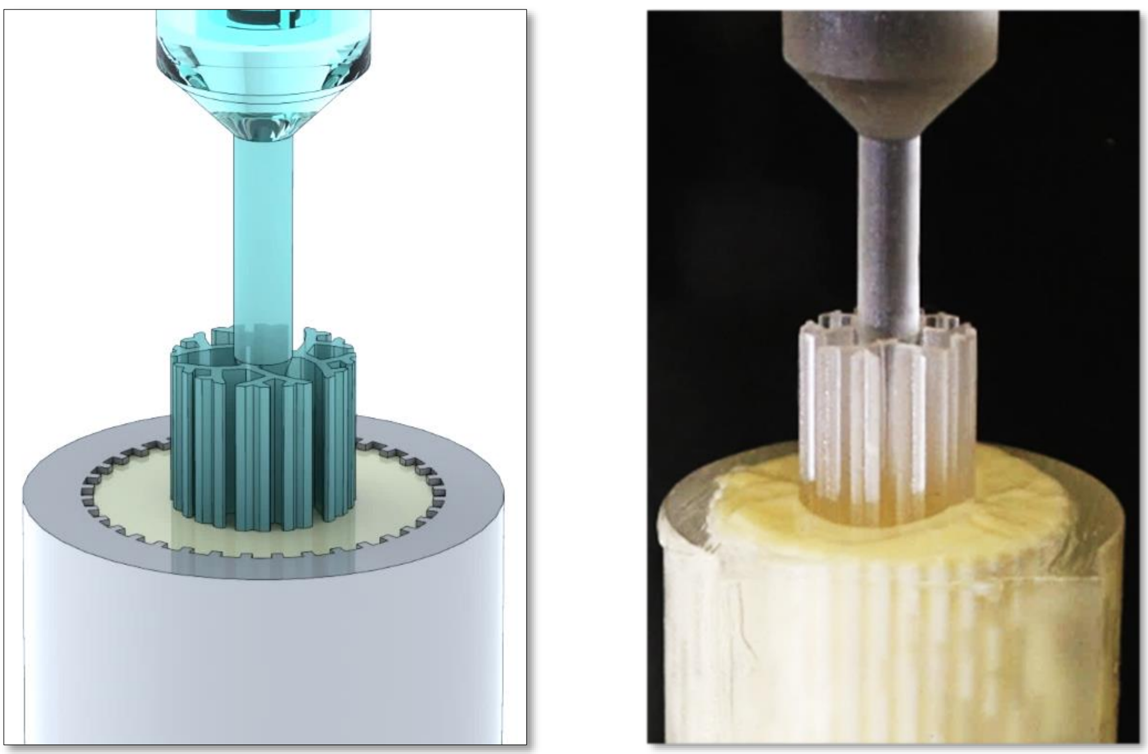
HATSOPOULOS MICROFLUIDS LABORATORY

mechanosynthesis

The NNF Guide to

# Using 3D Printed Rheometer Tools

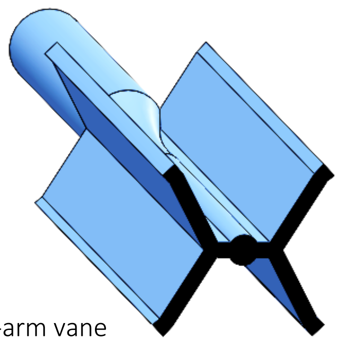


*Computer rendering and photograph of fractal vane modeled after a Bethe lattice with 24 end points. It sits partially submerged in a cup of material (mayonnaise).*

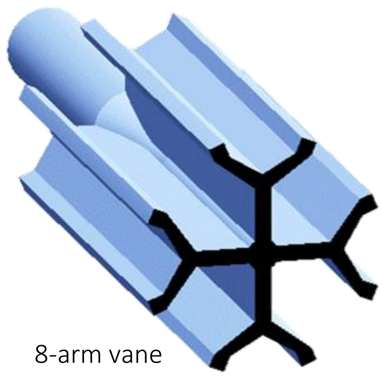
Crystal E. Owens, A. John Hart, Gareth H. McKinley

# 1. Design choice

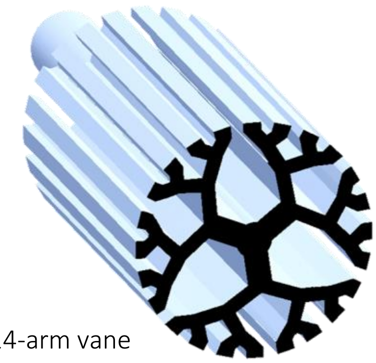
**Choice of vanes:** Vanes with 4-24 arms depending on material needs.



4-arm vane



8-arm vane



24-arm vane

**Sparser structures**

→ Best for stickier and denser materials

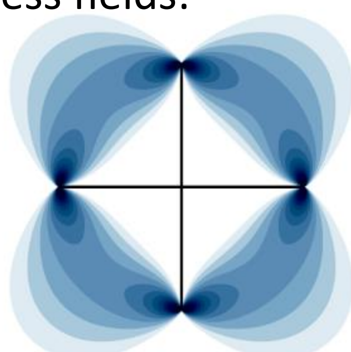
→ Easy to insert into material

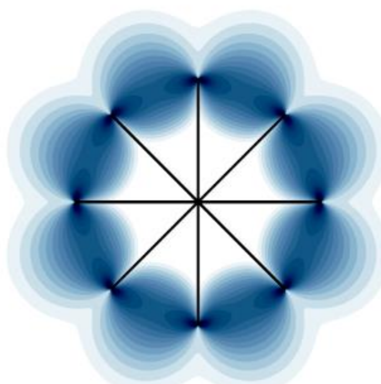
**Denser structures**

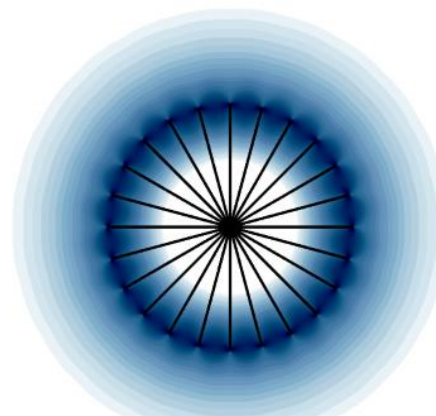
→ Best for lower-viscosity materials

→ Homogeneous stress field

## Stress fields:







Most uniform!

## Choice of cups

For larger cups and cups with additional features (like optical windows), a second base mounts to the standard Peltier plate.

Alternative base with textured cup filled with ketchup.

# 2. About the Parts

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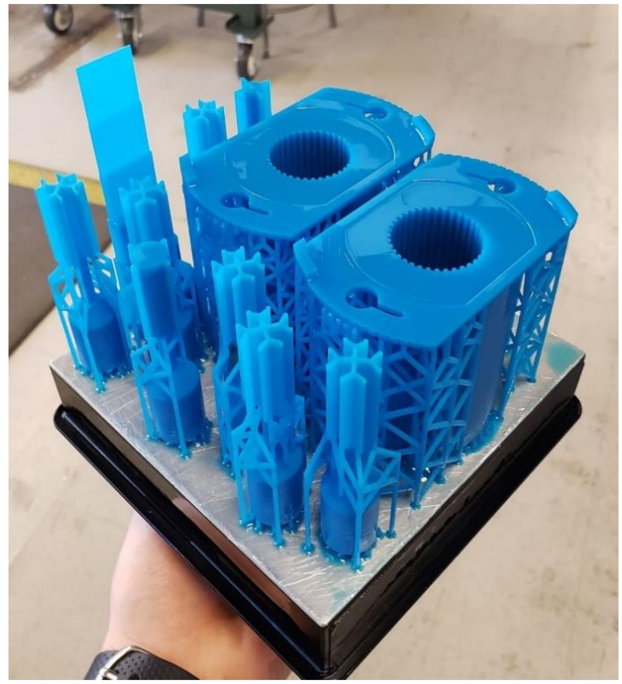
They are fabricated by stereolithography 3D printing using a methacrylate-based photopolymer with blue dye.

The material is compatible with acetone, isopropyl alcohol, and water. For best results, rinse but do not soak when washing. Avoid rubbing surface vigorously after it has been soaking in pure solvents.

Keep out of sunlight for long-term use.



Rheometer tools right after printing and before post-processing.

## Solvent Compatibility

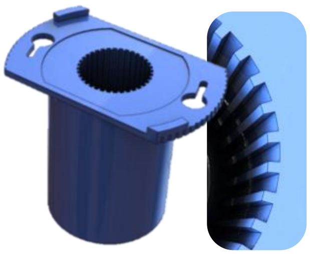
Percent weight gain over 24 hours for a printed and post-cured (60 °C for 5 minutes) 1 x 1 x 1 $cm^3$ cube immersed in respective solvent:

| Solvent | 24 hr size gain (%) | 24 hr weight gain (%) | Solvent | 24 hr size gain (%) | 24 hr weight gain (%) |
|---|---|---|---|---|---|
| Acetic Acid, 5 % | <1 | <1 | Hydrogen Peroxide (3 %) | <1 | <1 |
| Acetone | <1 | 2 | Isooctane | <1 | <1 |
| Isopropyl Alcohol | <1 | <1 | Mineral Oil, light | <1 | <1 |
| Bleach, ~5 % NaOCl | <1 | <1 | Mineral Oil, heavy | <1 | <1 |
| Butyl Acetate | <1 | <1 | Salt Water (3.5 % NaCl) | <1 | <1 |
| Diesel | <1 | <1 | Sodium hydroxide (0.025 %, pH = 10) | <1 | <1 |
| Diethyl glycol monomethyl ether | <1 | 1 | Water | <1 | <1 |
| Hydrolic Oil | <1 | <1 | Xylene | <1 | <1 |
| Skydrol 5 | <1 | 1.1 | Strong Acid (HCl Conc) | <1 | <1 |

**FORMLABS MATERIAL PROPERTIES – DRAFT RESIN:** Draft Resin for Truly Rapid Prototyping 2

*Formlabs.com*

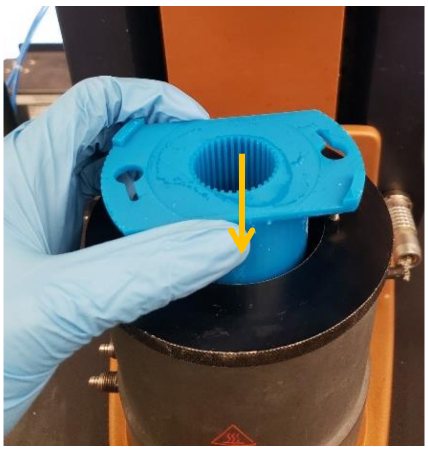
# 3. Getting Started

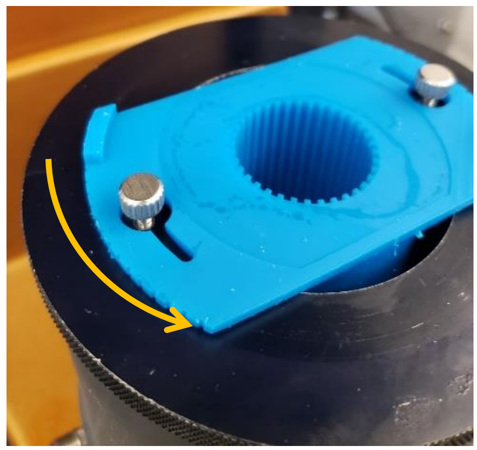


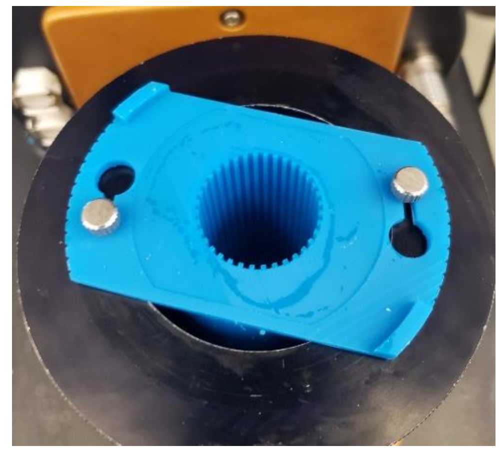
## Textured Cup

Inner Diameter: $2R_c = 28.5$ mm
Depth: 70 mm

Use with TA's Concentric Cylinder Peltier Jacket







1. Insert in jacket and align screws.
2. Twist in place, aligning both screws with grooves at the same time.
3. The screws will fit **tightly** in the grooves, and do not need to go all the way to the end.

## The 8-Arm Fractal Vane

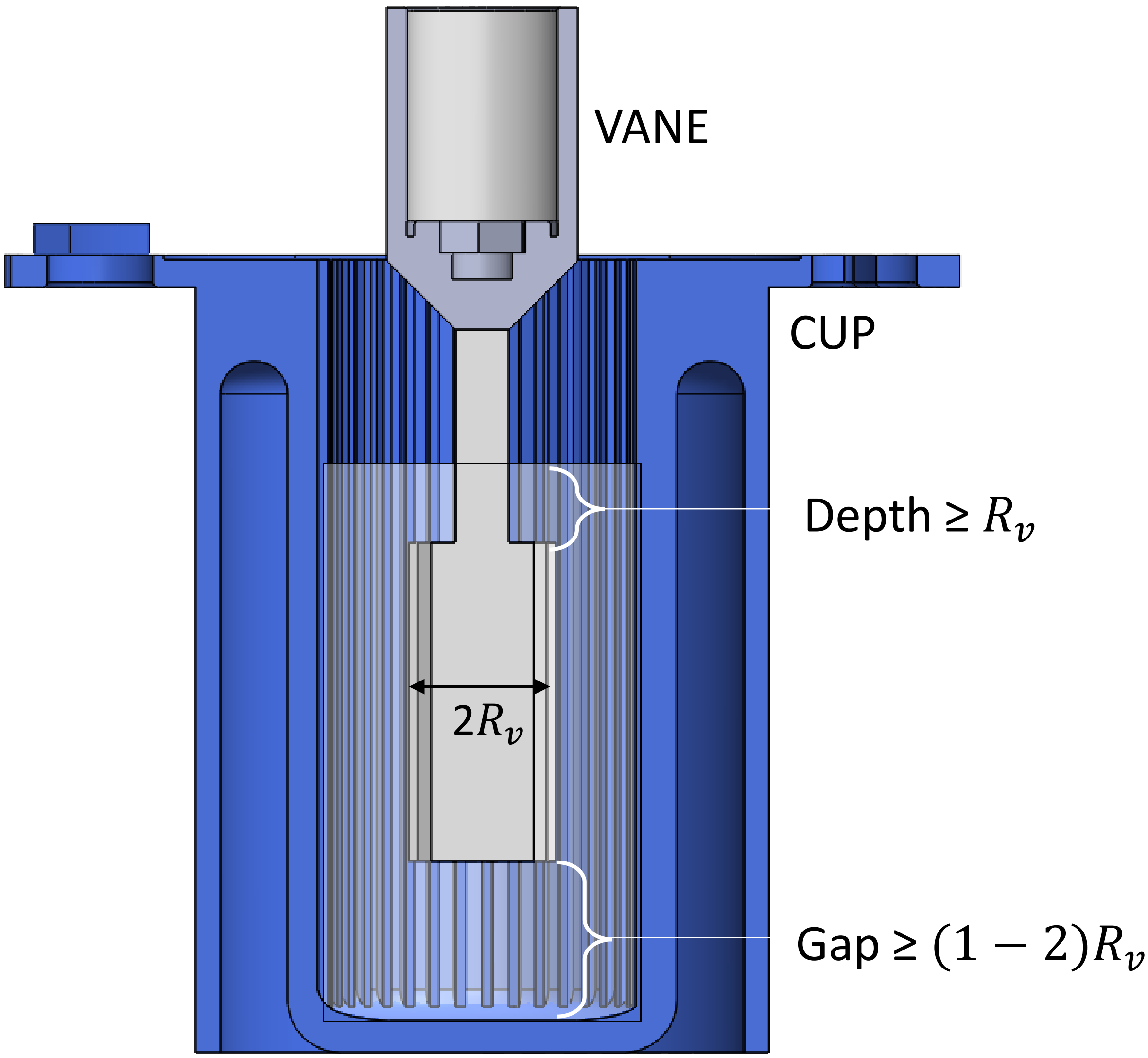
Radius: $R_v = 7.6$ mm
Length: $L = 30$ mm

1. Insert onto spindle, possibly using force
2. If required, screw on with threaded rod.
3. Calibrate and use as normal.

The specific dimensions of the vane affect performance. An M14 ream should give a good fit. If too loose, it will wobble during experiments, so a tigher fit is better. The tightness will decrease mildly with age if it's 3D printed.

# 4. Sample Loading

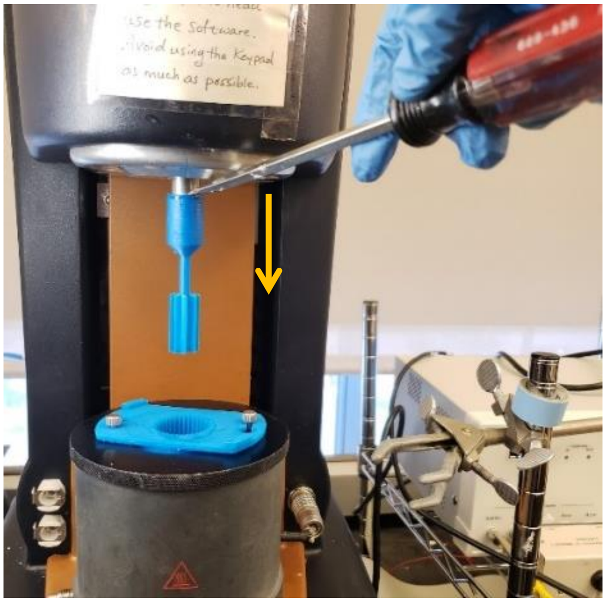
## Minimizing end effects and boundary layers with vanes




Insertion procedure:

- For thicker samples, insert slowly to ensure no air pockets are trapped inside vane.
- For much thicker materials, insert to depth of 1000 μm and raise slowly back up to 7500 μm to ensure the interstitial spaces in the vane are filled with sample.

# 5. After use: Cleaning Tips



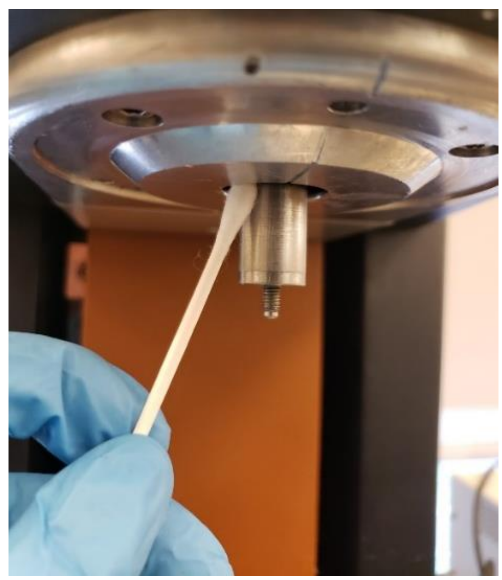
Removing the vane

For tight-fitting vanes, if a vane is difficult to remove, it can be gently pried off without damaging the instrument.

Cleaning the vane after tests

The vane may be effectively cleaned with small brushes.

The vane is compatible with acetone, isopropyl alcohol, and water. For best results, rinse but do not soak.



Cleaning the spindle

If required, the spindle may be cleaned after use using a cotton swab wetted with isopropyl alcohol.

# 6. Data Analysis

## Converting Torque-Rotation to Stress-Shear Rate

### Variables [and units]:

$N$ number of vane arms
$L$ vane length [m]
$\Omega$ rotation [rad/s]
$M$ Torque [N-m]
$R_v$ vane radius [m]
$R_c$ cup inner radius [m]
$\dot{\gamma}$ shear rate [s$^{-1}$]
$\sigma$ shear stress [Pa]

### Precise conversion:

$$\sigma = M \Big/ 2\pi R_v^{\,2} L\left[\left(1-\frac{1.113}{N}\right)+\frac{R_v}{4L}\left(2.75-\frac{3}{\sqrt{N}}\right)\right]$$

This becomes less accurate for

$$\frac{\sigma}{\sigma_{yield}} > \left(\frac{R_c}{R_v}\right)^2 \sim 3.6$$

$$\dot{\gamma} = \frac{2\Omega}{d\ln T / d\ln \Omega}$$

Recommended to fit $T(\Omega)$ to a polynomial or spline so the derivative is smooth.

### Approximate fitting (~10-300% error):

$$\sigma \approx 95{,}000M$$

Calculated for 8-arm vane

$$\dot{\gamma} \approx 9\Omega$$

~10-300% error. Estimated from one Carbopol material.

Key References:

[1] C. Atkinson, J.D. Sherwood. The torque on a rotating *n*-bladed vane in a Newtonian fluid or linear elastic medium. Proc. R. Soc. Lond. A (1992).
[2] C. E. Owens, T. Narayanan, A. J. Hart, G. H. McKinley. Additively manufactured vanes with modified geometries for measurements of yield-stress fluids. Society of Rheology (2018).