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Advanced Mixing Models

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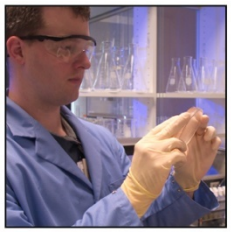
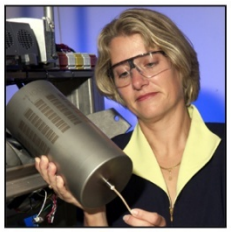
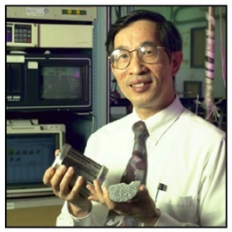
May 21, 2009

EM-21 Technical Exchange, Denver, CO, May 19-21

Background – Waste Recovery from SRS Storage Tanks

Mix tank contents with 1 – 4 dual-nozzle jet mixers

Long mixing times

- Historically-based operations
- Difficult to measure / sample contents

High cost

- Operational
- Maintenance / repair / replacement

Safety impact

- Sampling hazardous materials
- Complex maintenance operations
- Combustible gas generation associated with pump mixing time
- Radiological implications

Objective

Quantify the mixing time required to suspend sludge particles with the mixer pumps

- Expect a smaller time than historical values based on current literature
- Requires a validated calculation

Establish mixing criteria for waste processing

- Generalized mixing criteria will be widely applicable in computational applications
- Validate computational capability to calculate the mixing criteria

Benefits

- Improved safety exposure
  - Sampling operations
  - Pump maintenance / replacement operations
- Ensure uniformity in tank discharge flow – meet downstream WAC
- Reduced operating time – shorter schedules
- Reduce maintenance time
- Significantly reduced operating and maintenance costs

Solution Approach & Methodology

Identify data from the literature

- Grenville & Tilton (G-T) (1996, 1997)

Propose mixing indicators

- Turbulence kinetic energy
- Turbulence energy dissipation rate
- Eddy diffusivity

Proof-of-concept calculations

- CFD simulations using G-T data from literature
- Independent Calculations using L-B method (PNNL)

Computational Observation

- Key turbulence parameters related to mixing indicators
- Geometry dependence / energy dissipation scales

Solution Approach & Methodology

Eddy scales and energy cascade

- Local mixing via dissipation of turbulence kinetic energy
- Length scales

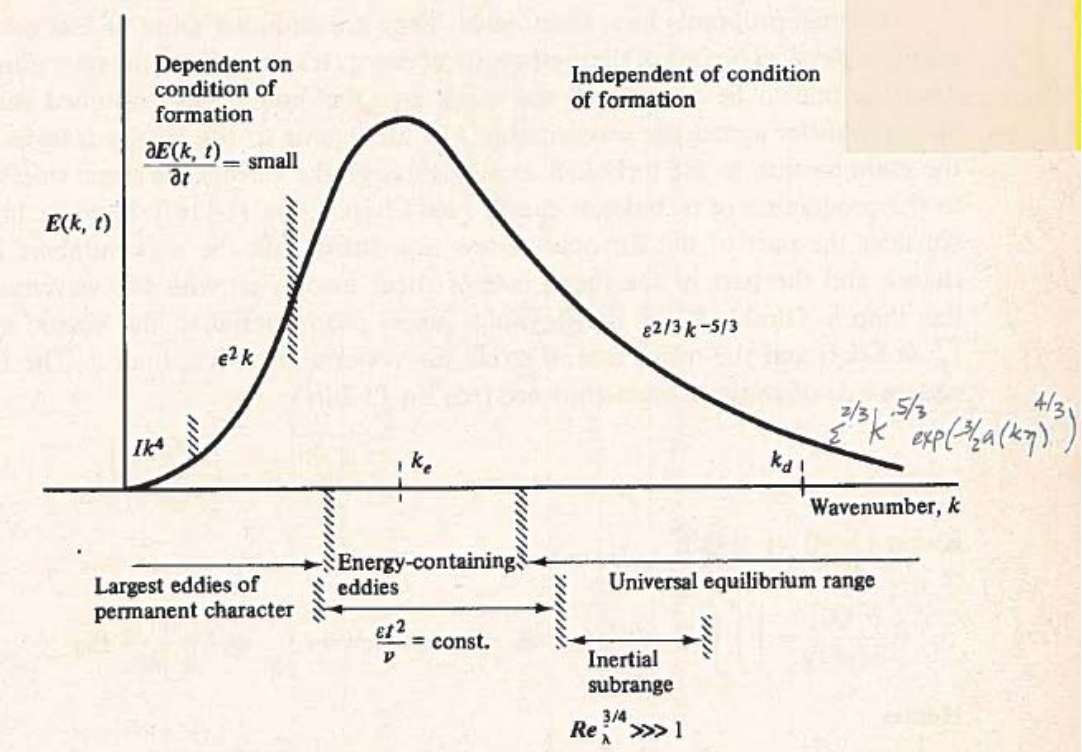
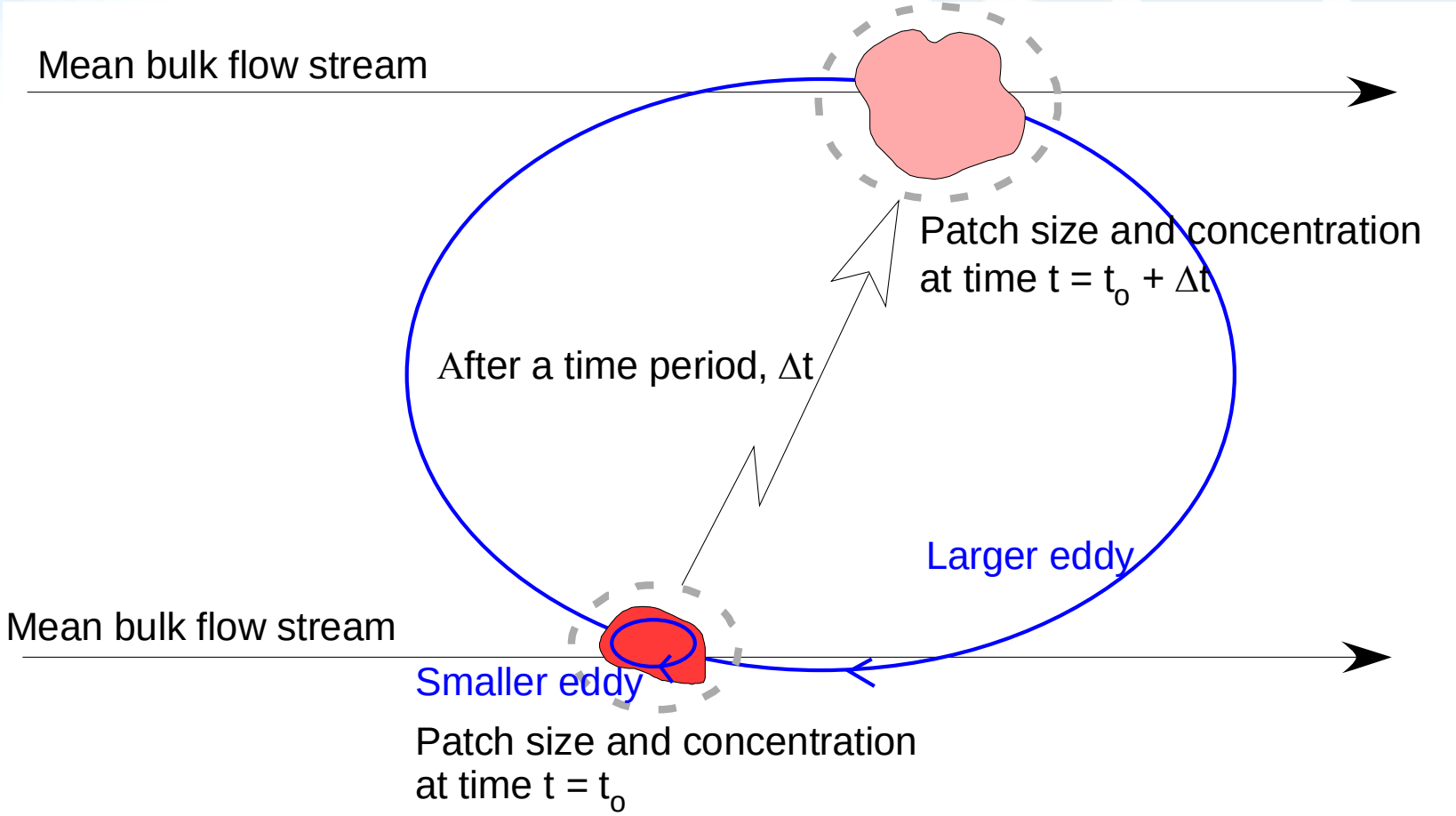


FIGURE 3-13
Form of the three-dimensional spectrum E(k,t) in the various wavenumber ranges.

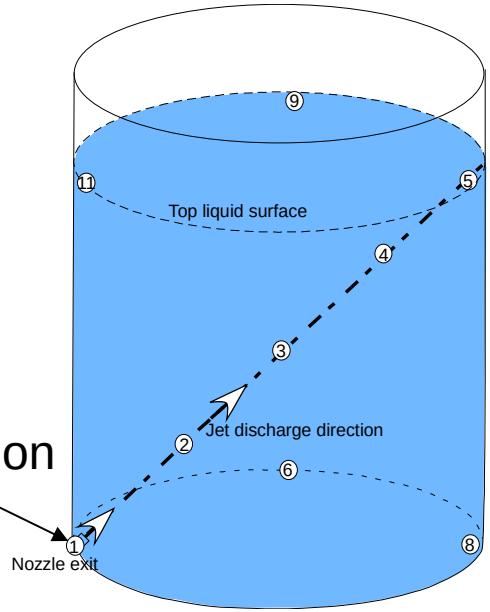
from Hinze, *Turbulence*, 2ed.,McGraw-Hill, 1975, p. 229.

Mixing Mechanism



Modeling Conditions from the Literature Data (G-T)

Tank	Tank dia.	Liquid height	Inclination angle of Jet	Jet dia.	U_o m/sec	Re_{jet}	Mixing time (literature)
Tank A	1.68 m	1.55 m	42.6°	9.4 mm	2.2	20,680	758 sec.
Tank B	1.68 m	1.55 m	42.6°	26.1 mm	19.8	516,780	30 sec.
Tank C	36 m	11.16	17°	50 mm	19.5	975,000	4371 sec.

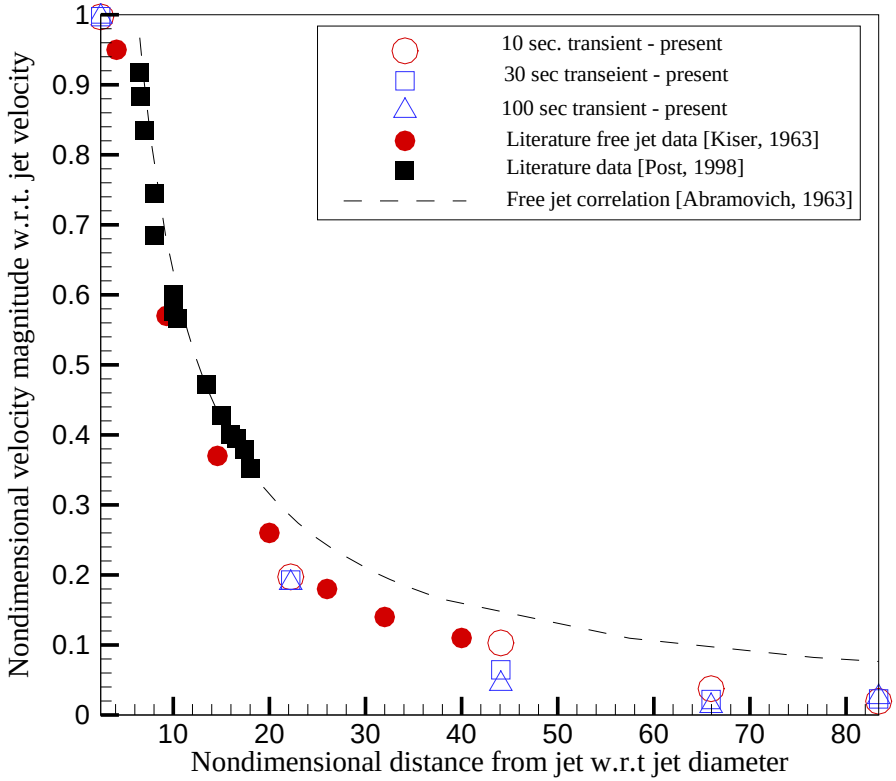


Jet nozzle location

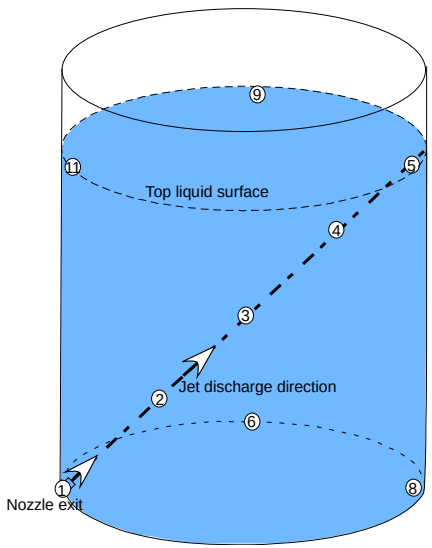
(9 numerical observation points under transient modeling simulations)

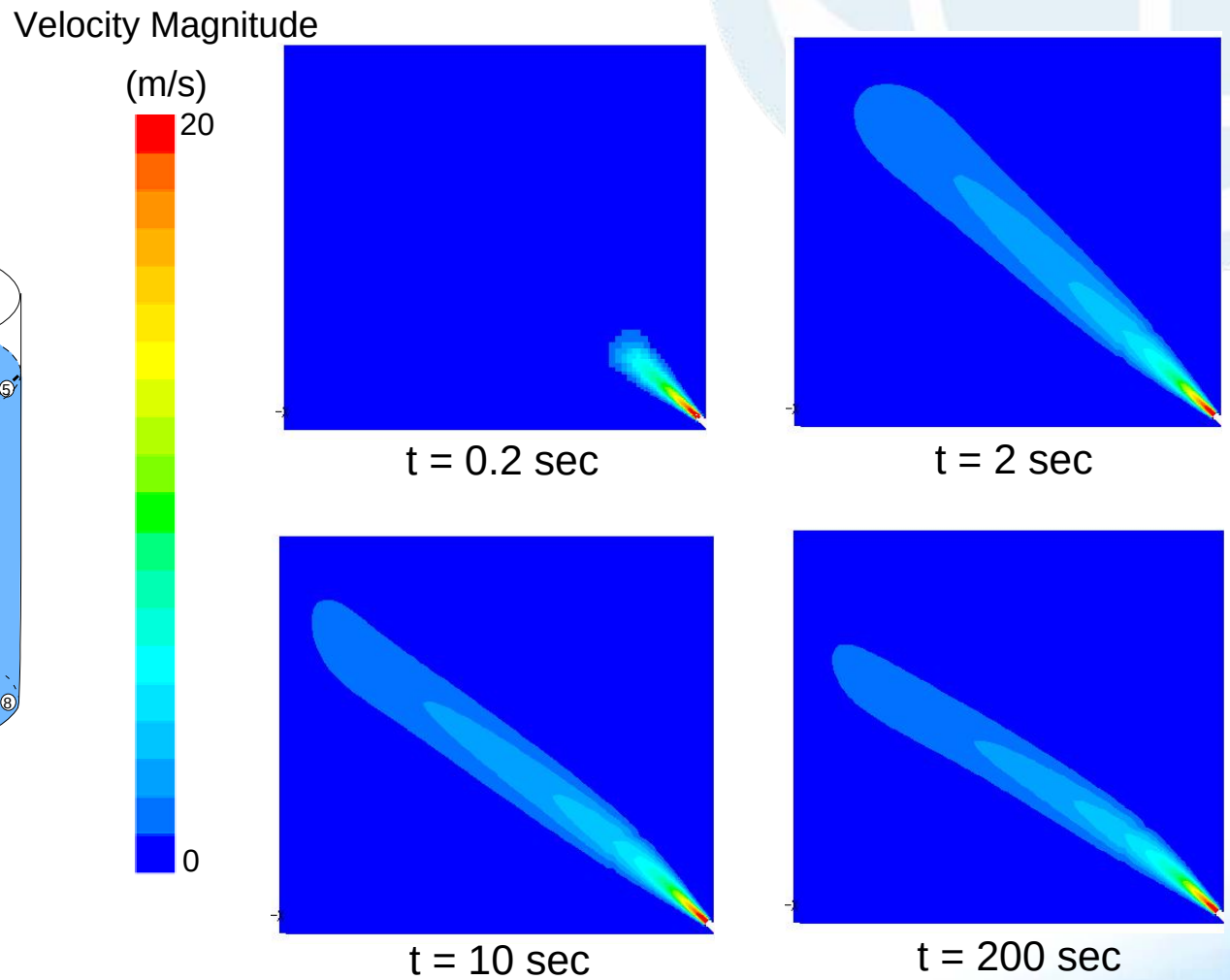
Turbulence Model Benchmarking Results

Authors	Jet diameter (mm)	Fluid	Re_{jet}
Tank B (present)	26.1	Water	520,000
Kiser (1963)	9.525	Water	35,000
Post (1998)	10	Air	10,000



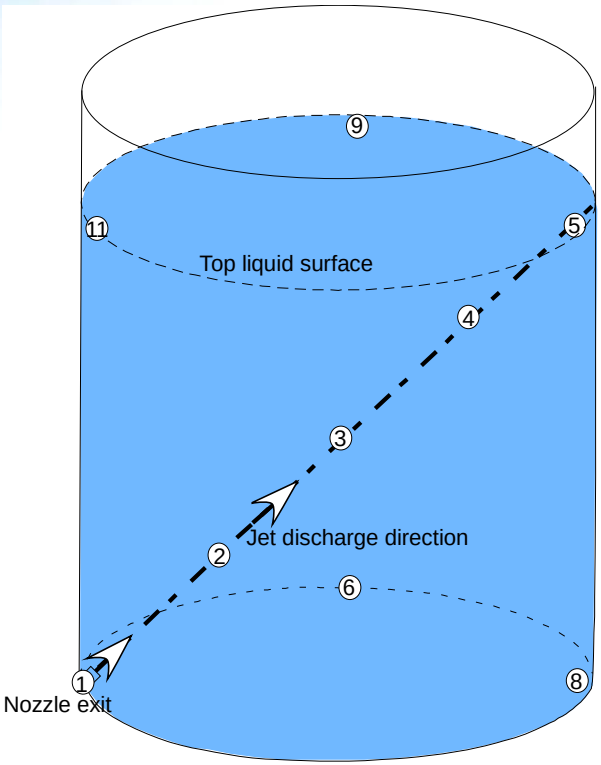
Computational Results

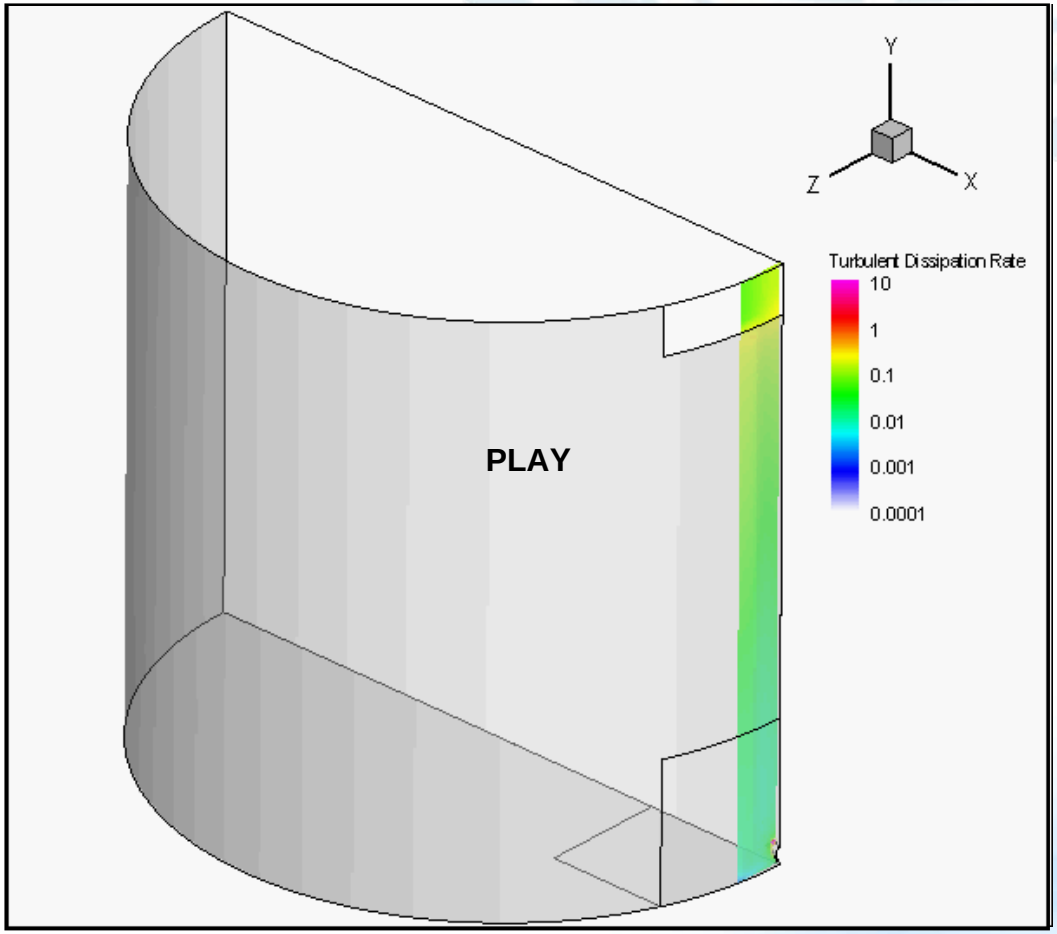




Computational Results : Simulations for Flow Evolutions

Propagation through the tank at
t = 21 seconds

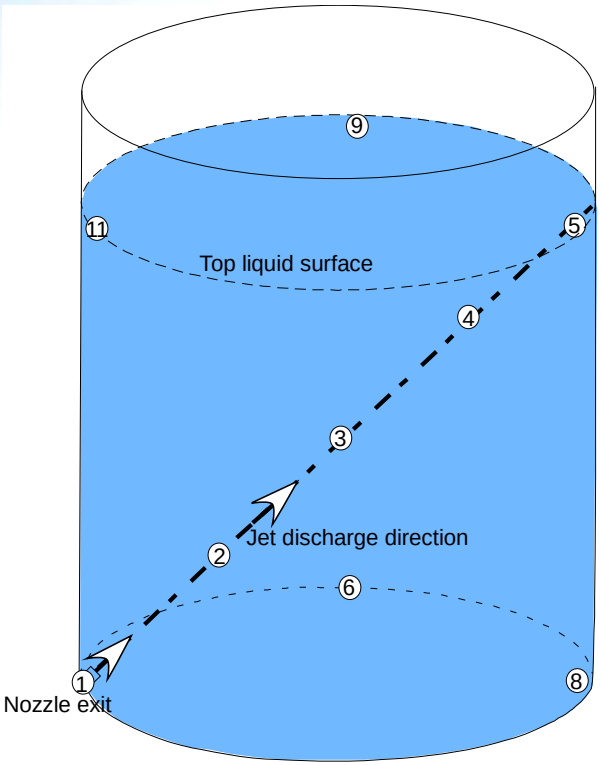


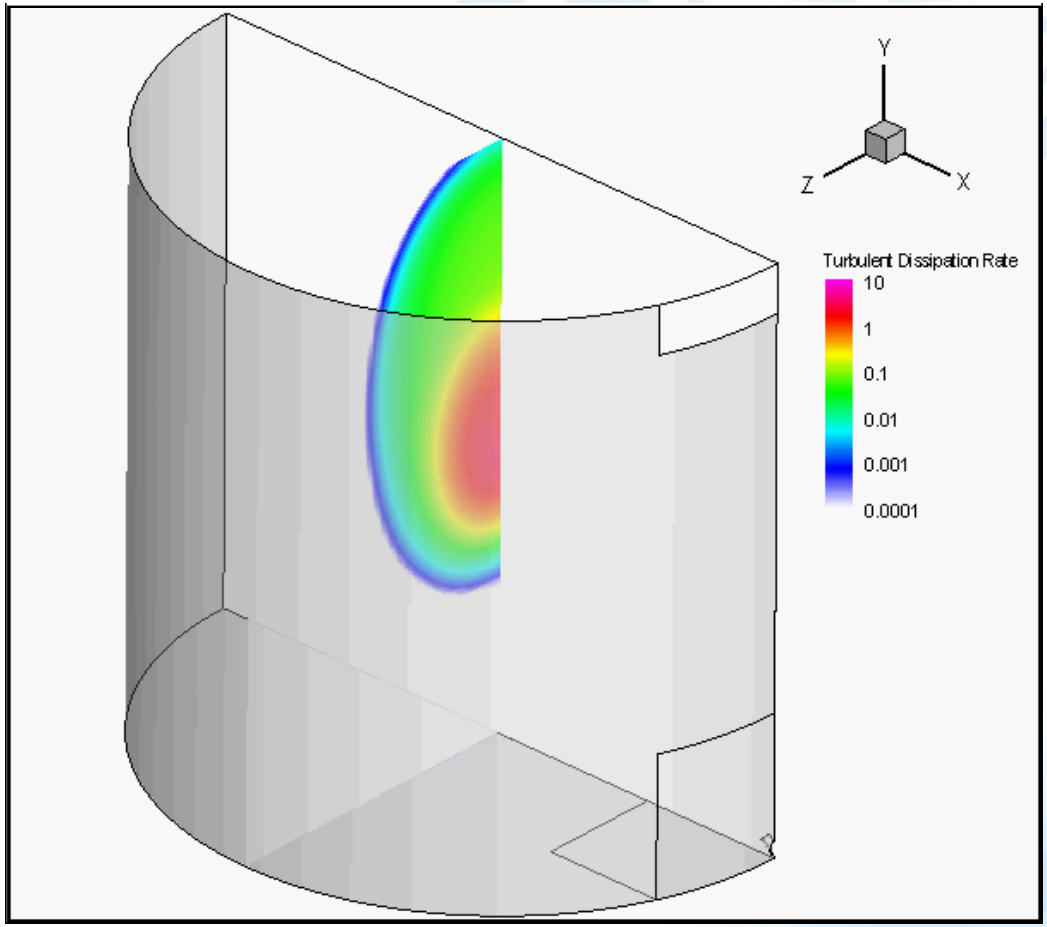


Click on Graphic Above to Play Animation

Computational Results : Simulations for Flow Evolutions

Propagation with time





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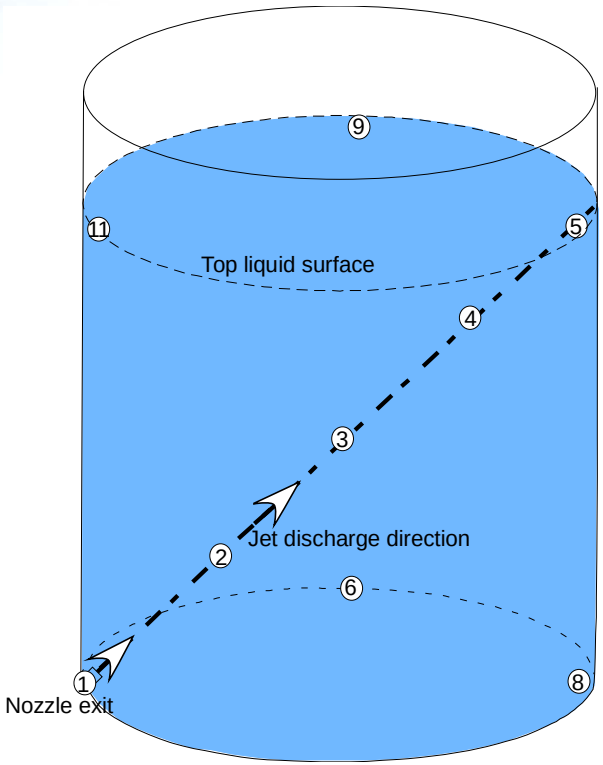
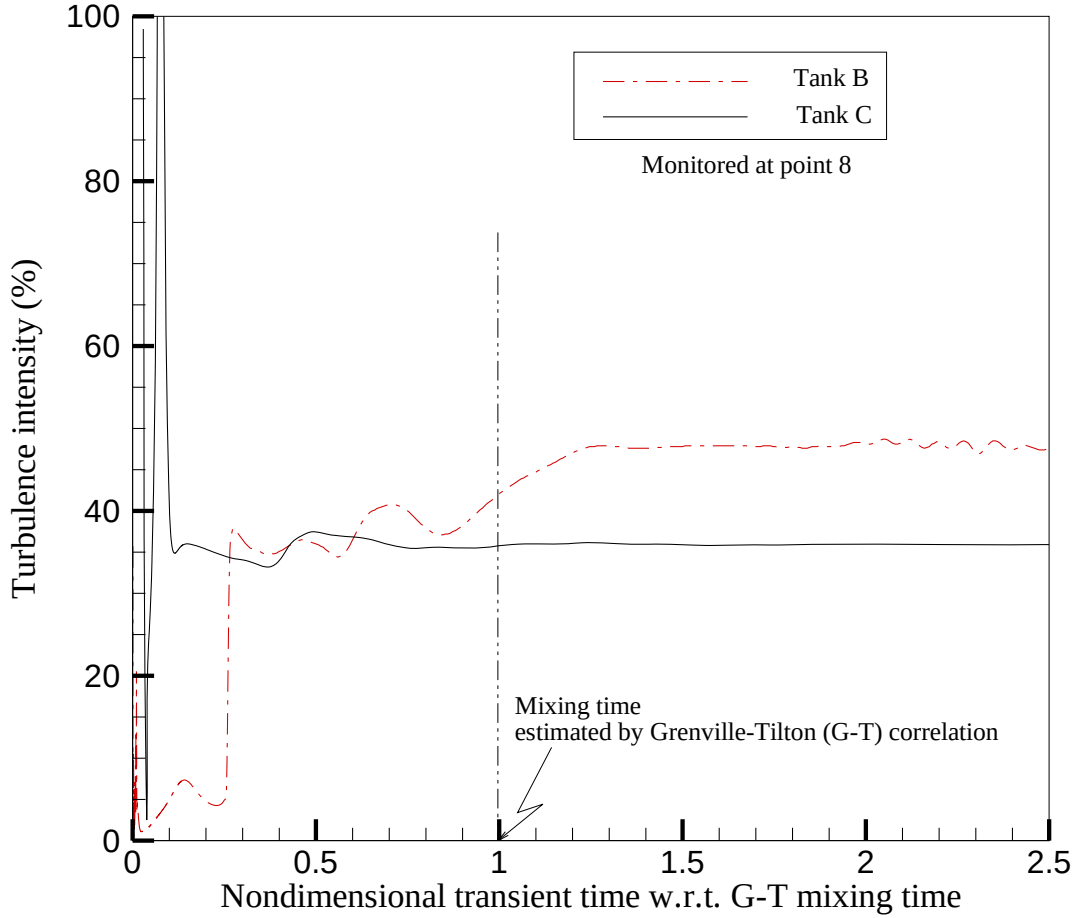
Computational Results

(Turbulence intensity observed at Point 8 in Tank B & C)





Mixing Mechanism

Length Scales:

Characterizing the eddies responsible for the dissipation of energy

- Large Eddy Scale (L):

$$L = \frac{k^{1.5}}{\varepsilon}$$

- Small eddy scales:

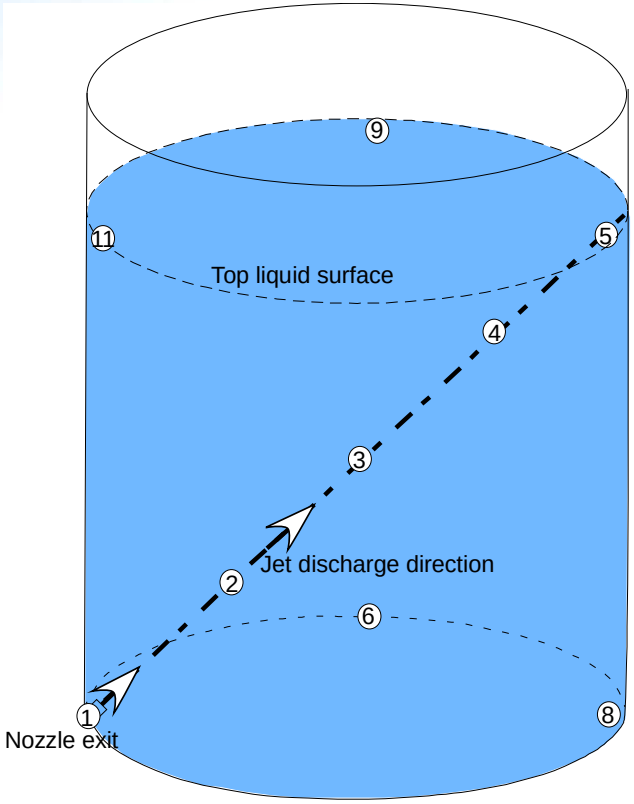
Taylor scale (λ_g):

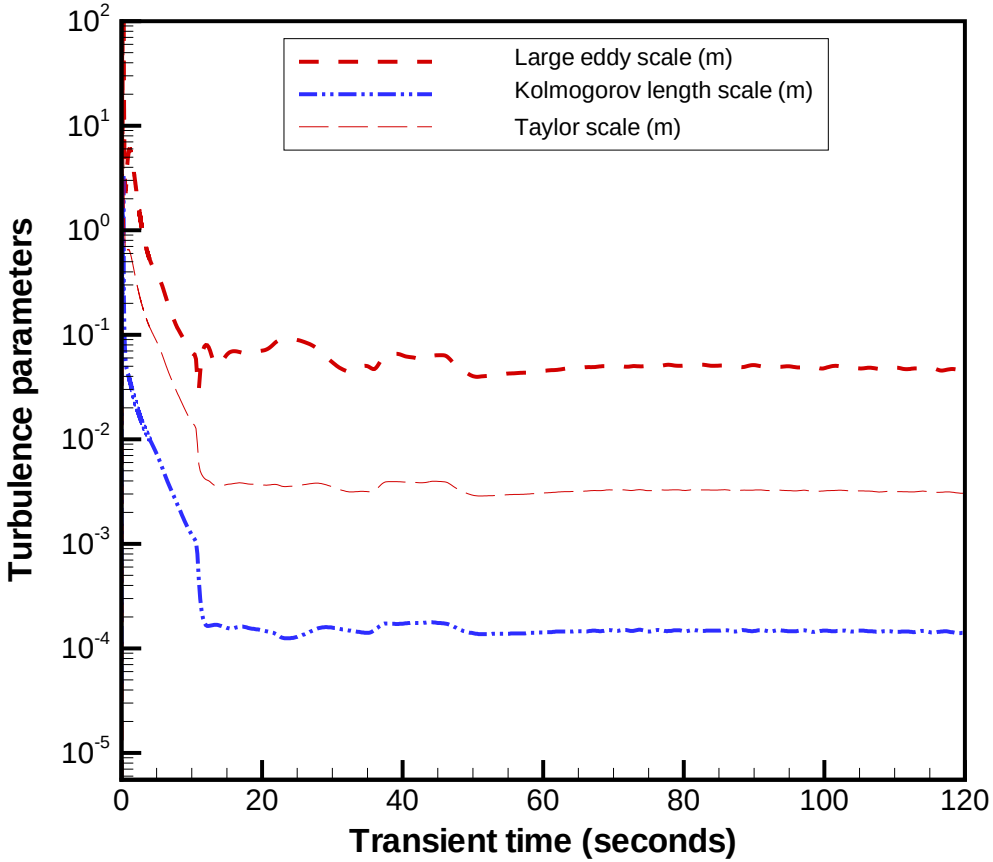
$$\lambda_g = \sqrt{10}L\left(\frac{\rho k^2}{\varepsilon\mu}\right)^{-0.5} = \sqrt{10}L\left(\mathrm{Re}_L\right)^{-0.5}$$

Kolmogorov scale (η):

$$\eta = L\left(\frac{\rho k^2}{\varepsilon\mu}\right)^{-0.75} = L\left(\mathrm{Re}_L\right)^{-0.75}$$

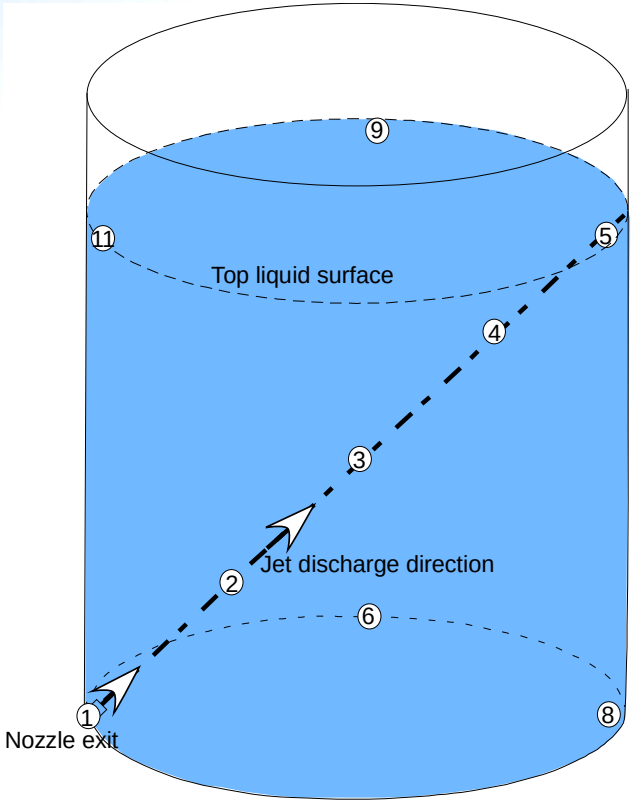
Computational Results

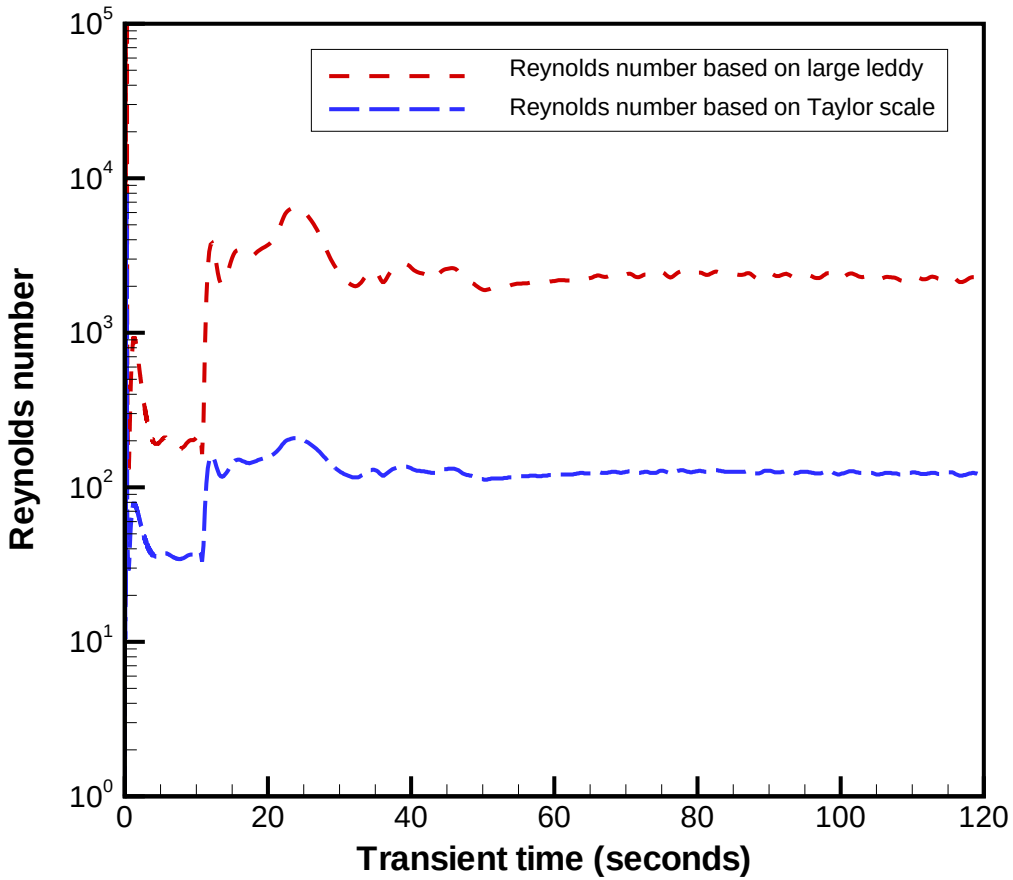




Eddy length scales observed at Point 6 in Tank B

Computational Results





Reynolds number based on eddy length scales observed at Point 6 in Tank B

Summary

- **Theoretical concept of using key turbulence parameters as mixing indicators was validated by using Grenville-Tilton correlation (1996, 1997) under several different conditions.**
- **The recent validation results for the realizable k-ε (RKE) turbulence model demonstrate that key turbulence parameters, energy dissipation rate and eddy viscosity, provide good indicators of jet mixing.**
- **Based on the validation results completed in FY08, theoretical development for turbulent mixing characteristics and its indicators will be completed through FY09.**

FY09 principal goal is to establish mixing criteria and to provide "mixing time guidelines"

Pathforward

FY-09 deliverables

- **Establish mixing indicators as the fundamental criterion**
- **Determine required magnitude of key indicators**
- **Validate computational methodology (with PNNL)**
- **Liquid-liquid mixing recommendations**
- **Low concentration, small solids (low Stokes number)**

FY-10,11

- **Demonstrate use of the mixing indicators established by FY-09 work as the engineering application**
- **Particles, settling rate, multiphase, erosion, wall shear**