Vortex Formation in a Partially-Baffled Tank

Fall 2018

SPXFLOW

Background

Vortex formation and vortex depth are important for the incorporation of gases or light solids into stirred tanks. However, large vortices formed in unbaffled tanks fail to facilitate good mixing. Because of this, partially-baffled tanks, which allow for both mixing and vortex formation, are often used in these applications. In this experiment, vortex formation and vortex depth were studied in a partially-baffled tank.

Parameters

T: tank diameter (in.)
D: upper impeller diameter (in.)
COV: vertical distance from center of upper impeller to undisturbed fluid surface (in.)
Fr: Froude number
μ: fluid viscosity

$$Fr = \frac{N^2 D}{1.39\times10^6} = \frac{u_0}{\sqrt{g_0 l_0}}$$

Tank Diameter (T)	11.5”	17.5”	
D/T	0.20	0.29	0.40
COV/D	0.33	0.67	1.0
Mixer Speed (Fr)	Minimum	Average	Maximum
Fluid Viscosity (μ)	1 cP	100 cP	1000 cP

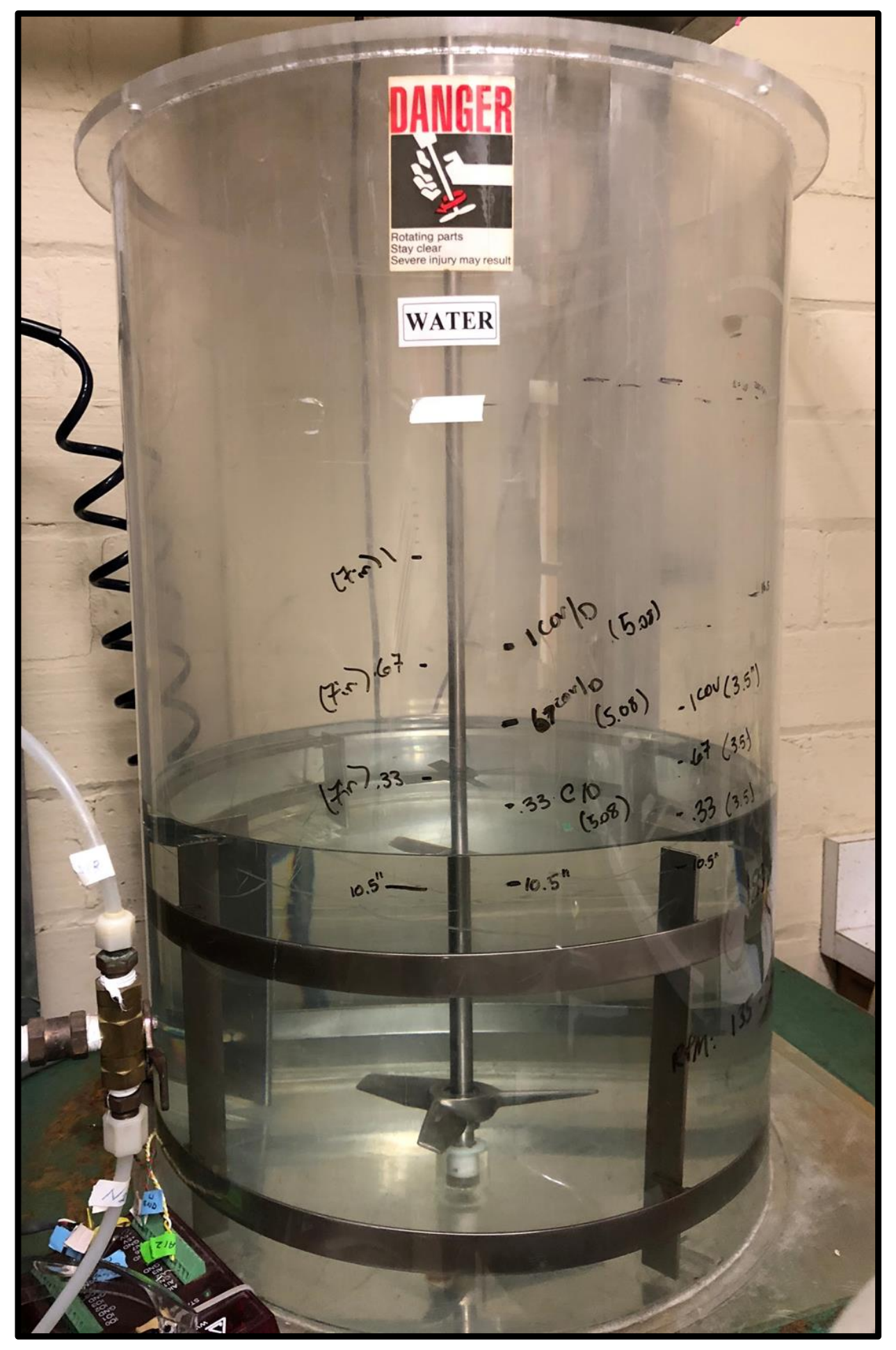
Design & Setup

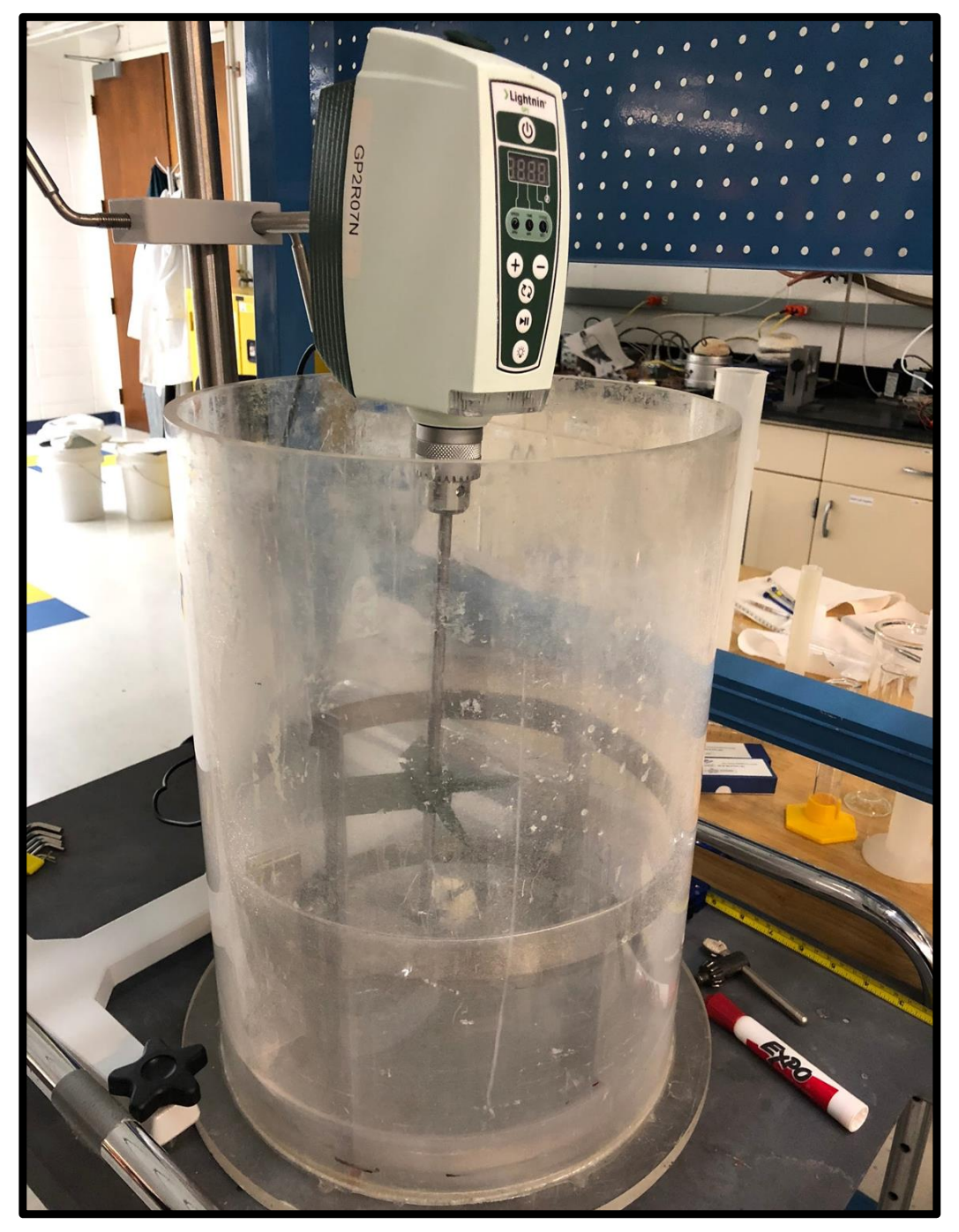
Tank Design:

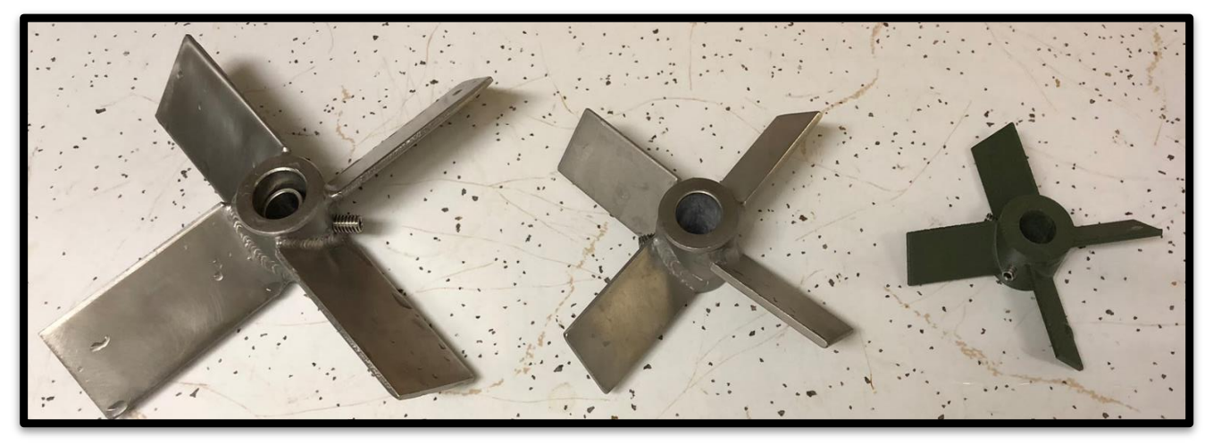
- Baffles with a height 0.6 that of the tank diameter
- A200 impeller placed at same height as top of the baffles
- A310 impeller placed a third of the way up the baffles

Testing:

- Three minute videos for each trial after system reached steady-state
- Carbopol 941 used to alter viscosity of fluid
- Minimum mixer speed was minimum speed to begin vortex formation
- Maximum mixer speed was maximum speed whose vortex did not collide with impeller







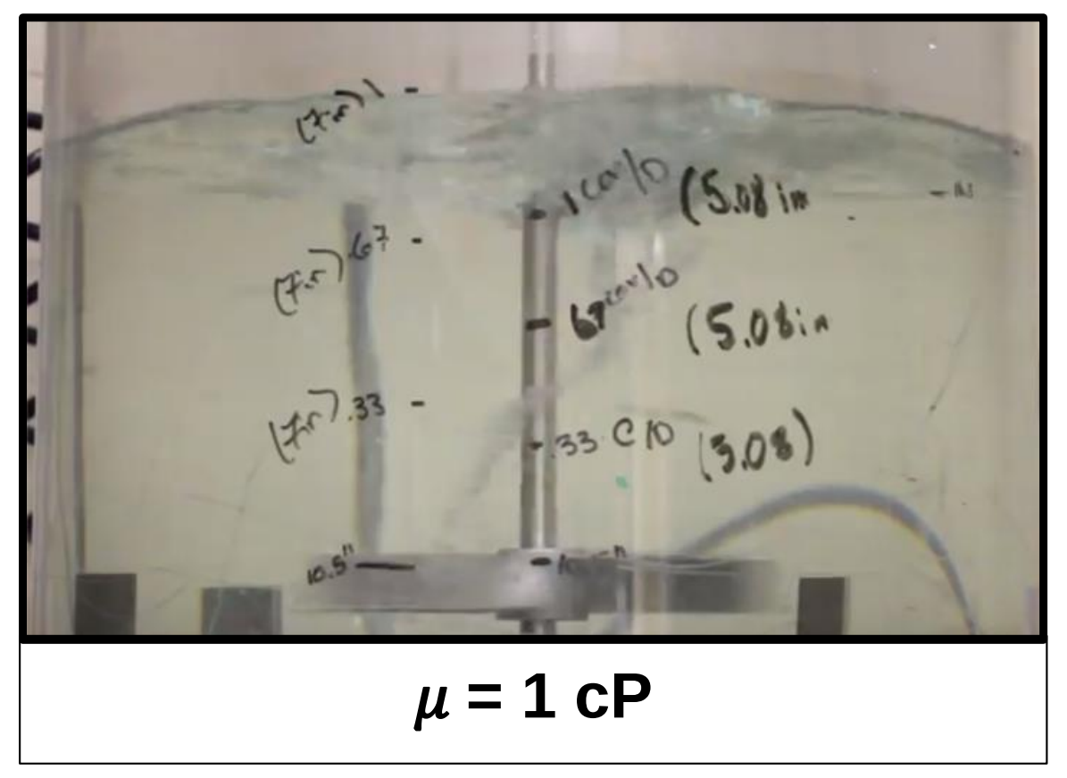
Results

Data Analysis:

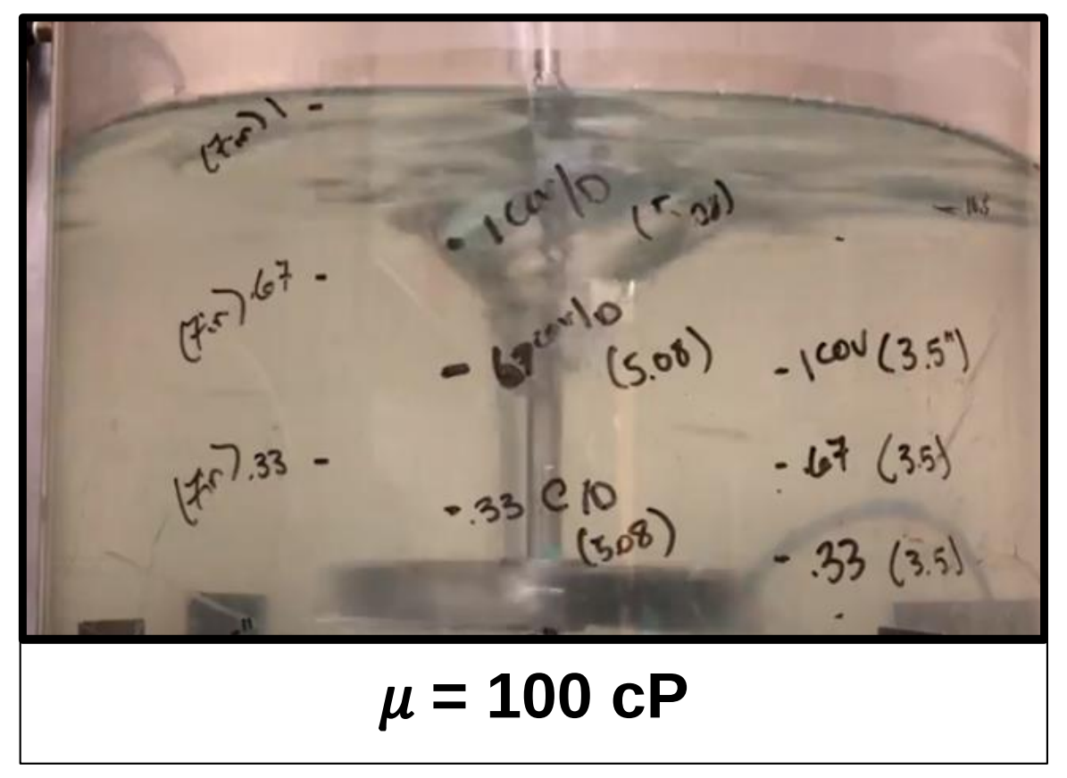
After analyzing the videos taken to collect maximum vortex depth and the fraction of time a vortex appeared for all 162 trials that were run, the data was analyzed using a factorial regression in Minitab. This analysis was performed to analyze maximum vortex depth for all 32 parameters; average vortex depth for all parameters; maximum vortex depth for 1 cP; maximum vortex depth for 100 cP; and maximum vortex depth for 1000 cP.

Parameter Effects:

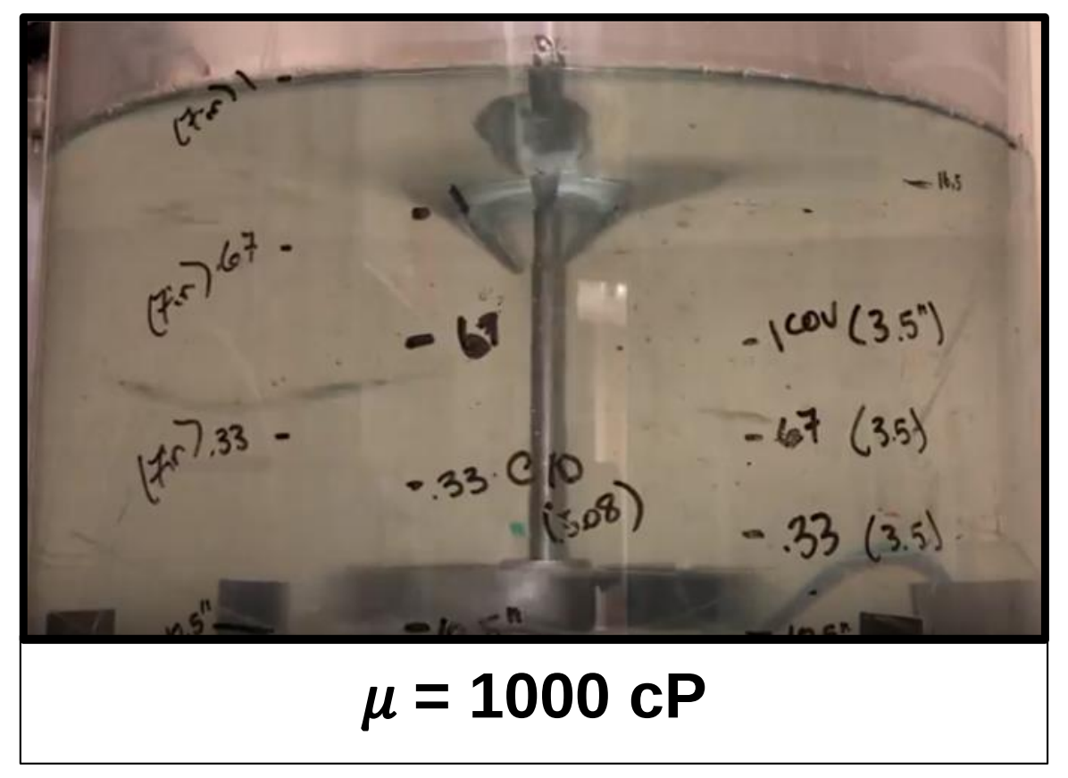
T = 17.5’’, D/T = 0.40, COV/D = 1.0, Fr ≈ 0.45



μ = 1 cP

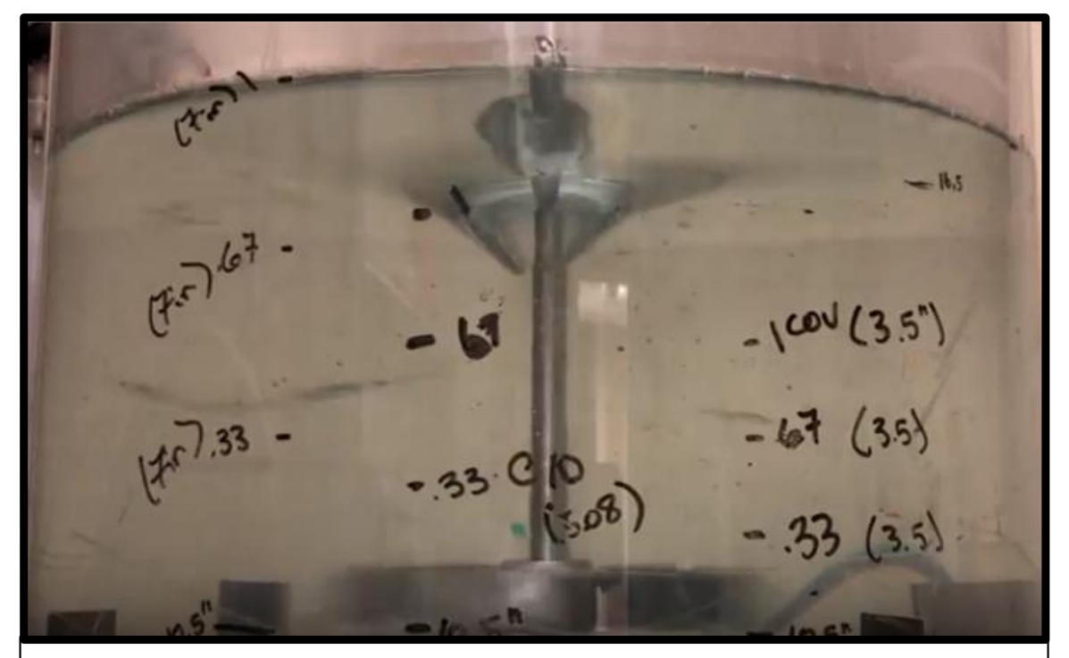


μ = 100 cP

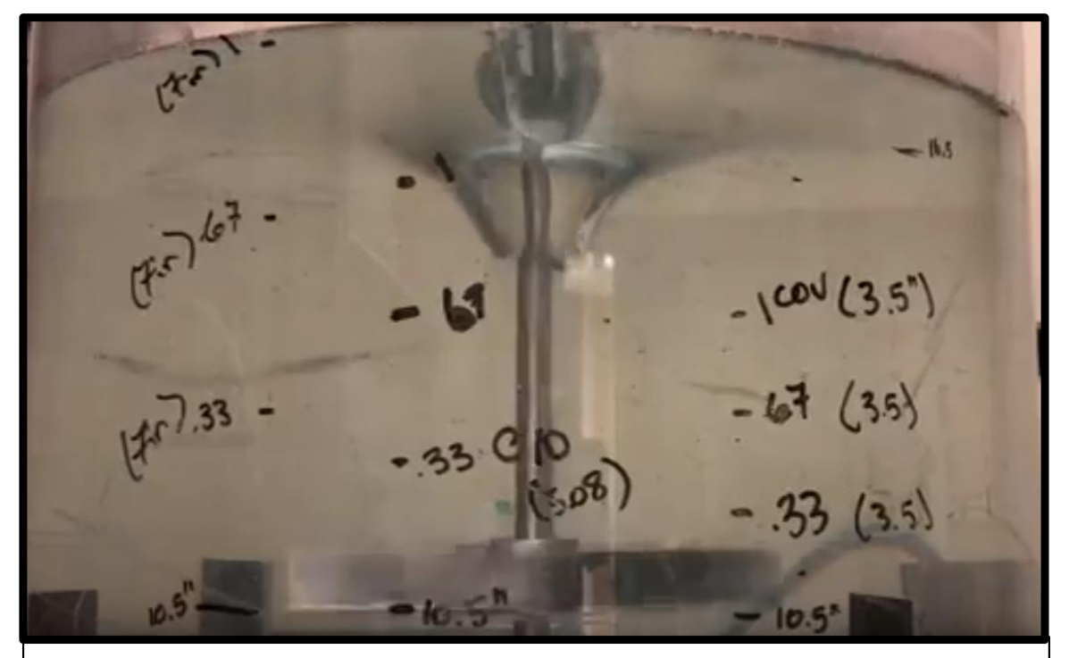


μ = 1000 cP

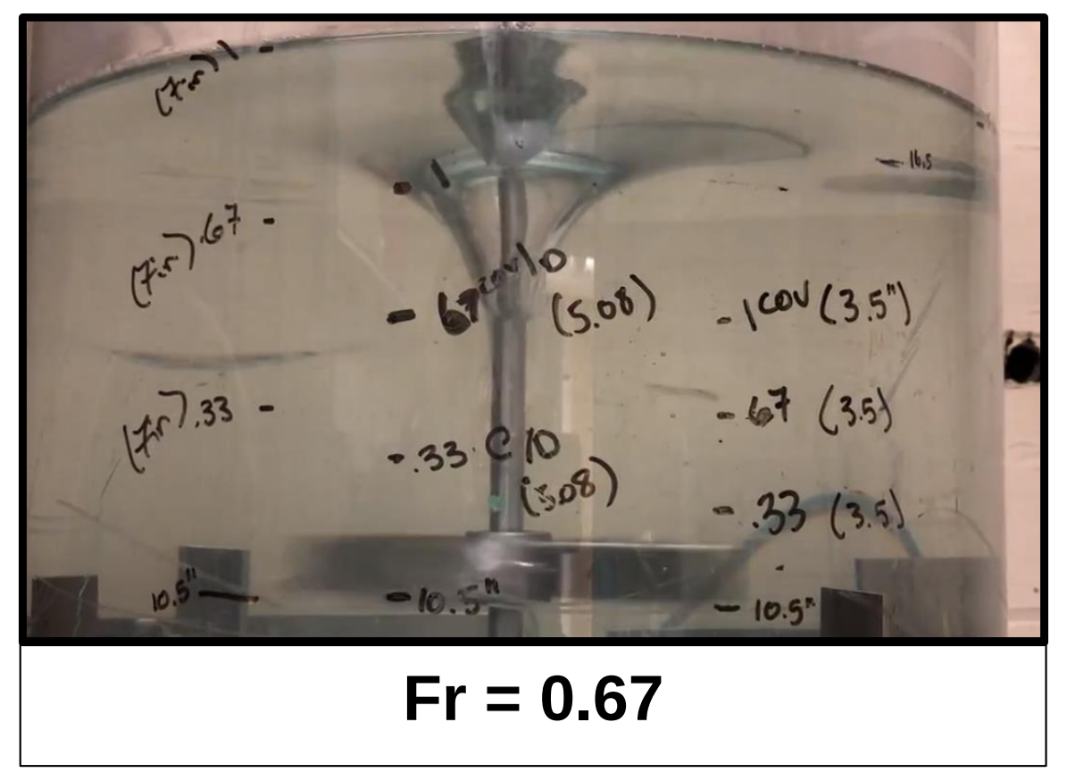
T = 17.5’’, D/T = 0.40, COV/D = 1.0, μ = 1000 cP



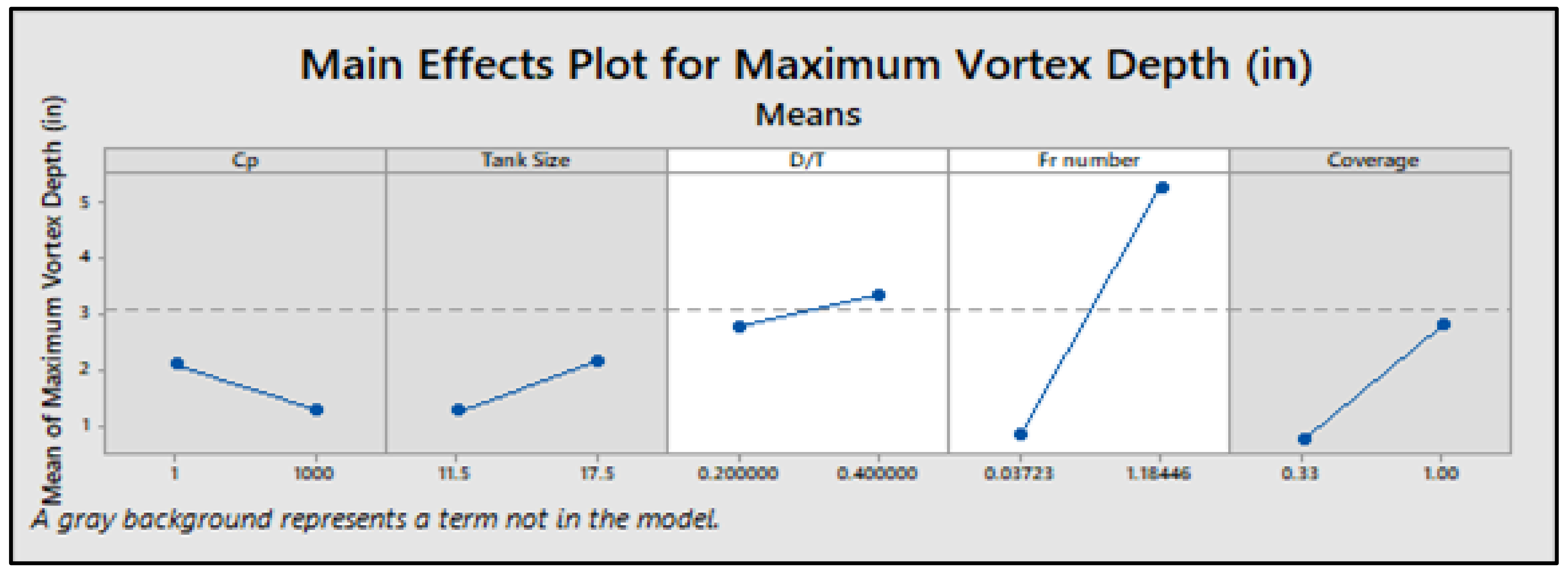
Fr = 0.55



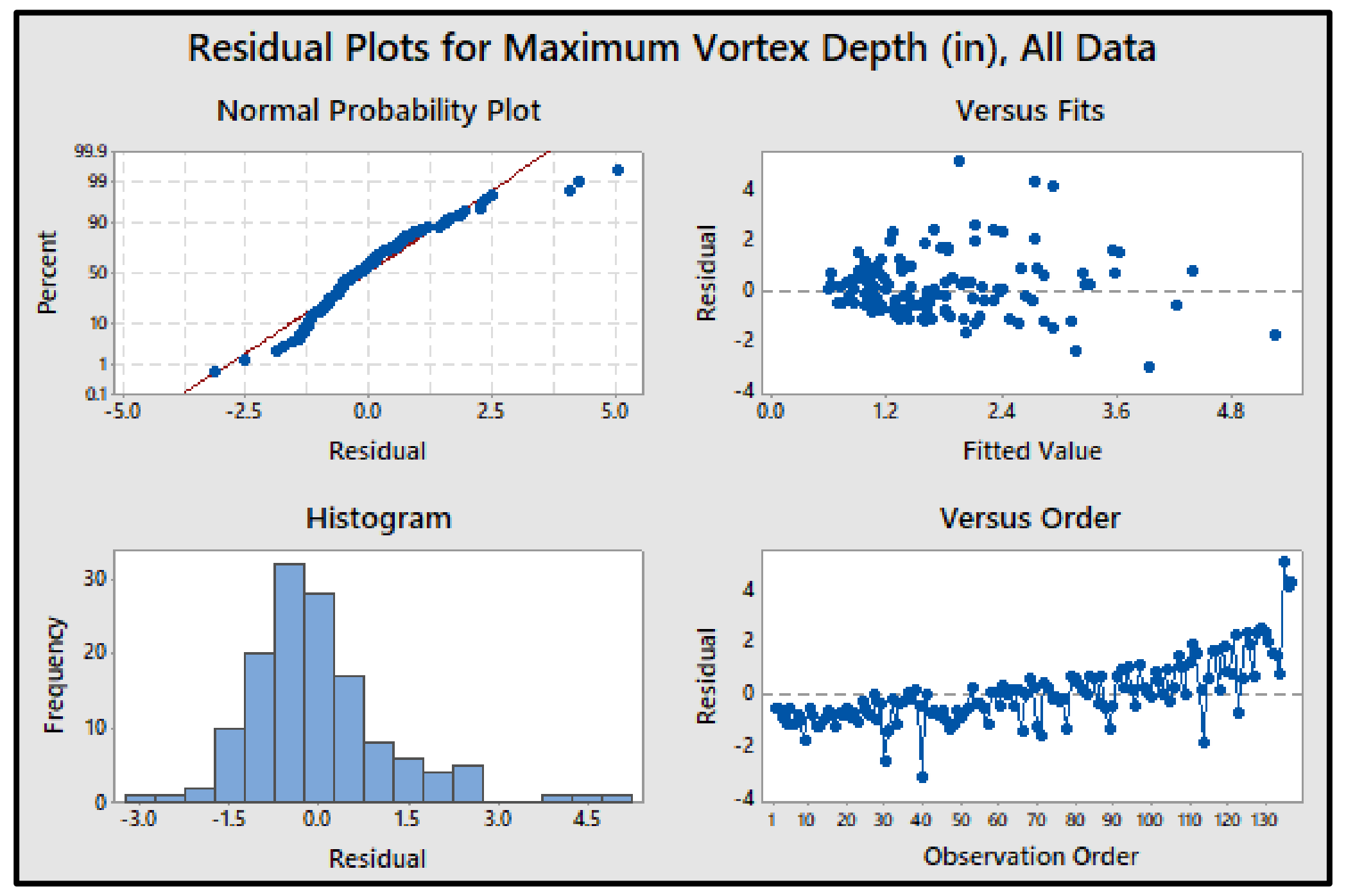
Fr = 0.60



Fr = 0.67



- Most important parameters: **D/T** and **Fr**
- **Higher D/T** → larger vortex depth
  - Larger impellers shear the fluid more
- **Higher COV/D** → larger vortex depth
  - Compounded effect with Fr
  - Surface should feel impeller less for higher COV/D (smaller vortex depth)
- **Higher Fr** → larger vortex depth
  - More shearing of fluid
- **Higher viscosity** → smaller vortex depth, increased vortex stability
  - Greater resistance to shear



Discussion

In performing these trials, the 1 cP liquid showed unstable and spontaneous vortices that frequently dipped down to hit the impeller. The higher viscosity trials showed more stability, but under certain conditions still displayed this behavior. Because of this, average (or steady state) vortex depth was hard to quantify, as was the stability of the vortex. it is hypothesized that both of these effects are most impacted by multiple parameter interactions.

It should also be noted that there were a few conditions for which no vortex formed. This is due to the limitation of the setup design, as the Fr number and speed of the impeller was limited due to shaft stability. These limitations were not sufficient to induce vortex formation at higher coverages and smaller impeller sizes for the 1000 cP and small tank conditions.

All Data Maximum Vortex Depth (in)		
Δ_{max} (in) = -0.130 + 3.859(Fr) + 2.80(D/T)		
R^2=33.19% Model F-Value = 33.28		
Parameter	Significance	F-Value
Fr	$p < 0.01$	60.78
(D/T)	$p < 0.05$	5.08

100 cP Maximum Vortex Depth (in)		
Δ_{max} (in) = 3.147 + 2.606(Fr) + 2.469(D/T)(COV/D) + 2.849(D/T)(COV/D)(Fr)		
R^2=60.42% Model F-Value = 23.92		
Parameter	Significance	F-Value
Fr	$p < 0.01$	57.31
(D/T)(COV/D)	$p < 0.01$	11.74
(D/T)(COV/D)(Fr)	$p < 0.01$	9.53

Conclusion and Future Work

A working model for vortex depth was created. However, in trying to simplify the model, the R^2 values became quite small. Any project attempting to draw a relationship in such a complex system would benefit from a larger data set with a larger range Fr numbers in order to draw a more effective correlation.

It is recommended that in future work continue to collect data for a wider range of Fr numbers, as well as work to better quantify vortex stability. One recommendation is to use time weighted averages to quantify vortex stability.

Acknowledgements

Special thanks to Kevin Logsdon, Aaron Strand and Richard Kehn, SPX Flow, Professor David Foster, Wenshi Zhang, John Miller, Doug Kelley, Rachel Monfredo, Mark Juba

References

1. Deshpande, S.s., et al. “An Experimental and Computational Investigation of Vortex Formation in an Unbaffled Stirred Tank.” Chemical Engineering Science, vol. 168, 2017, pp. 495–506., doi:10.1016/j.ces.2017.04.002.
2. Lubrizol Advanced Materials, INC. “Pharmaceutical Bulletin.” 31 May 2011.
3. Peters, Sara. “Baffled By Baffle Size For Industrial Mixing?” *Crane's Fluid Connection Blog*, CRANE'S FLUID CONNECTION, 3 Nov. 2016, blog.craneengineering.net/baffled-by-baffle-size-for-industrial-mixing.

Department of Chemical Engineering

Presented by Team Fig Newton: William Funkenbusch, Luke Oluoch, Sabrina Westgate, Sean Wilson-Leslie

HAJIM
SCHOOL OF ENGINEERING
& APPLIED SCIENCES
UNIVERSITY of ROCHESTER