Stirring of Ceramic Resins for 3D Printing

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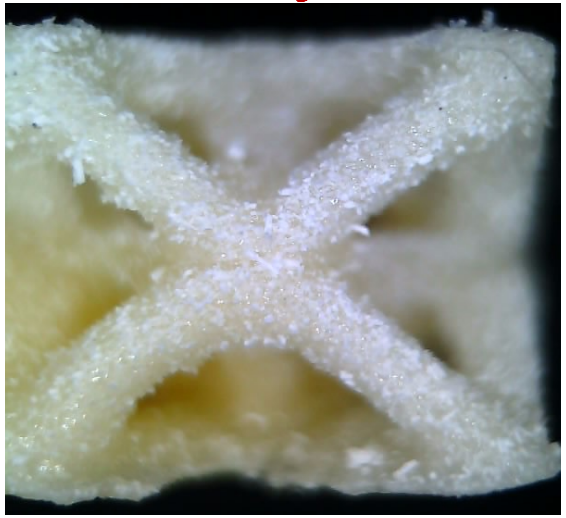
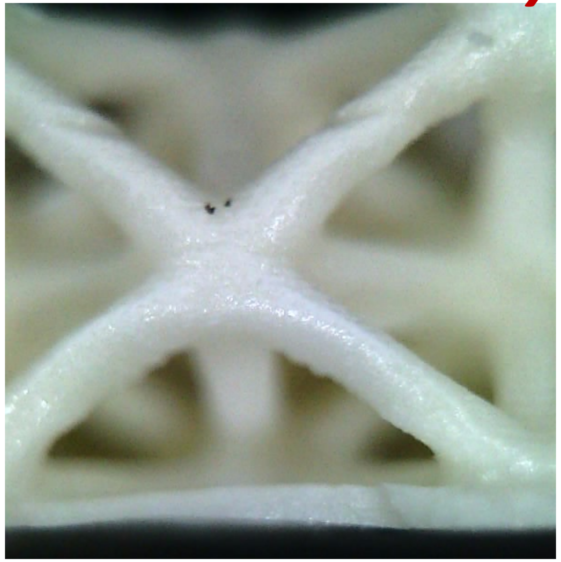
Mixing time affects 3D printing

difference from ***2 days of mixing***

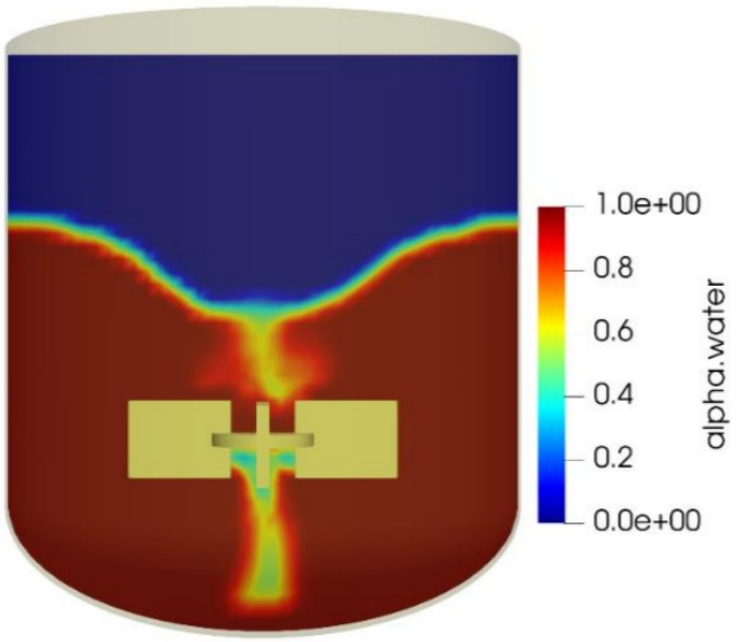
few hours



1 day

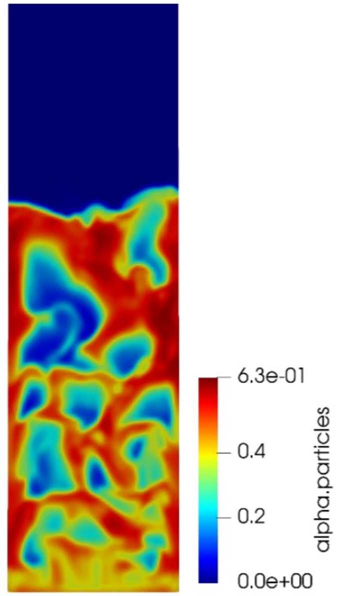


Reference materials



stirred tank reactor
(water, air)

geometry, meshing reference



fluidized bed
(glass particles, air)

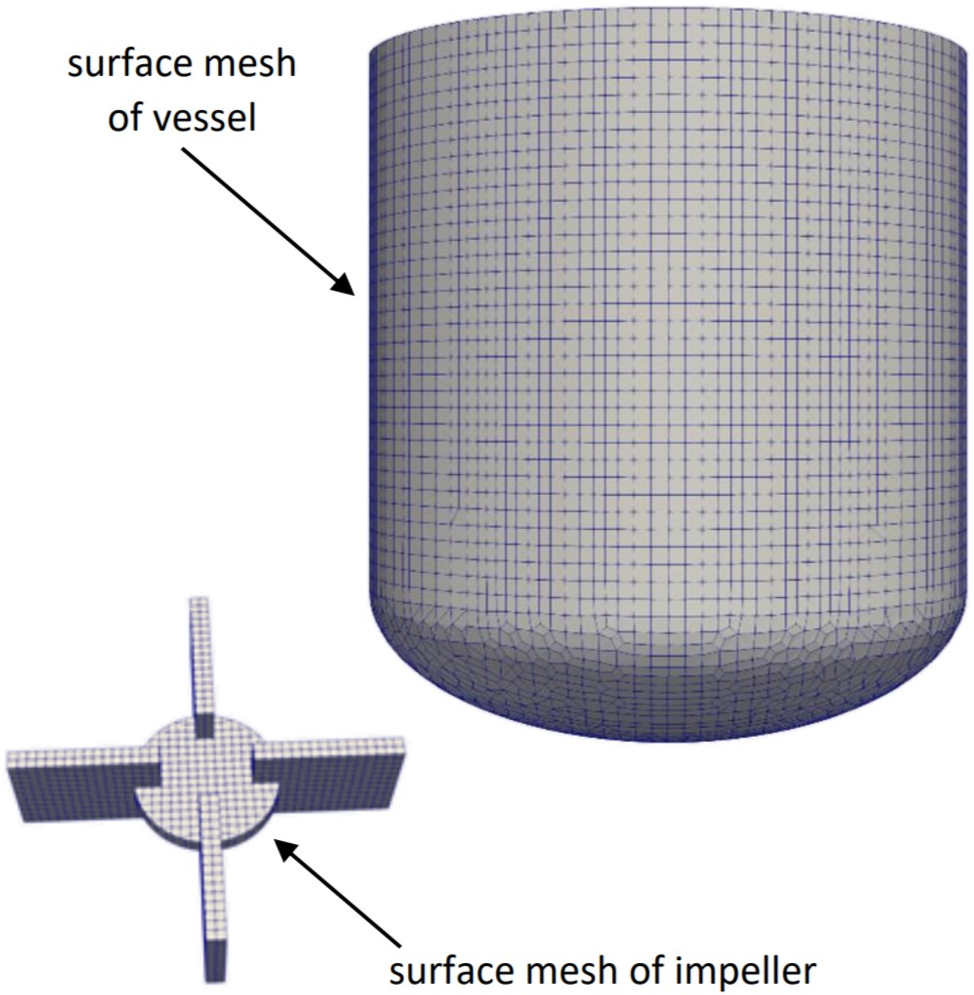
physics, phase interaction reference

goal is to
combine!
(set up the problem)

Meshing

snappyHexMesh

- generates 3D mesh with hexahedra and split-hexahedra from triangulated surfaces of STL files
- start with a ***blockMesh*** that encompasses extra volume, then conforms to surface by iteratively refining starting mesh



“Mastering twoPhaseEulerFoam Four: Two-Phase Stirred Tank Reactor” Hamidreza Norouzi

Moving walls for mixing:

used **multiple reference frame (MRF)** technique

whole volume subdivided into:

- one (or more) rotating zone
- one stationary zone

can rotate the impeller without moving mesh by making necessary changes in momentum equation

$$\vec{u}_r = \vec{u} - (\vec{\Omega} \times \vec{r})$$

$\vec{u}_r =$ relative velocity
$\vec{u} =$ absolute velocity
$\vec{\Omega} =$ rotation speed
$\vec{r} =$ vector from rotation center to point of $\vec{u}_r$

$$\frac{\partial}{\partial x}(\rho\vec{u}) + \nabla.(\rho\vec{u}_r\vec{u}) + \underbrace{\rho(\vec{\Omega} \times \vec{u})}_{\text{Coriolis force}} = RHS$$

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Multiphase model of choice

multiphase system: ***twoPhaseEulerFoam***

- each phase treated as interpenetrating continuum
- phases represented by a volume fraction at each point of the system
- fluid-fluid couples differently from solid-fluid
- particle-wall and particle-particle interactions can be considered

liquid: Reynolds Averaged Simulation (**RAS**), **k-ε**

solid: stress tensor **kinetic theory of granular flow**

"CFD Simulation of Solid-Liquid Stirred Tanks for Low to Dense Solid Loading Systems"
Wadnerkar et al.

Treatment of particles

particles &turbulence:

- simplest: ***phasePressure***
  - no shear stress tensor considered for the solid (considered an **inviscid fluid**)
  - solid pressure becomes high near maximum packing, solid cannot be packed beyond max
- model used: ***kineticTheory***
  - viscosity (thus shear stress tensor) of the solid estimated by “granular temperature”

particles & boundary conditions:

- granular flow: behave between no-slip & slip conditions
- Jahnson & Jackson (1987) proposed BCS for solid velocity & granular temperature

$$\mu_s \frac{\partial u_s}{\partial x} = -\frac{\pi\, \phi_s \rho_s \alpha_s g_0 \sqrt{\theta_s}}{2\sqrt{3}\alpha_s^{max}} u_s$$

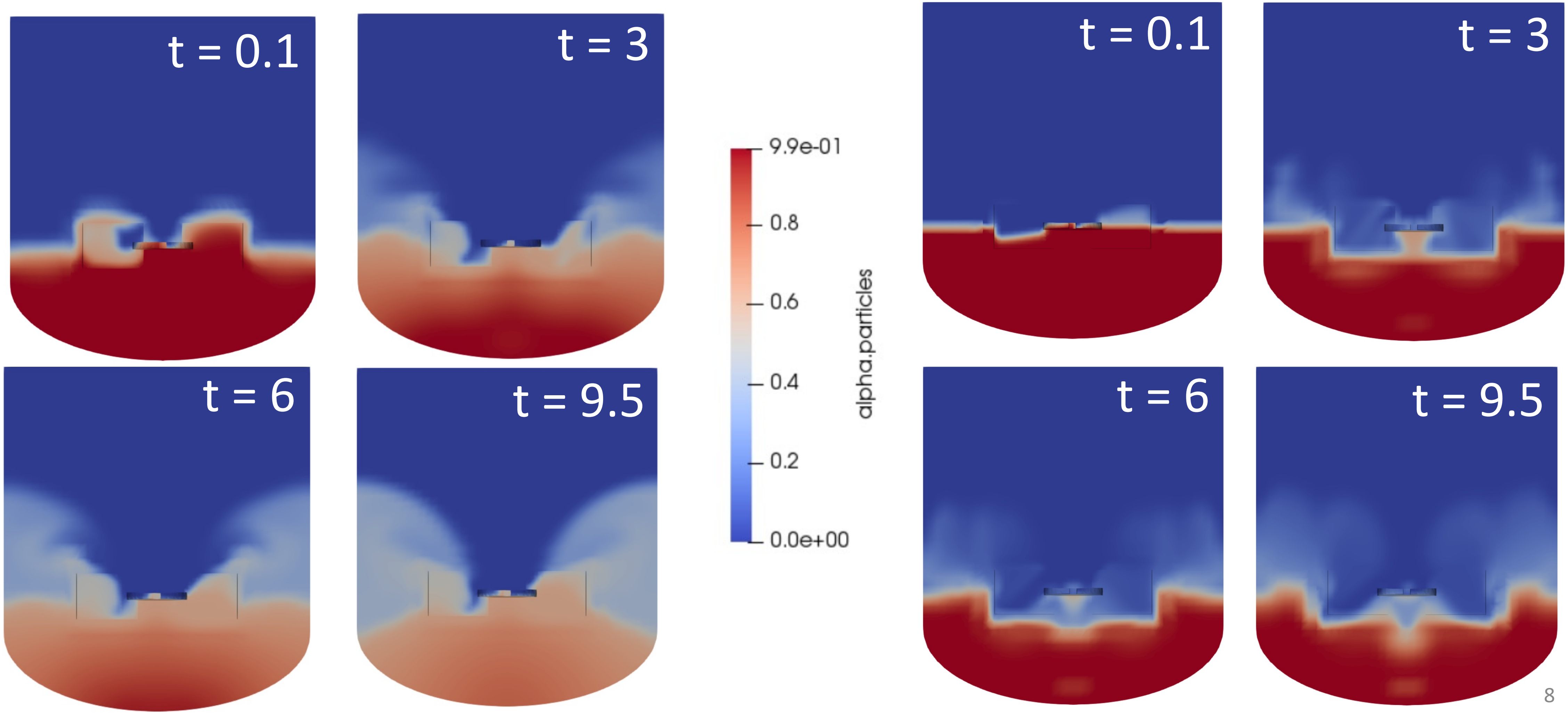
$$\kappa_s \frac{\partial \theta_s}{\partial x} = -\frac{\pi\, \phi_s u_s^2 \rho_s \alpha_s g_0 \sqrt{\theta_s}}{2\sqrt{3}\alpha_s^{max}} - \frac{\pi\sqrt{3}\rho_s \alpha_s g_0 (1 - e_W^2)\sqrt{\theta_s}}{4\alpha_s^{max}} \theta_s$$

“How to simulate a gas-solid fluidized bed using OpenFOAM®” Hamidreza Norouzi and Ramin Khodabandehlou

Results: it runs

water – glass particles

resin – ceramic particles



A look at some papers on the topic

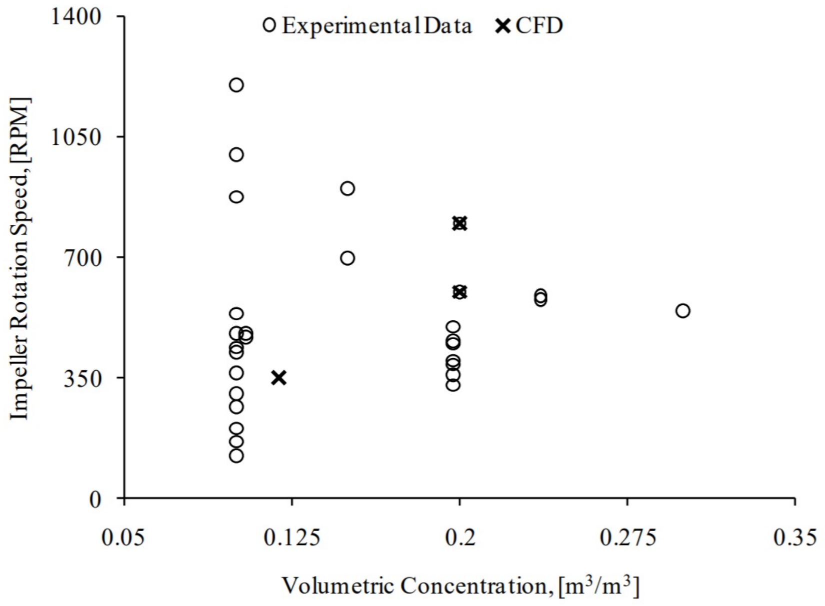


Figure 1. The studies conducted above 10% volumetric concentration.

"CFD Simulation of Solid-Liquid Stirred Tanks for Low to Dense Solid Loading Systems" Wadnerkar et al.
"CFD simulation of liquid-phase mixing in solid–liquid stirred reactor" Kasat et al.

- stirring at **high solid concentrations not as widely studied**
- also harder to validate experimentally
- **Euler-Euler** most common
- **Reynolds averaged simulation (RAS) based k-ε** most common
- many other schemes could be used (LES, Reynolds Stress models)
- also many different models & methods for drag & turbulence dispersion force

How to determine if something is fully mixed?

"suspension quality"

- cloud height = 90% liquid height
- standard deviation of α solids concentration < 0.2

"CFD simulation of liquid-phase mixing in solid–liquid stirred reactor" Kasat et al.

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Future work

- reduce computational cost
- geometry changes – different mixing methods
- more phenomena? different schemes?
- experimental validation

"CFD simulation of liquid-phase mixing in solid–liquid stirred reactor" Kasat et al.

Thank you!