Using CFD simulations and Positron Emission Particle Tracking to Study the Mixing of Shear Thickening Fluids in a Stirred Tank

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STATE OF THE ART

- Mixing of complex fluids in mechanically agitated vessels is an essential part of many different processes across various industries, such as the pharmaceutical, food processing and wastewater treatment.
- Complex fluids are frequently encountered in these industries. There is growing interest in developing and studying these fluids, especially for those of shear thickening (ST) behaviour.

APPLICATIONS

- ST fluids (STFs) are a specific type of non-Newtonian fluids which acts as a rigid solid when it is experiencing a shear force.
- There is growing interested in developing and studying these fluids, especially because of their industrial applications such as flexible body armor and force damping applications which can protect a person from danger or risk and ultimately saveone's life.

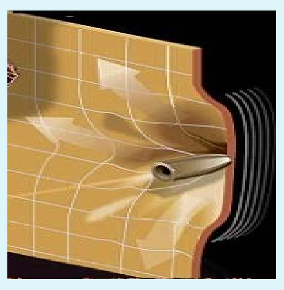
OBJECTIVES

- Develop new shear thickening fluid formulations.
- Investigate the mixing of shear thickening fluids. For the first time, the mixing of an opaque ST fluid studied numerically and experimentally and the formation of pseudo-cavern in addition to the local shear rate, flow pattern and 3D velocity patterns inside and around the pseudo-caverns was measured
- Compare the mixing behavior of ST fluids with different types of rheological fluids.

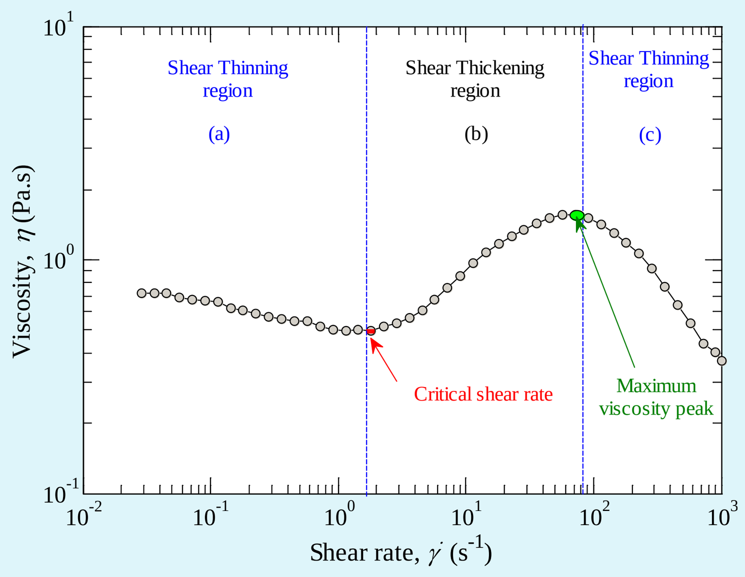
DEVELOPMENT OF STFs

Model Fluid used in mixing

22% nano silica-polyethylene glycol solution (PEG)



STFs since the 2000s, invented to be used in defence industry, as using these fluids combined with a composite material in the armor system provides protection and flexible movement to the users (Kuşhan et al., 2014).



Rheological Characterization

Power Law ➡ $\tau = k\dot{\gamma}^n$ where :k is the consistency index, n is the flow behavior index

Flow curve of ST fluids shows three regions:

a) Shear thinning, n< 1, Apparent Viscosity decreases with shear rate
b) Transition, Occurs at the critical shear rate
c) Shear thickening, n > 1, Apparent Viscosity increases with shear rate.

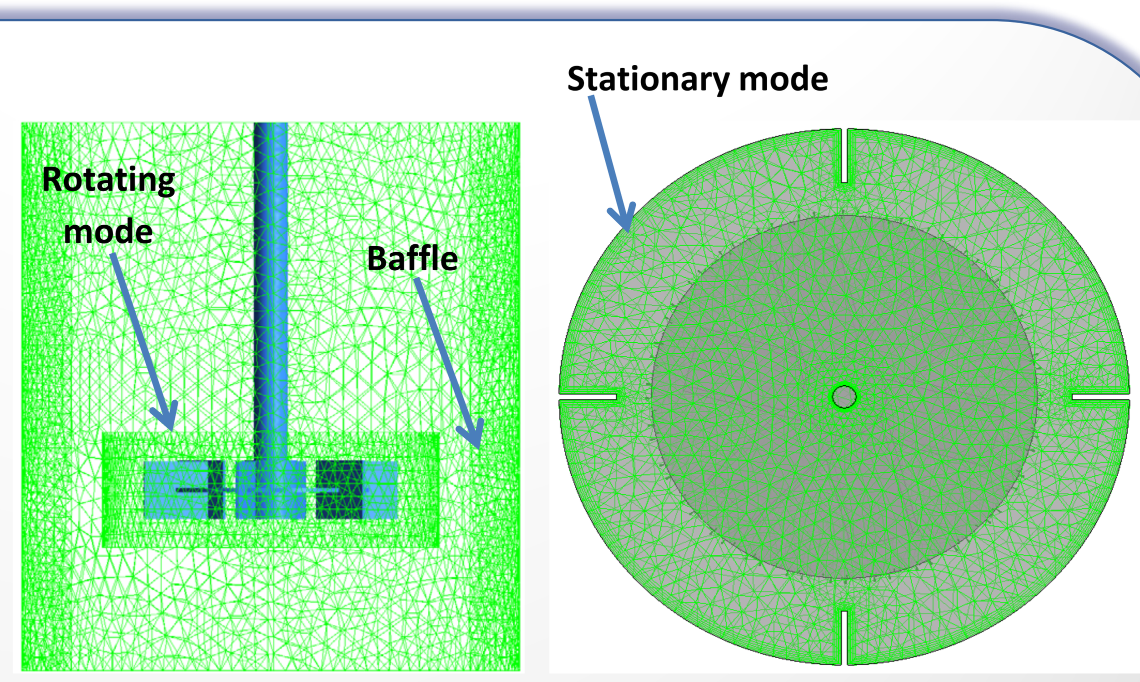
CFX Simulation and Validation

Software ➡ ANSYS CFX 14.5

Mesh ➡ **701,527** unstructured tetrahedral elements distributed non-uniformly

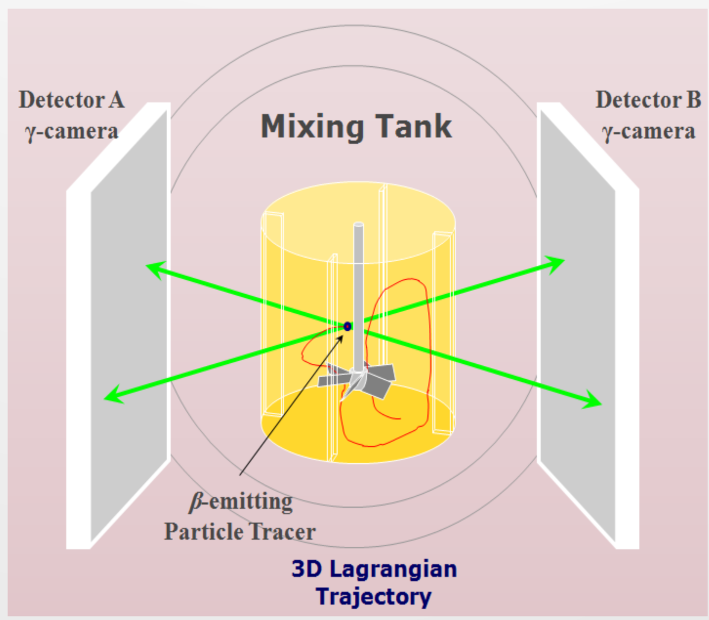
Method ➡ Multiple frame of reference (MFR)

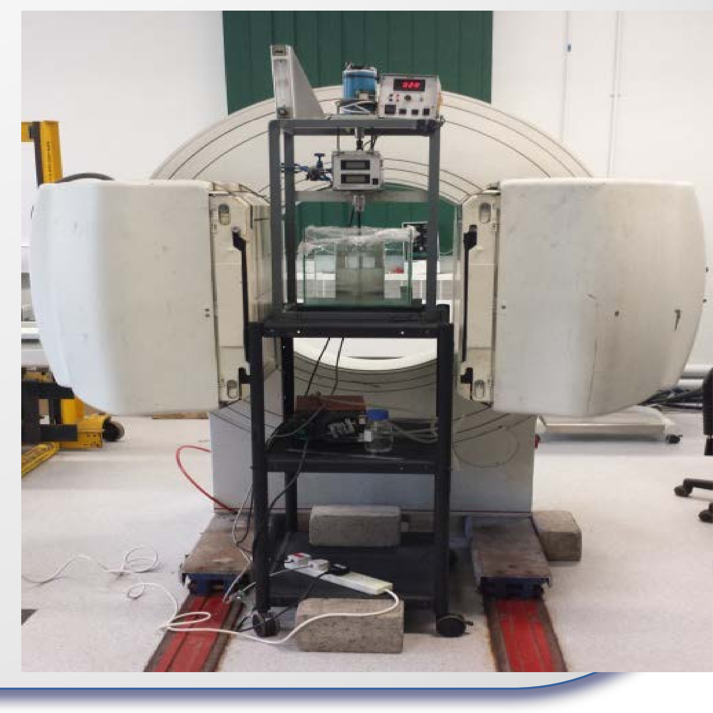
Conditions ➡
- All the simulations were managed in the laminar and low transitional regimes.
- The Rheology of the fluid was identified to cover the whole flow curve.
- To achieve an accurate prediction of cavern size, the simulation was operated to steady state with no initial conditions and maintain the simulation until the sum of all the normalized residuals were no more than **10^{-6}**.



Validation ➡ using PEPT which is a powerful experimental technique that is able to quantitatively investigate the flow phenomena, in three dimensions of opaque systems which cannot be studied by optical methods.

PEPT data were analysed using MATLAB code, defining three dimensional grid cell consists of 512 equal volume cells. The local shear rate can be determined in each cell using the analysed PEPT data.





Mixer Configuration ➡

Impeller:
6 blade, 45° PBT
D = 60 mm
Baffles: 4 - 90° apart

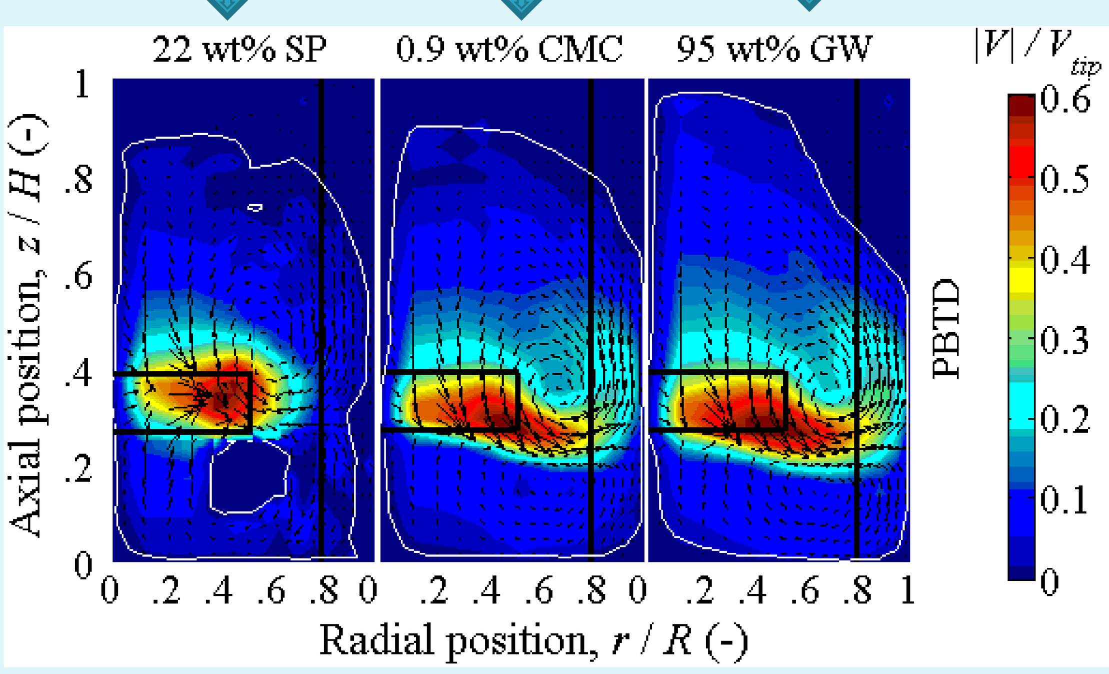
Vessel:
Flat-base cylindrical vessel
Vessel diameter (T)=Vessel height (H)=115
Off-bottom clearance of PBT =T/3

RESULTS AND ANALYSIS

Compare the mixing behaviour of different Rheological fluids with ST fluids at the same Reynolds number (Re = 70)

Table 1: Normalised pseudo–cavern size for the PBTD at Re = 70.

Fluid type		Normalised pseudo–cavern size (A_c/A_T)
ST	22 wt% SP	0.81
SN	0.9 wt% CMC	0.77
Newtonian	95 wt% GW	0.80



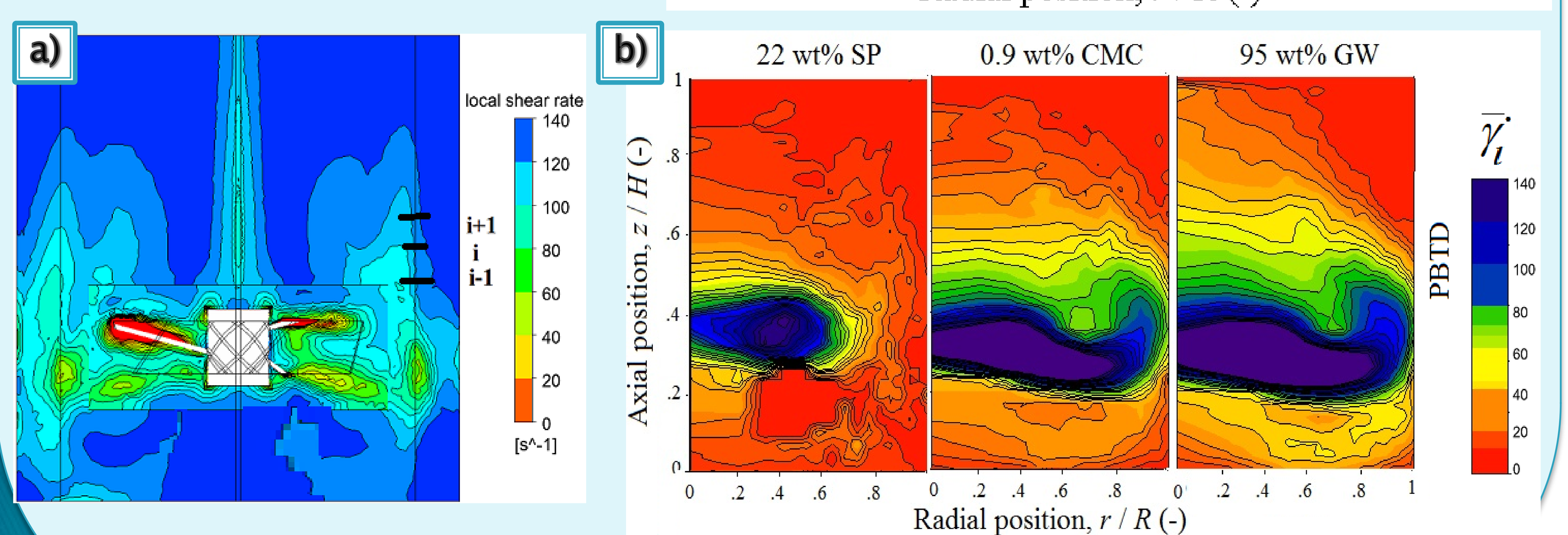


Figure 2. Local shear rate map for a) STF from CFD and b) different types of rheological fluids (ST, SN and Newtonian) from PEPT data at Re =70 using PBTD.

CONCLUSION

- Pseudo-Cavern size predicted from CFD predictions showed a good agreement with experimental measurements.
- For the first time, PEPT was used to compare the flow performance inside opaque ST fluids, mixed by PBTD impeller, in addition to a comparison with other types of Rheological fluids. Thus these results are very valuable for understanding the mixing behaviour of STFs and compare it to the SN and viscous Newtonian fluids at the same Reynolds number, and to the author's knowledge, this has not been done before.
- The unique results obtained show, counter-intuitively, that shear thickening fluids are considerably easier to mix than shear thinning fluids, as caverns in shear thickening fluids are better mixed and grow faster as a function of impeller tip speed than in shear thinning fluids
- A new method to evaluate the local shear rate and the local Reynolds number from PEPT data have been proposed which enable rapid identification of the flow regimes in each part within the stirred vessel. Such detailed analysis could be used to further study the mixing performance and the local mixing efficiency of different rheological fluids. The local shear rate determined from PEPT data using the new method have been compared with the local shear rate determined from CFX predictions. The comparisons shows very good agreement.

ACKNOWLEDGEMENTS

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