# Modellierung der Durchmischungsvorgänge im Fermenter für eine gezielte Optimierung der Rührwerke

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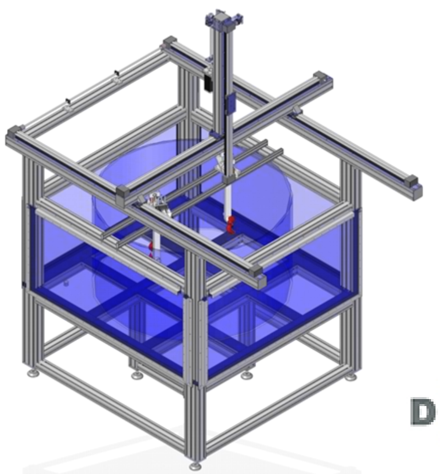
Fachgebiet Verfahrenstechnik



Technische Universität Berlin

Fraunhofer IKTS

DBFZ

RTO Repowering Technik Ost

Bundesministerium für Ernährung und Landwirtschaft

FNR Fachagentur Nachwachsende Rohstoffe e.V.

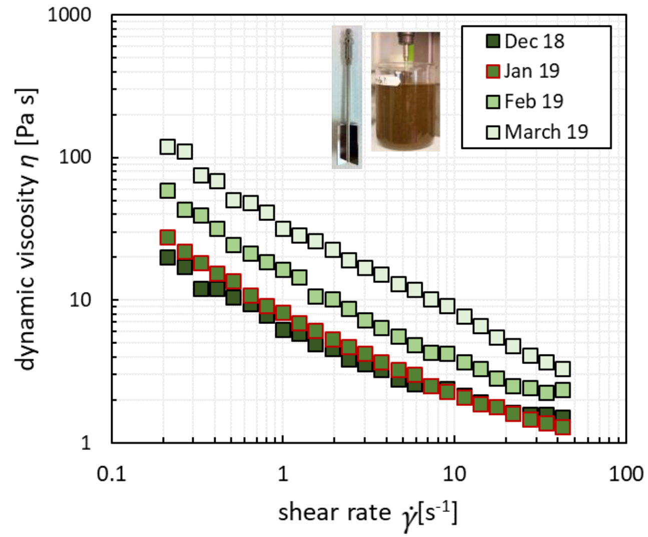
**Sens-O-Mix**

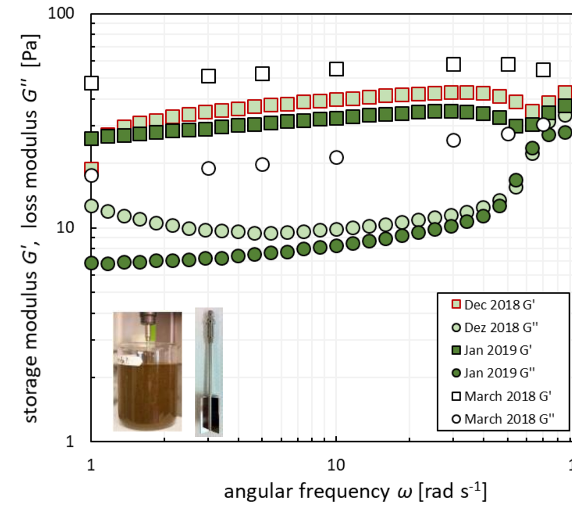
https://www.fnr.de/index.php?id=11150&fkz=2219NR437

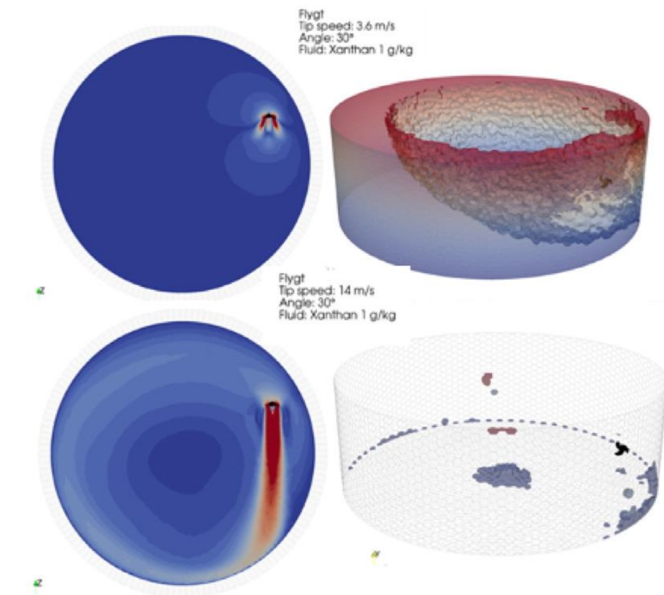
# Motivation – Agitating biogas fermenters

http://www.rotaria.com/

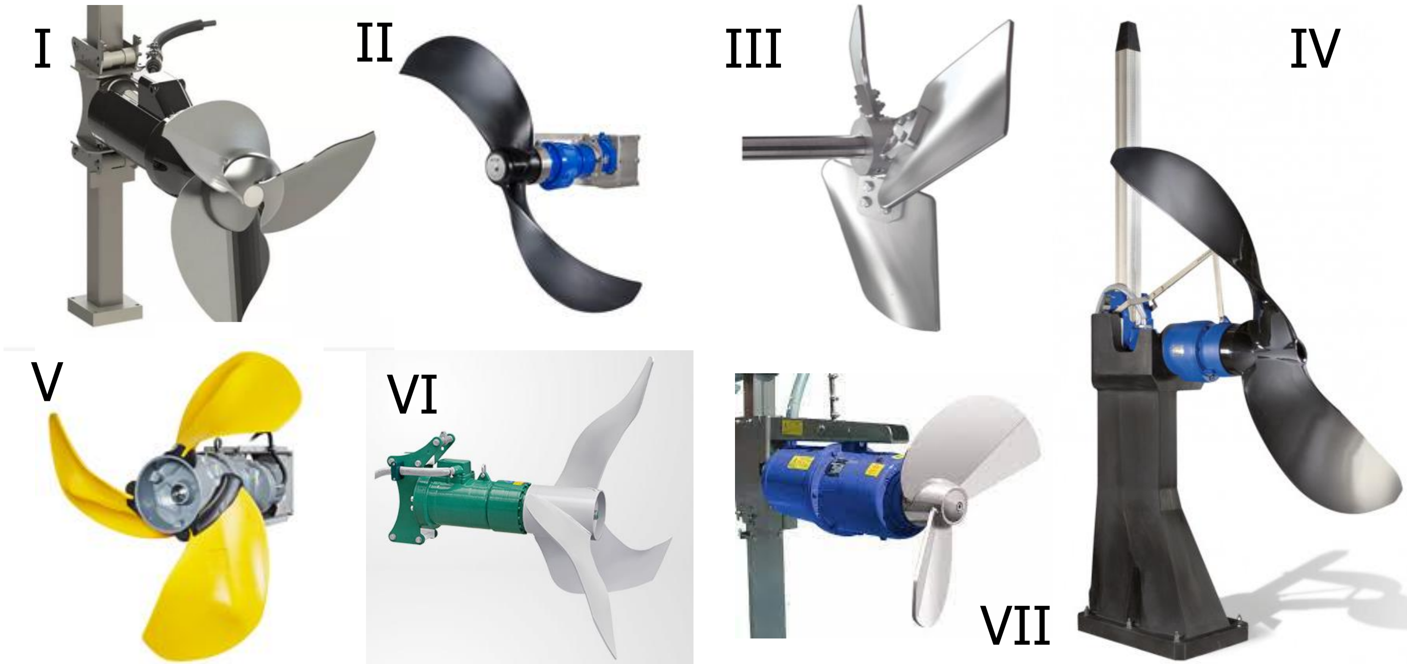
http://www.dh1ply.de/riedlbauer547.html

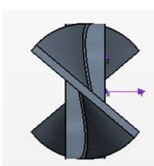


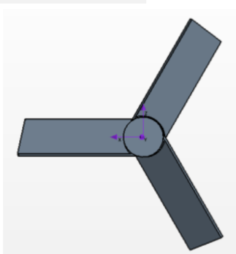



# Motivation – Agitating biogas fermenters

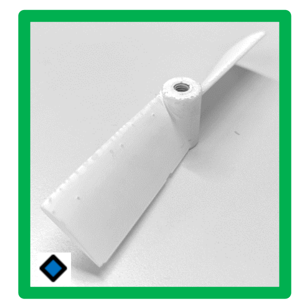




**How should an efficient biogas agitator be designed?**

- **Experimental** study on propeller flows in non-Newtonian media
- Geometrical parameter study using **CFD**
- Validation using **3D-printed models**

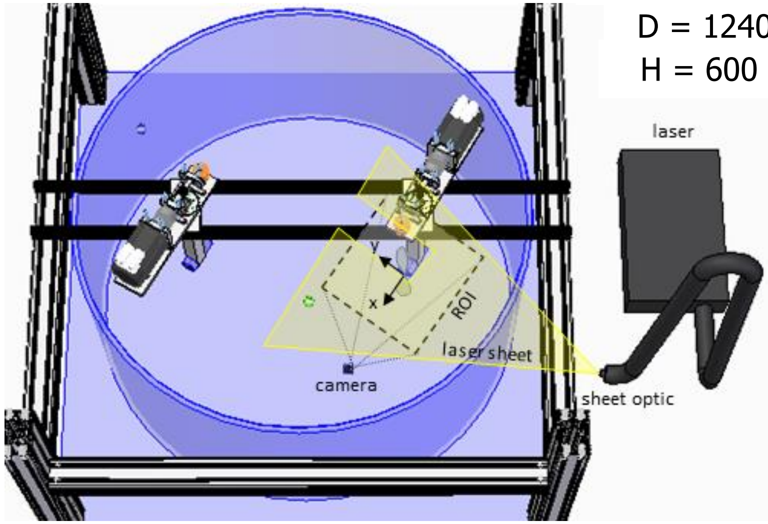


# Stirring experiments – Laser-induced fluorescence

Xanthan gum 1 g/kg

D = 1240 mm

H = 600 mm

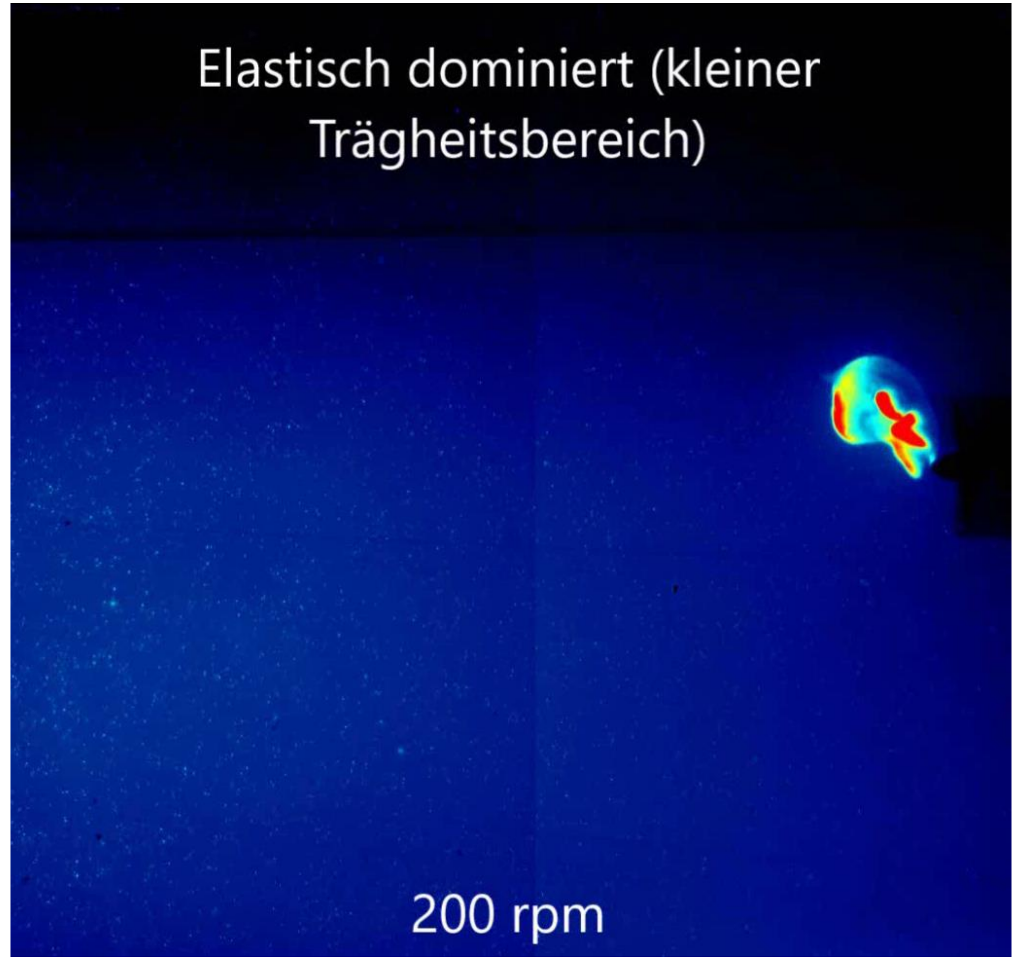




d = 142 mm


d = 102 mm


d = 175 mm

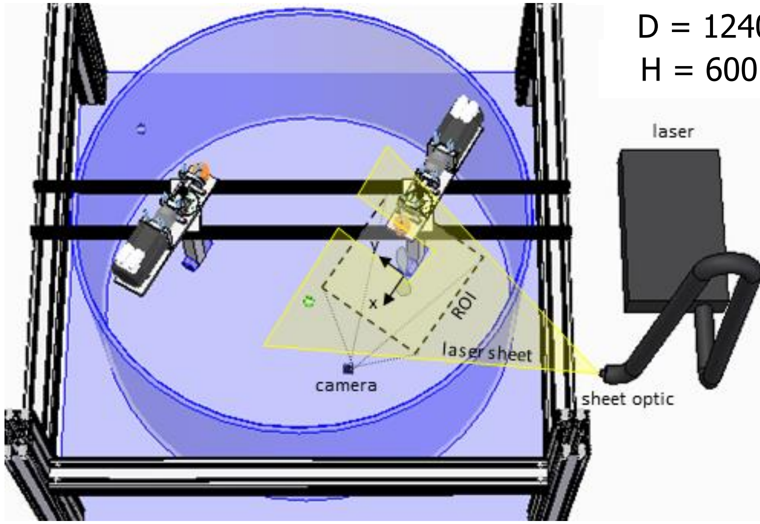


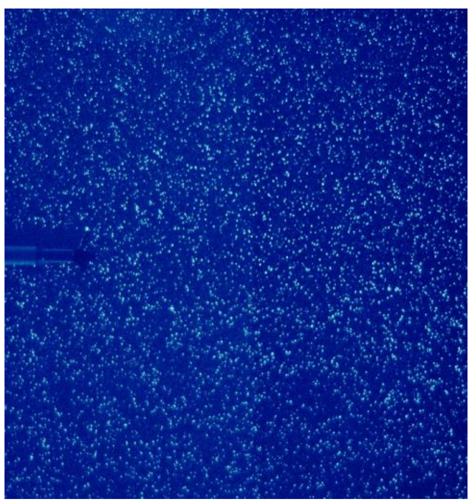
# Stirring experiments – Particle image velocimetry

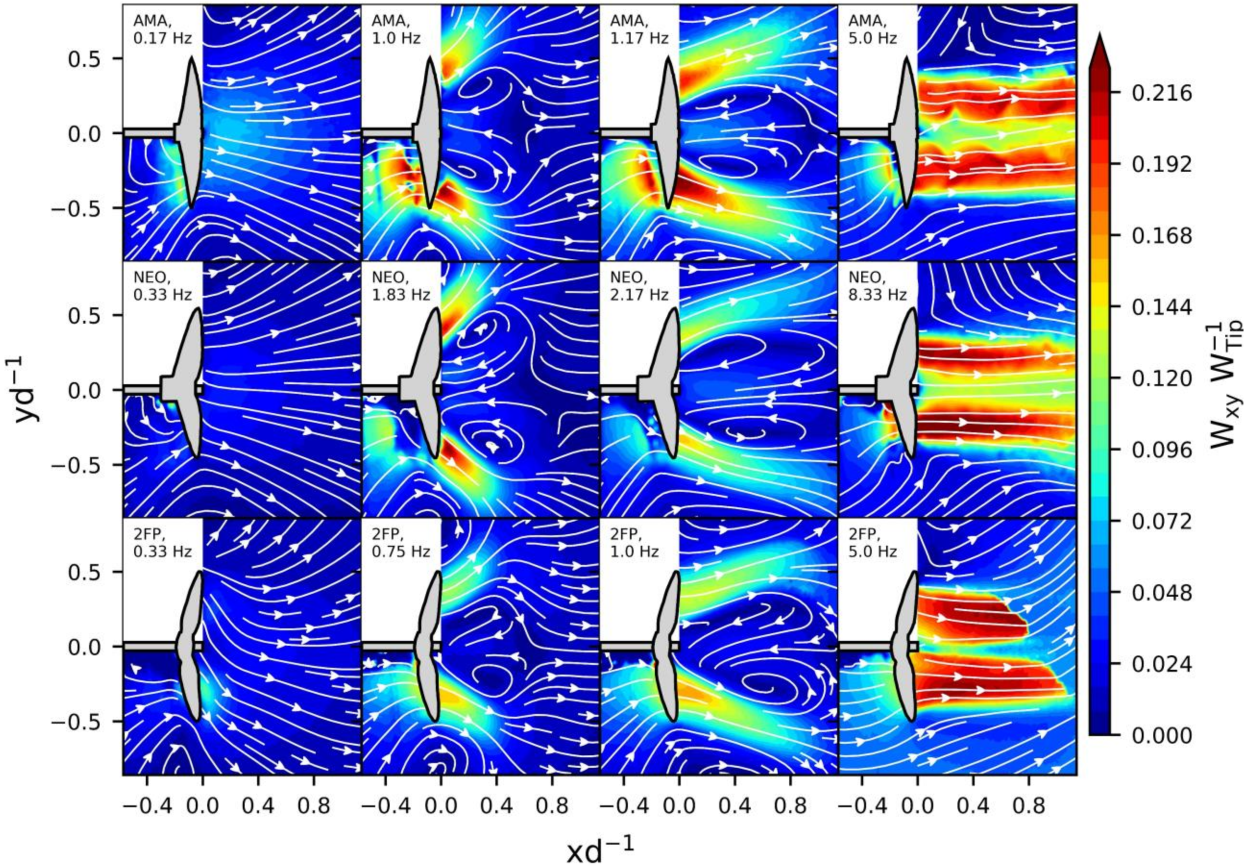
Xanthan gum 1 g/kg

D = 1240 mm

H = 600 mm

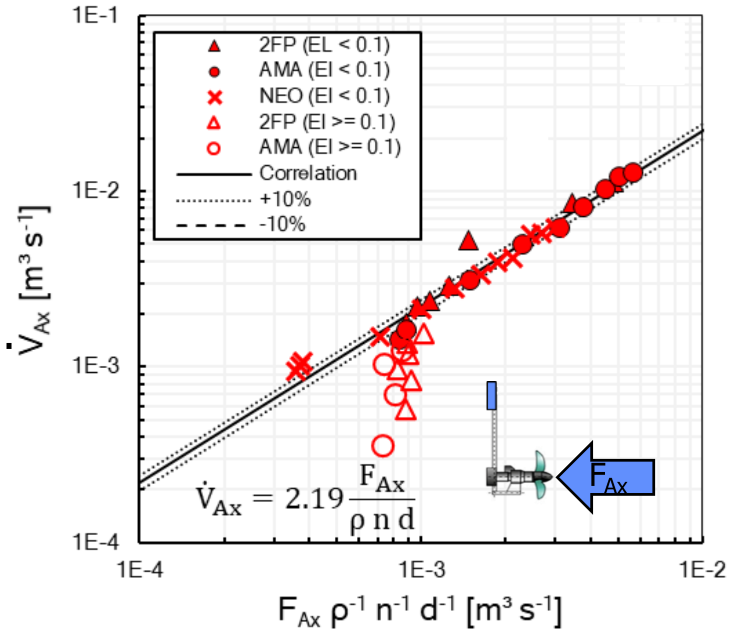


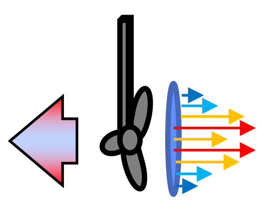



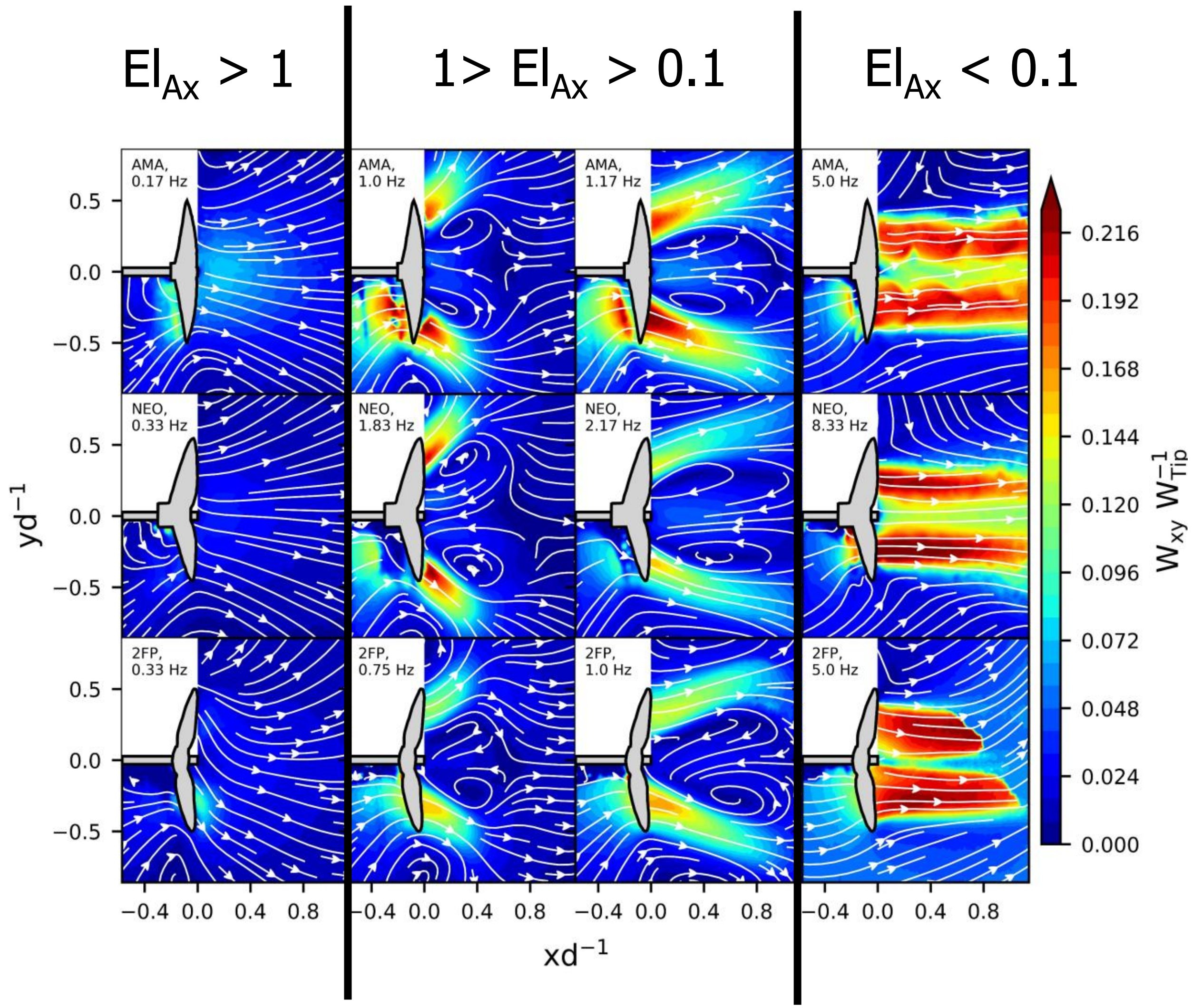


# Stirring experiments – Elasticity number and thrust correlation

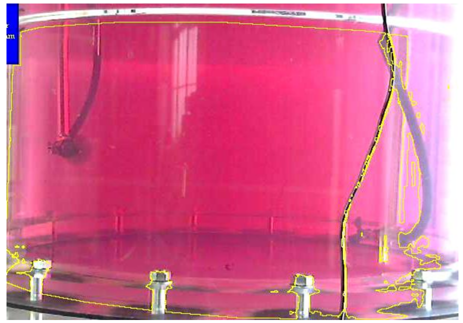
$$El_{Ax} = \frac{N_1}{\rho n^2 d^2 \sin(\overline{\alpha})}$$

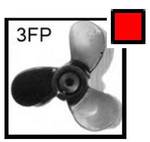


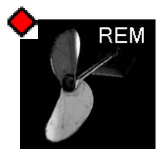



# Stirring experiments – Thrust & mixing times






d = 130 mm

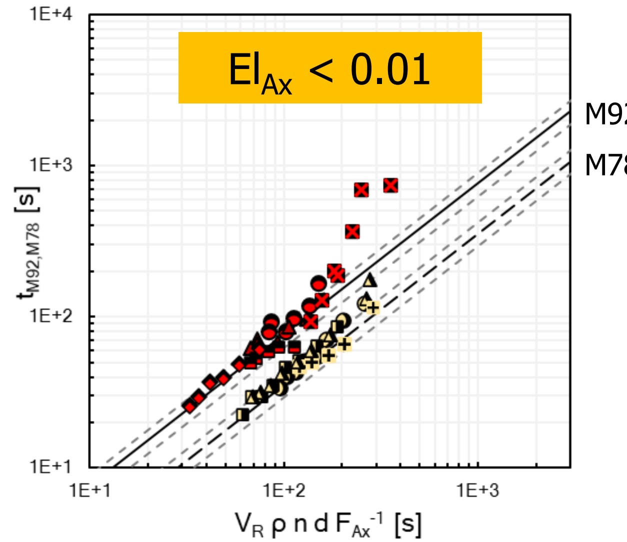



d = 155 mm


d = 175 mm


d = 102 mm

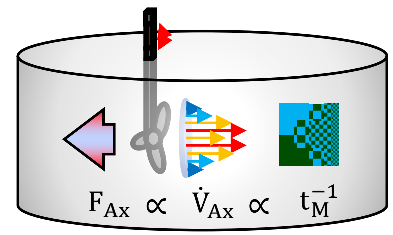

d = 142 mm




$$t_M = c_M\ V_R \frac{\rho n d}{F_{Ax}}$$

——— $c_M = 0.763$ for $t_{M92}$

– – – $c_M = 0.356$ for $t_{M78}$





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Research paper

Using thrust to control the mixing process in stirred tanks with side-entering agitators and viscoelastic fluids

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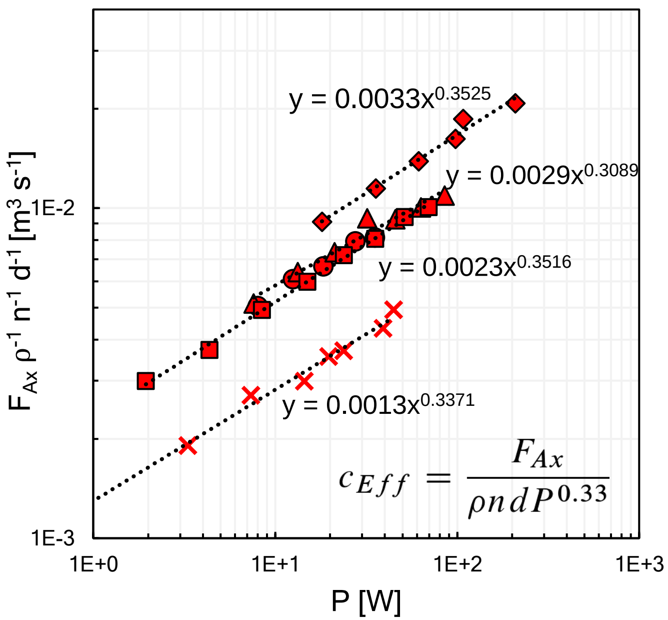
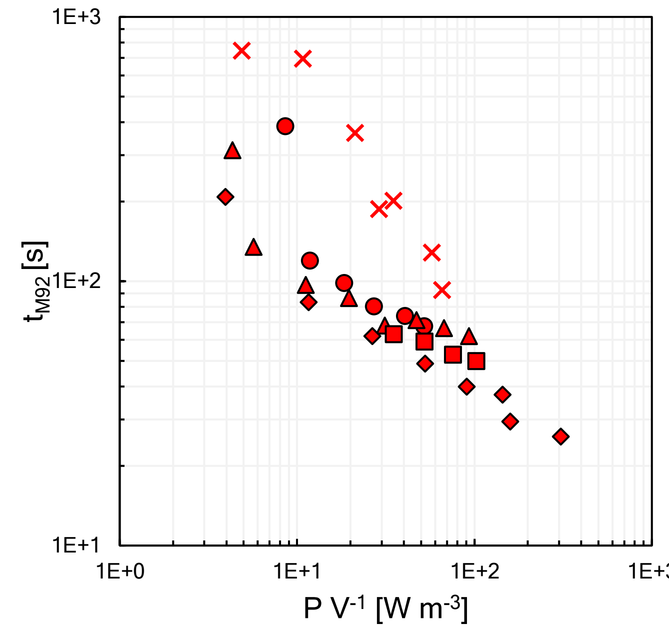
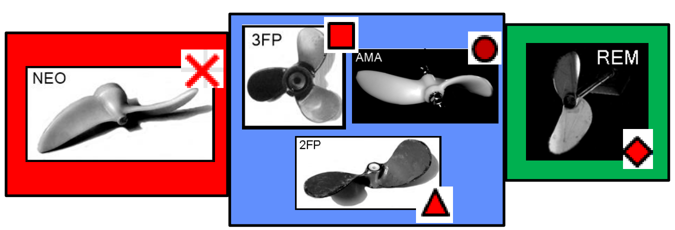
# Agitator optimization – Experimental data / Target function

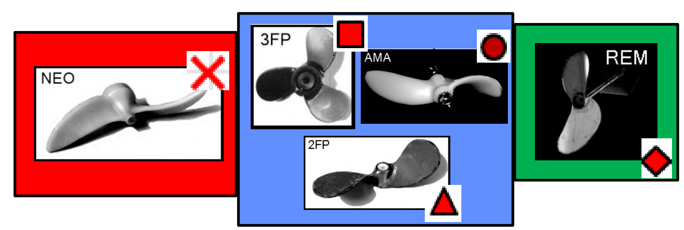
$$t_M = c_M V_R \frac{\rho n d}{F_{Ax}}$$

$$\max\left(\frac{\dot{V}}{P} \propto \frac{F_{Ax}}{\rho n d P}\right)$$

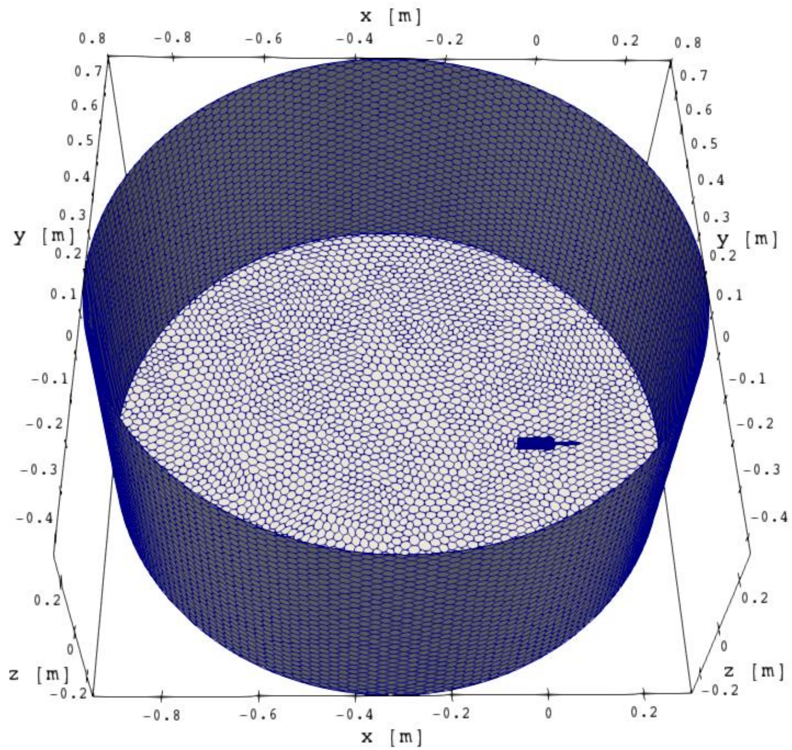


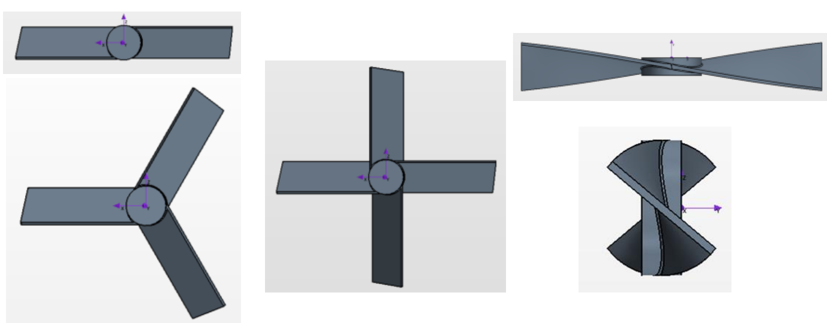



# Agitator optimization – CFD model



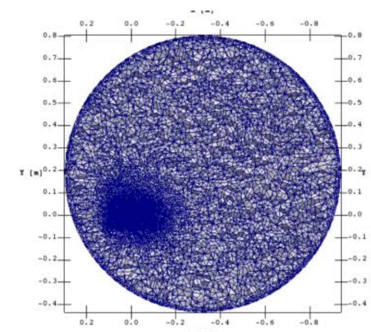



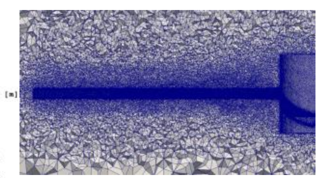
d = 130 mm; h = d/5; w = 3 mm

**Models/BC:**
MRF (Rotating reference frame = 300 rad $s^{-1}$; Re ≈ $10^6$)
K-omega turbulence model (low Re, no wall models)
Carreau-Yasuda viscosity

$$\eta = \eta_\infty + (\eta_0 - \eta_\infty)\left(1 + (\lambda \gamma)^a\right)^{(n-1)/a}$$
$$\eta_\infty = 10^{-3}\, Pa\ s$$


**Domain:**
Ca. 2.5 Mio
polyhedrals per blade
10 Prims layers
(growth rate 1.3)
$Y^+ \approx 1$





**Solver:**
SIMPLE (steady state, OpenFOAM v2012)
10000 Iterations (Relaxation p=0.3, U=0.7, k/omega= 0.5)

Convergence: $10^{-5}$ for each property

→ not reached due to transient effects in turbulence modeling, but deviation less then 5% from mean and periodic (tested by transient MRF simulation)

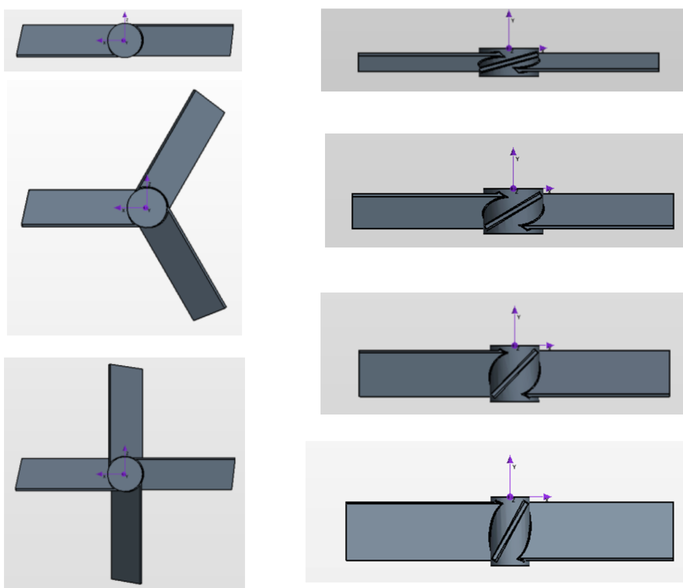
# Agitator optimization – Number of blades and pitch angle

Number of blades

$N_B$

Blade Pitch Angle

$\alpha$

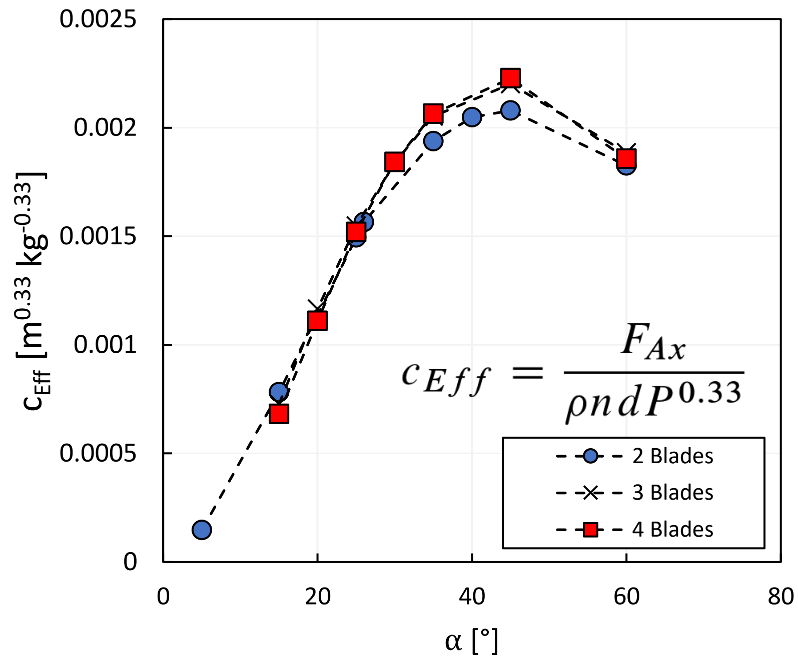


5°

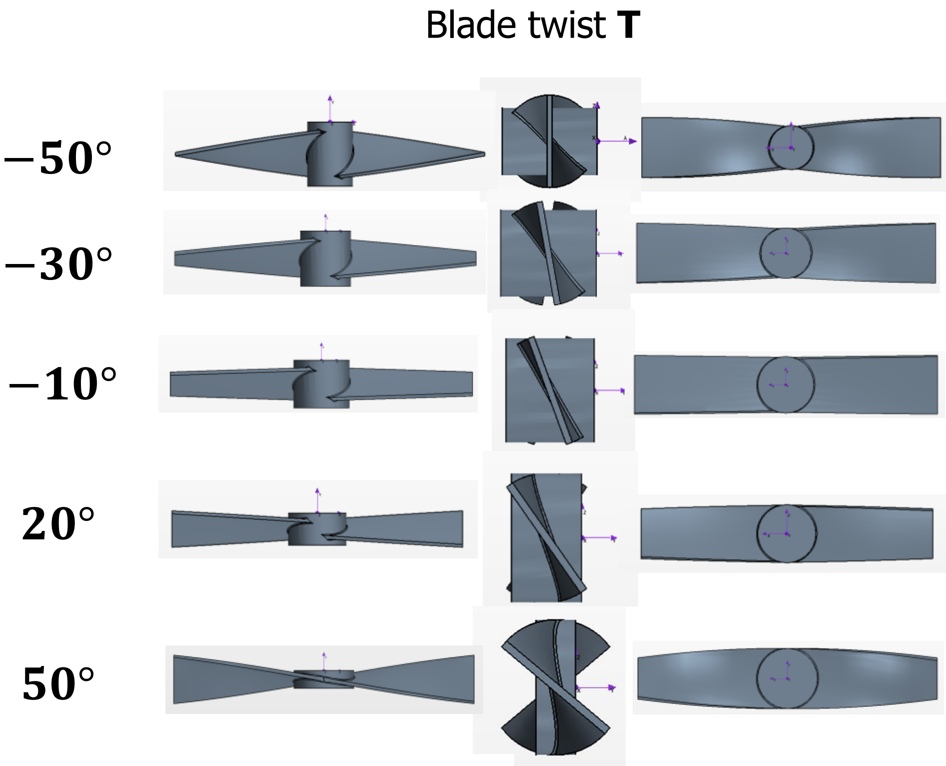
30°

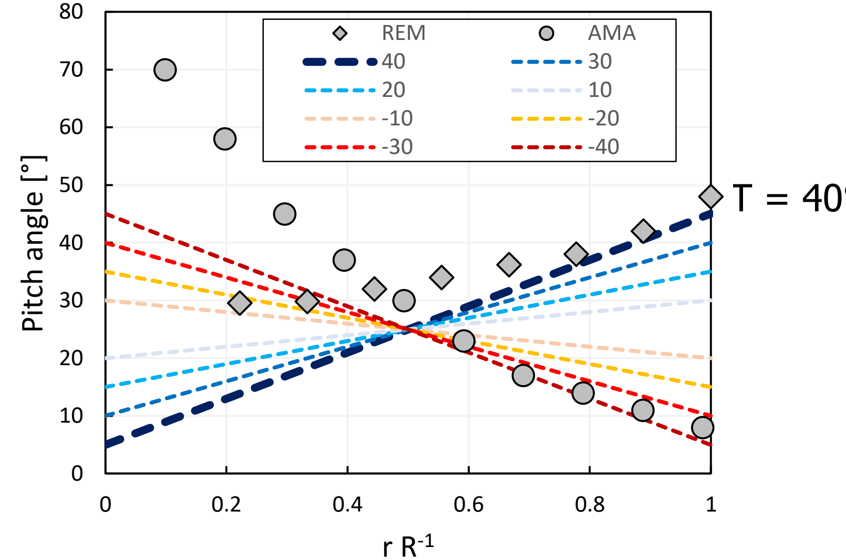
45°

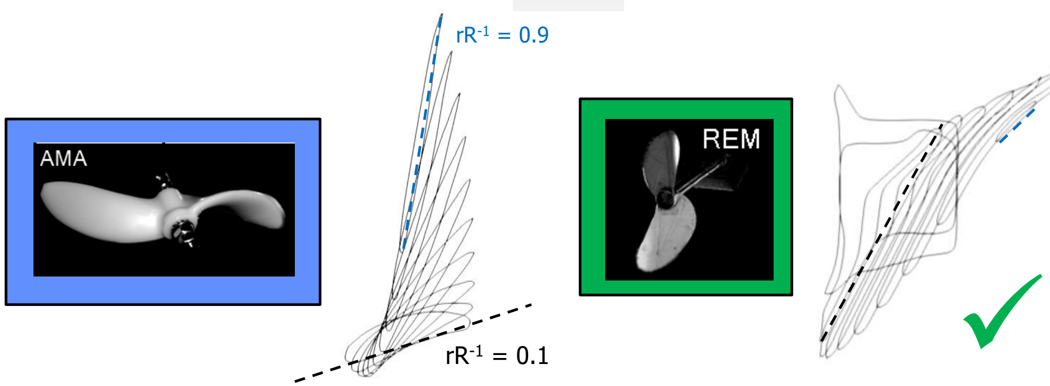
60°

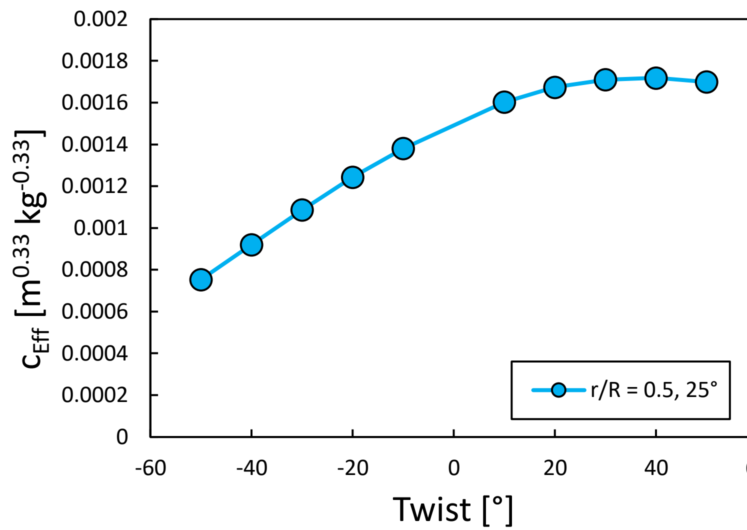


# Agitator optimization – Blade twist

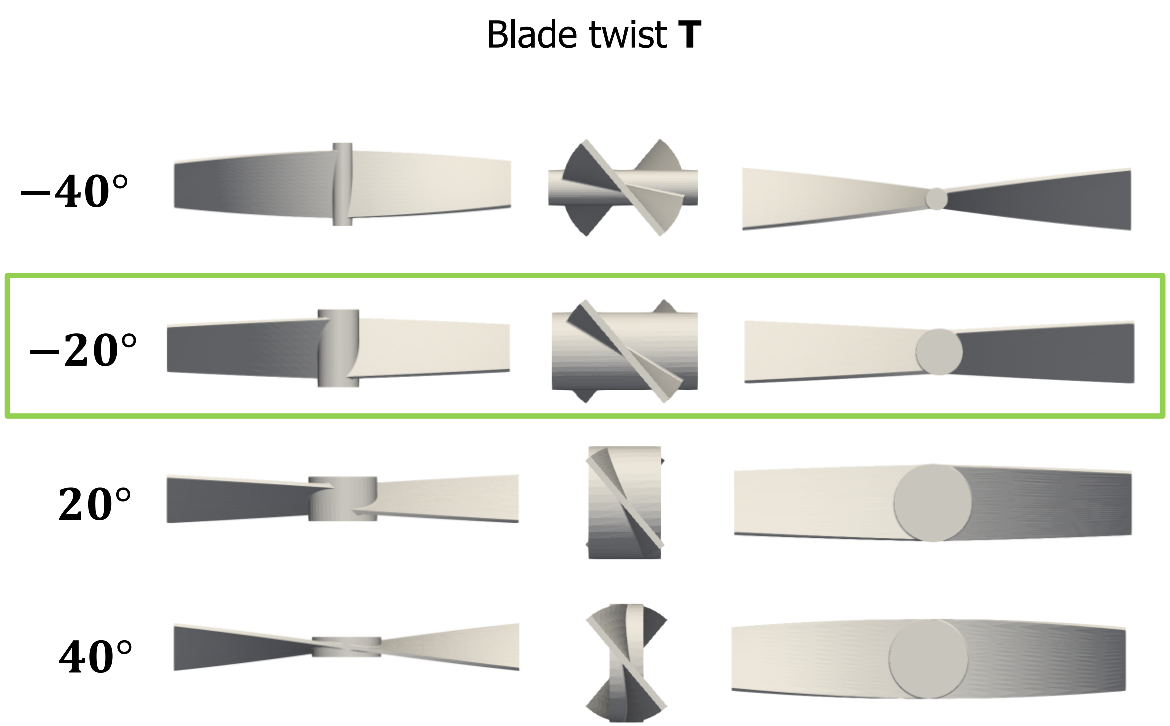


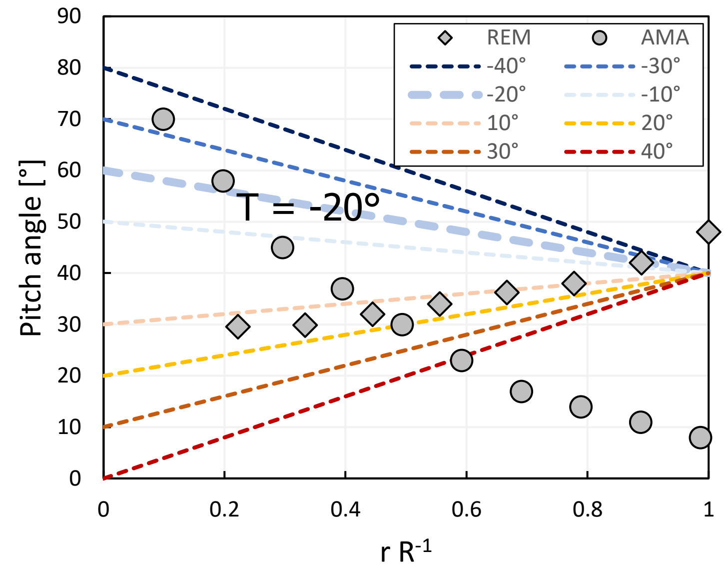



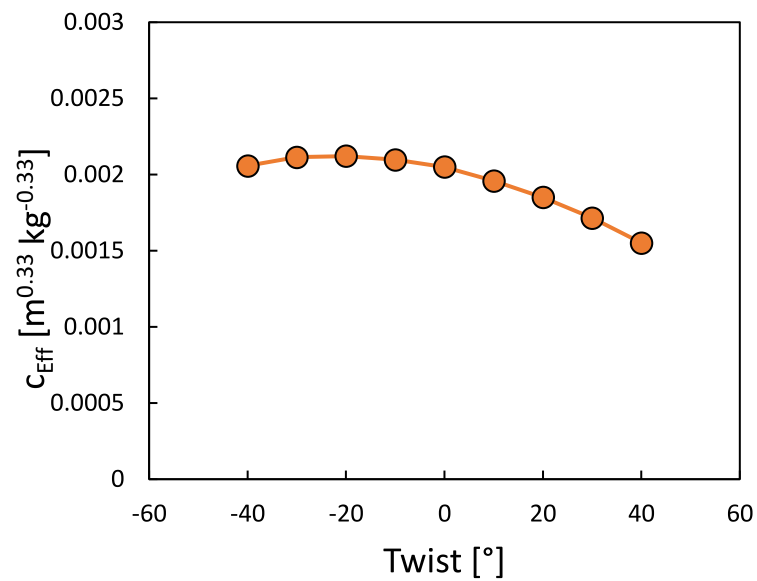
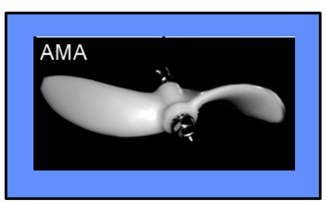



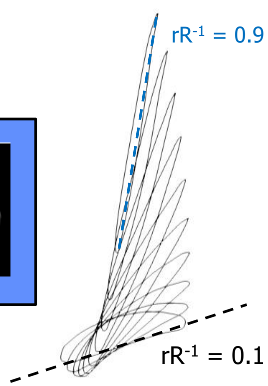



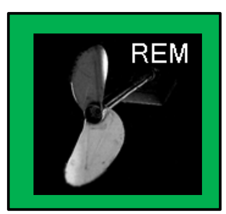
# Agitator optimization – Blade twist

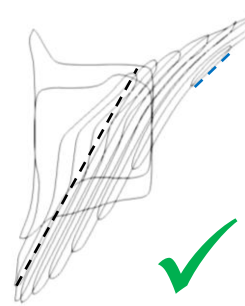


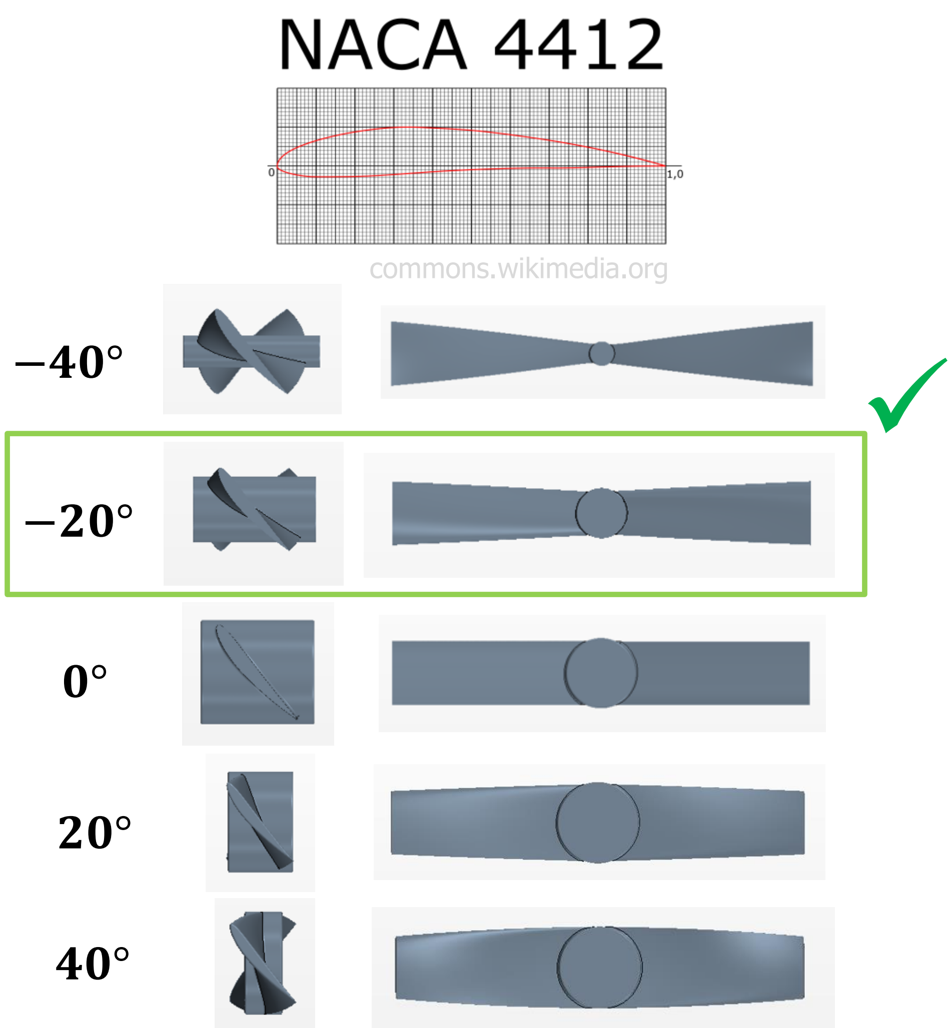




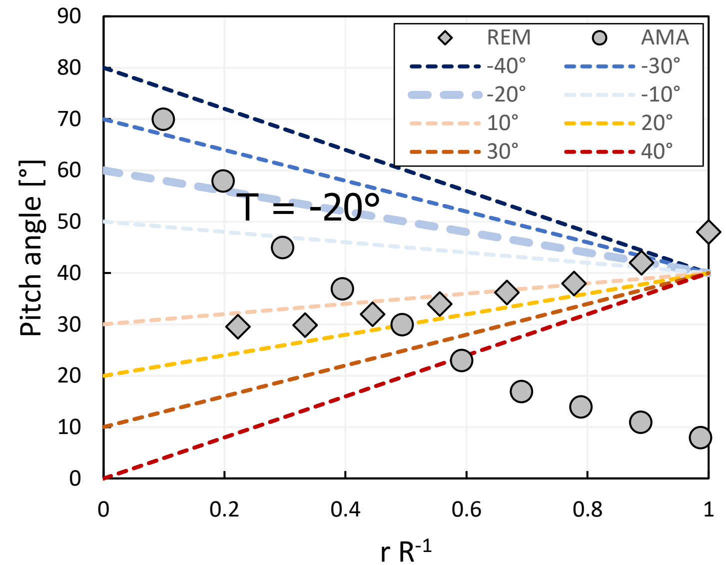



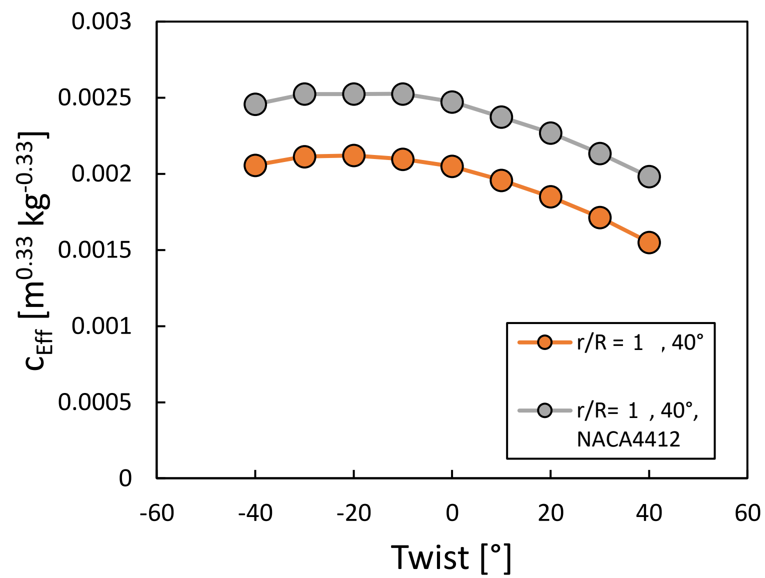



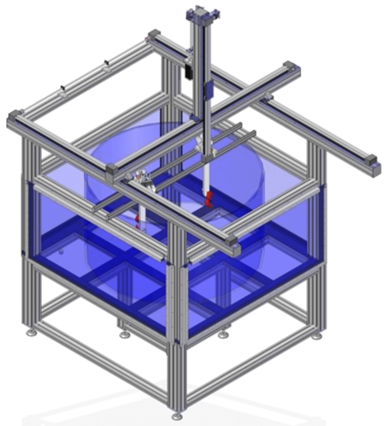
# Agitator optimization – Blade twist + NACA4412

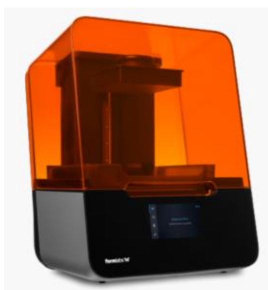


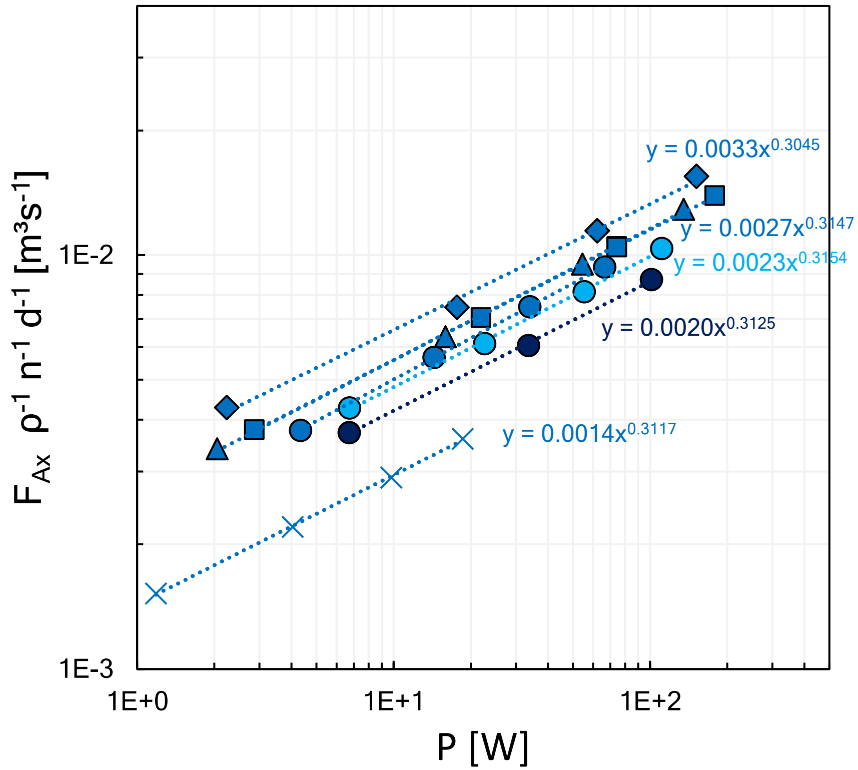



# Agitator optimization – 3D-printed models

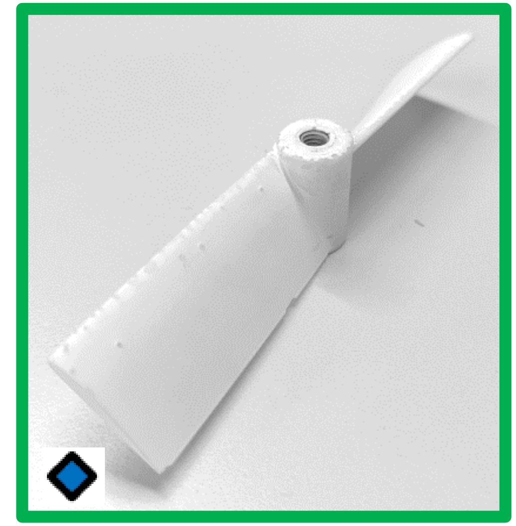




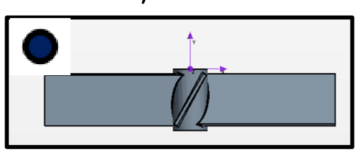
formlabs.com



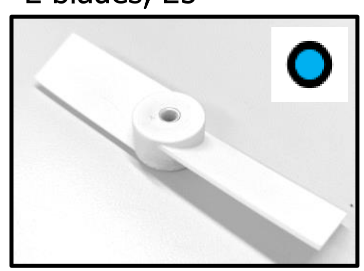

2 blades, 40°,
NACA4412,
Twist -20°



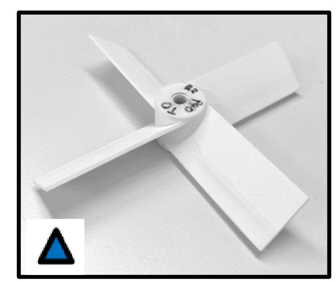

2 blades, 60°



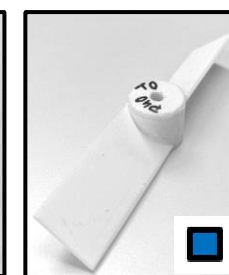
2 blades, 25°




4 blades, 40°



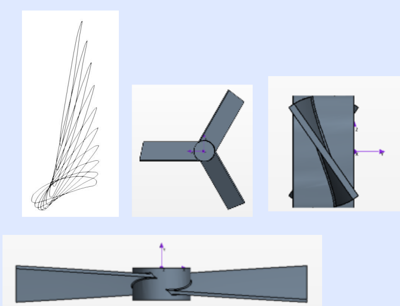
2 blades, 40°

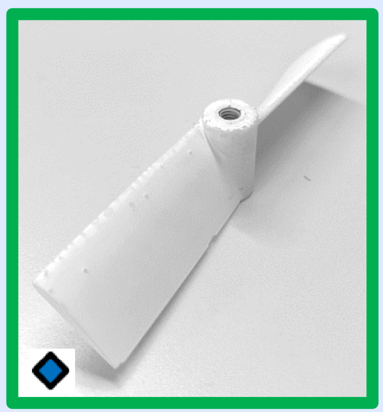


# Summary / Outlook

## Summary

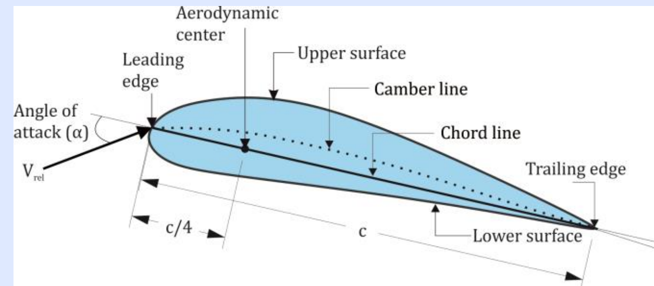
- Target function for efficient side-entry propeller design
- Geometrical optimization:
    - Optimal pitch angle 45°
    - Number of blades of minor importance
    - Pitch angle at r/R=1 most important
    - Hydrofoils improve efficiency distinctly
    - CFD results validated by experiments





## Outlook

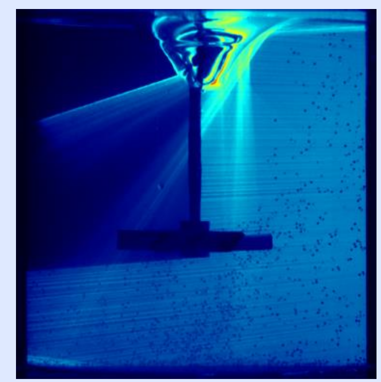
Hydrofoil




Propeller hub

Stability / Fibers

Suspension



# Thank you for your attention!

Bundesministerium
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Fachagentur Nachwachsende Rohstoffe e.V.

Sources:

I: https://zorg-biogas.com/
II: https://repowering-technik-ost.de/ruehrwerke/
III: https://www.spxflow.com/lightnin/products/a312-medium-solidity-hydrofoil-impeller/
IV: https://www.ksb.com/
V: https://www.xylem.com/en-US/brands/flygt/
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