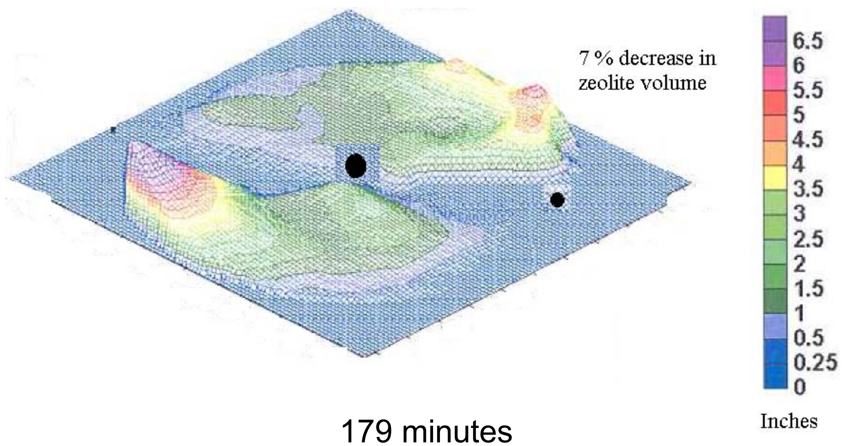
# Quarter Scale Zeolite Mixing




11 minutes




179 minutes

- Three hours of pump operation
- Fast settling solid, like sand
- Zeolite moved around in the tank, similar to sediment transport
- Only a small amount of Zeolite was transferred
- Ineffective transfer operation

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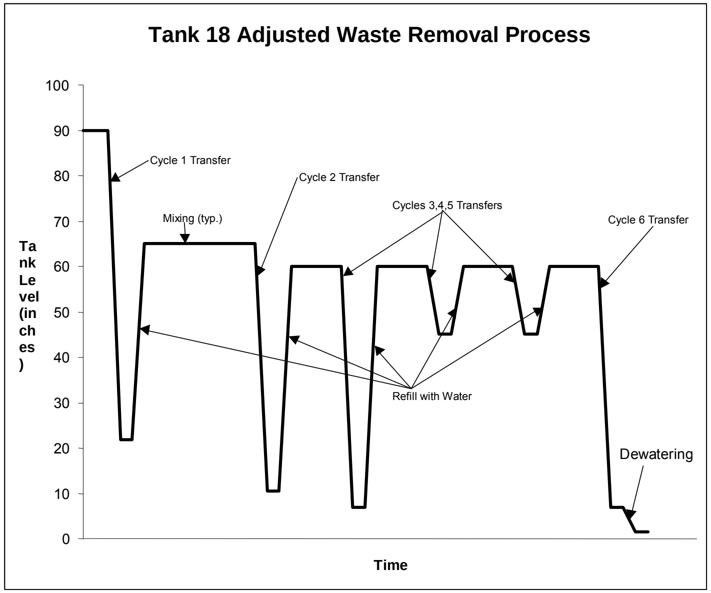
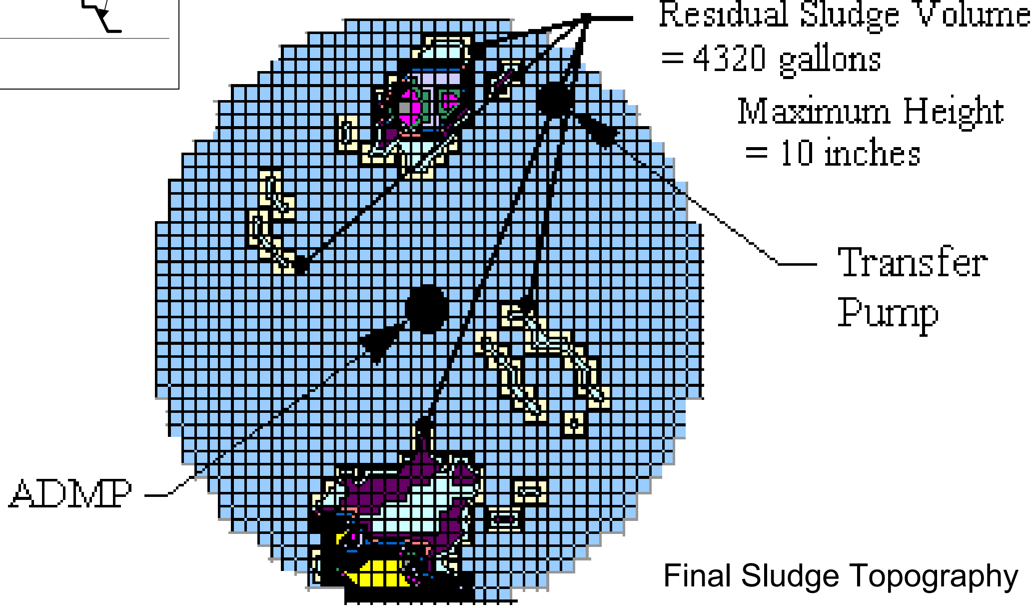
# Waste Tank Results, Augeri, Hubbard, Thomas




Waste removal Process

- Six waste processing cycles consisted of mixing, transferring, and refilling with water
- Sludge was mixed all the way to the wall
- Heel removal in process for Zeolite
- Foaming / low motor current issues?




Final Sludge Topography

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# Conclusions

- The ECR equation provides a conservative estimate for sludge removal, provided the sludge properties are known.
- Some additional waste removal can be obtained through pump indexing.
- CFD models were validated for future use in waste tank mixing and analysis of fluid jets
- The minimum fluid velocity required to produce a force sufficient to mix characterized sludge is approximately 2.27 feet / second.
- Particulate Zeolite is not effectively removed using a slurry pump.

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# References


- *Analysis of Turbulent Mixing Jets in a Large Scale Tank,* 2008, Lee, Dimenna, Leishear, Stefanko, ASME Journal of Fluids Engineering.
- *Mixing in Large Scale Tanks, IV,* Augeri, Hubbard, Thomas , 2004, ASME Joint Heat Transfer and Fluids Engineering Conference.
- *Mixing in Large Scale Tanks, III, Predicting Slurry Pump Performance*, Leishear, Lee, Dimenna, Stefanko, 2004, ASME Joint Heat Transfer and Fluids Engineering Conference.
- *Mixing in Large Scale Tanks, II, Full Scale Pump Testing*, Leishear, Stefanko, Lee, Dimenna, 2004, ASME Joint Heat Transfer and Fluids Engineering Conference.
- *Mixing in Large Scale Tanks, I, Flow Modeling of Turbulent Mixing Jets*, Lee, Dimenna, Stefanko, Leishear, 2004, ASME Joint Heat Transfer and Fluids Engineering Conference.
- *ADMP Mixing of Tank 18F Sludge; History, Modeling, Testing, and Results,* R. Leishear, M. Augeri, R. Dimenna, D. Stefanko, S. Lee, J. Thomas, M. Hubbard, 2004, WSRC-TR-2004-00036
- *Performance Analysis for Mixing Pumps in Tank 18*, 2001, Lee, Dimenna, WSRC-TR-2001-00391
- Additional references included in each of the reports and publications.


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