BIOOPT-MIX

Rheology in biogas substrates: The need of non-Newtonian fluid dynamic for numerical model simulations

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Introduction

- Flow and deformation behavior of biogas substrates in digesters cannot be described by classical fluid mechanics or elasticity
- Rheology has to be considered and the dynamics of non-Newtonian fluids, whose viscosity changes with the strain rate, taken into account
- Ostwald-de Waele power law is an excellent mathematical relationship, which useful describes the flow behavior, permits mathematical predictions and correlates experimental data on the basis of the shear stress

Goal and strategy

- To predict optimizing mixing conditions in digesters of biogas plants
- To use a combination of home-made digester (to give experimental detail of dynamic viscosity) and computational fluid dynamics (CFD) simulations (to match the parameters that describe the fluid rheology)

Rheology measurements

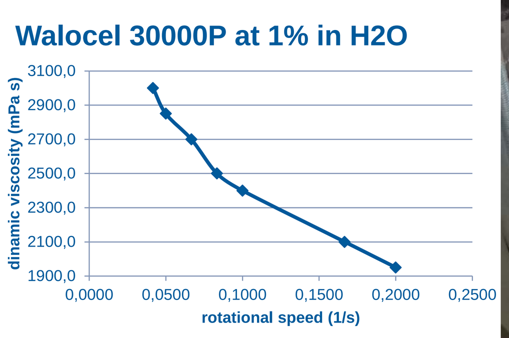
$M, torque\ (direct\ measurement)$

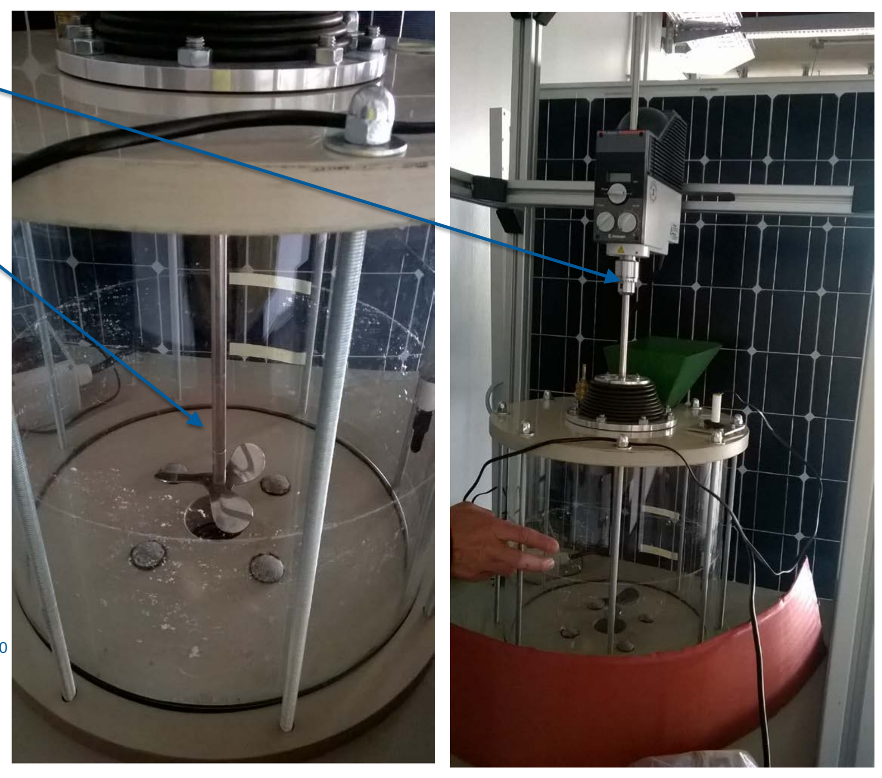
$n, rotational\ speed\ (direct\ measure)$

$$P = 2\pi n M = hydraulic\ rotational\ power$$

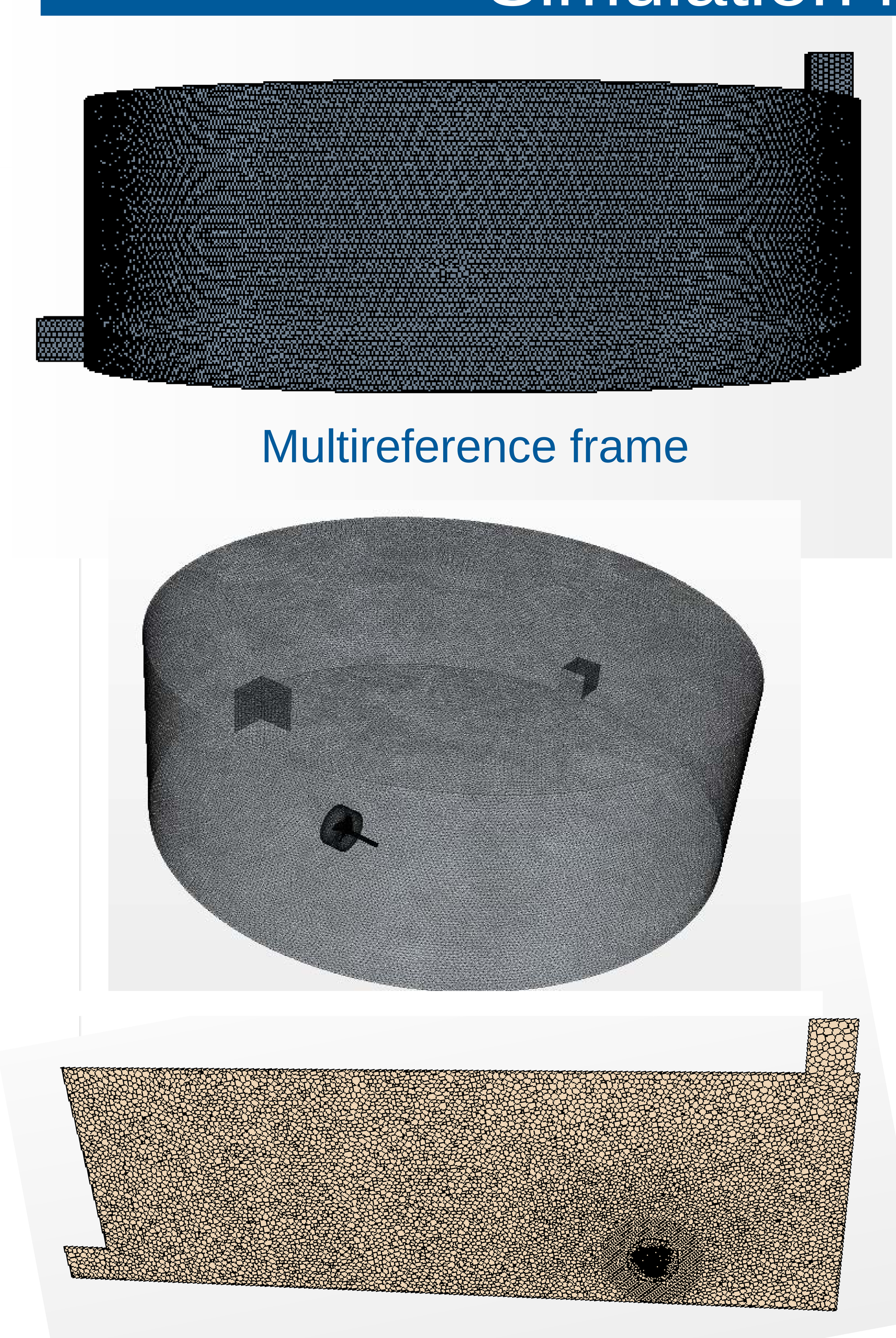
$$Ne = \frac{P}{\rho n^3 \emptyset^5_{propeller}} = Newton\ number$$

$$Re = \frac{\rho n \emptyset^2}{\eta} = Reynolds\ number$$





Simulation Model



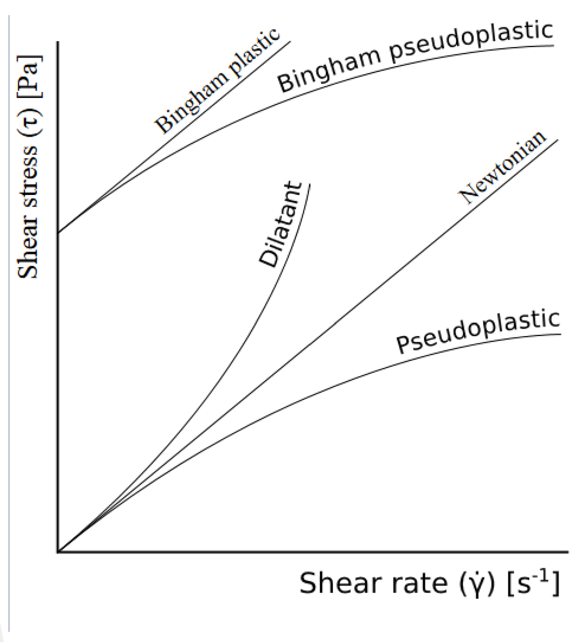
Multireference frame

$$\tau = k \cdot \dot{\gamma}^m = shear\ stress$$

$$\dot{\gamma} = shear\ rate$$

$$k = consistency\ factor$$

$$\eta = k \cdot \dot{\gamma}^{m-1} = apparent\ dynamic\ viscosity$$



Conclusions

- The methods are promising. A standardization is necessary
- The simulation program has to be optimized
- The experimental parameters related to model fluids and biogas substrates need to be opportunely down-scaled

gefördert von:

Bundesministerium für Bildung und Forschung

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Experimental Techniques

- A home-made torque measuring setup has been developed to measure the fluid torque moment of chemical model fluids and biogas substrates
- A home-made digester has been developed with electric heating shell for thermal equilibrium at 39°C
- A home-written program in StarCCM+ has been developed to simulate the mixing process in a scaled-down laboratory digester

Results from CFD simulations

INPUT parameters: $k = 0.7\ Pa \cdot s$ $\quad m = 0.35$

$\delta = density = 980 Kg/m^3$

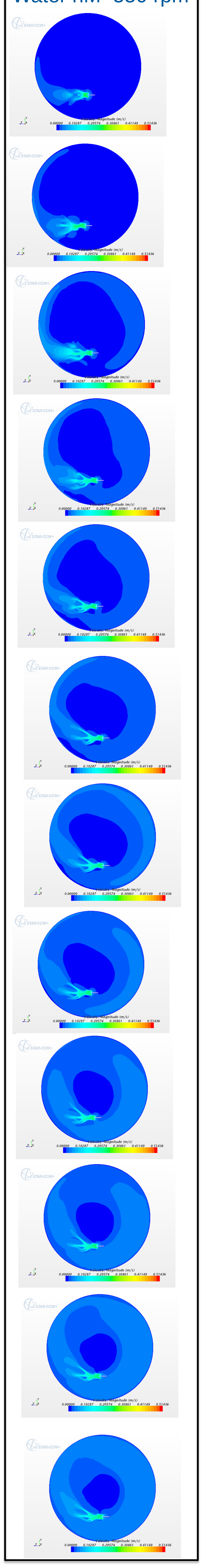
$\tau_0 = yield\ stress\ threshold = 0.08\ Pa$

$\eta_0 = yielding\ viscosity = 8\ Pa \cdot s$

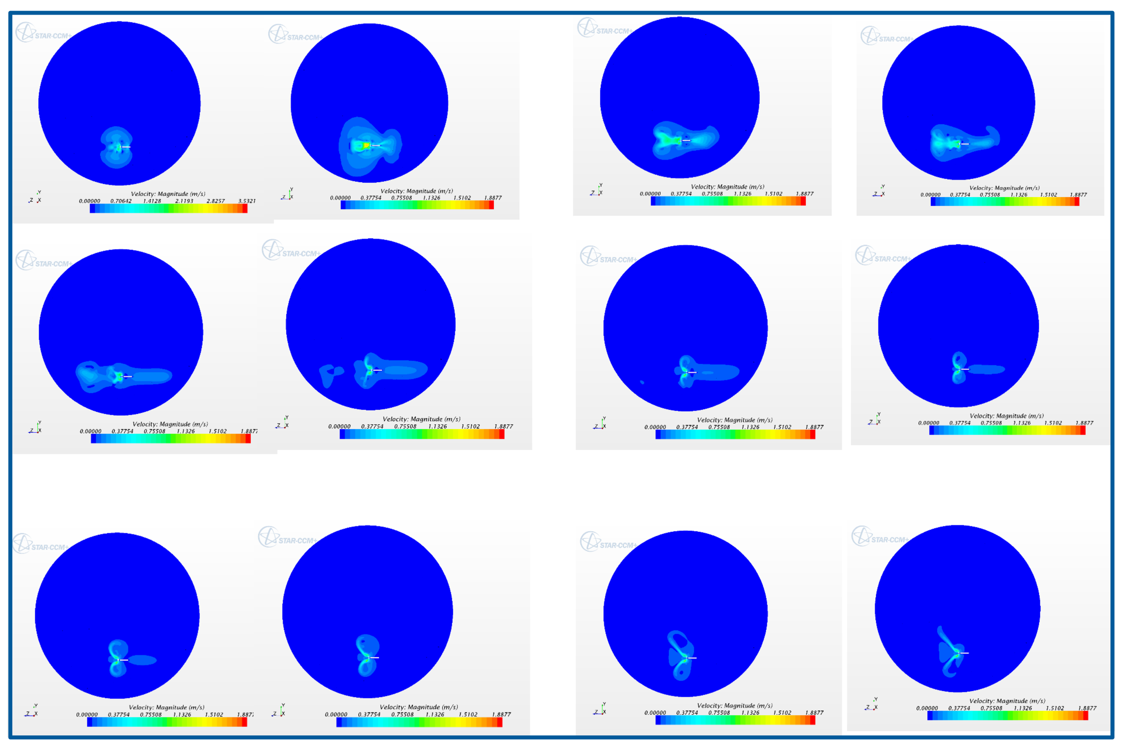
$[\eta_{min}; \eta_{max}] = viscosity\ limits = [0.1; 5.3]\ Pa \cdot s$

OUTPUT

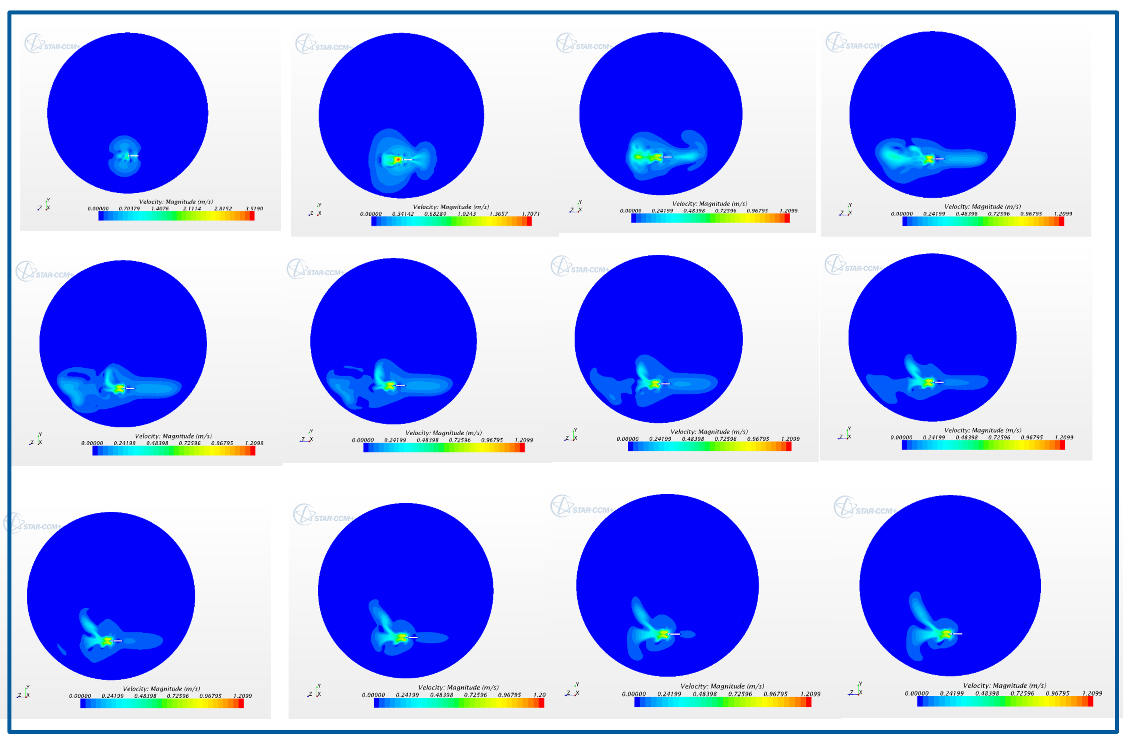
Water nM=550 rpm



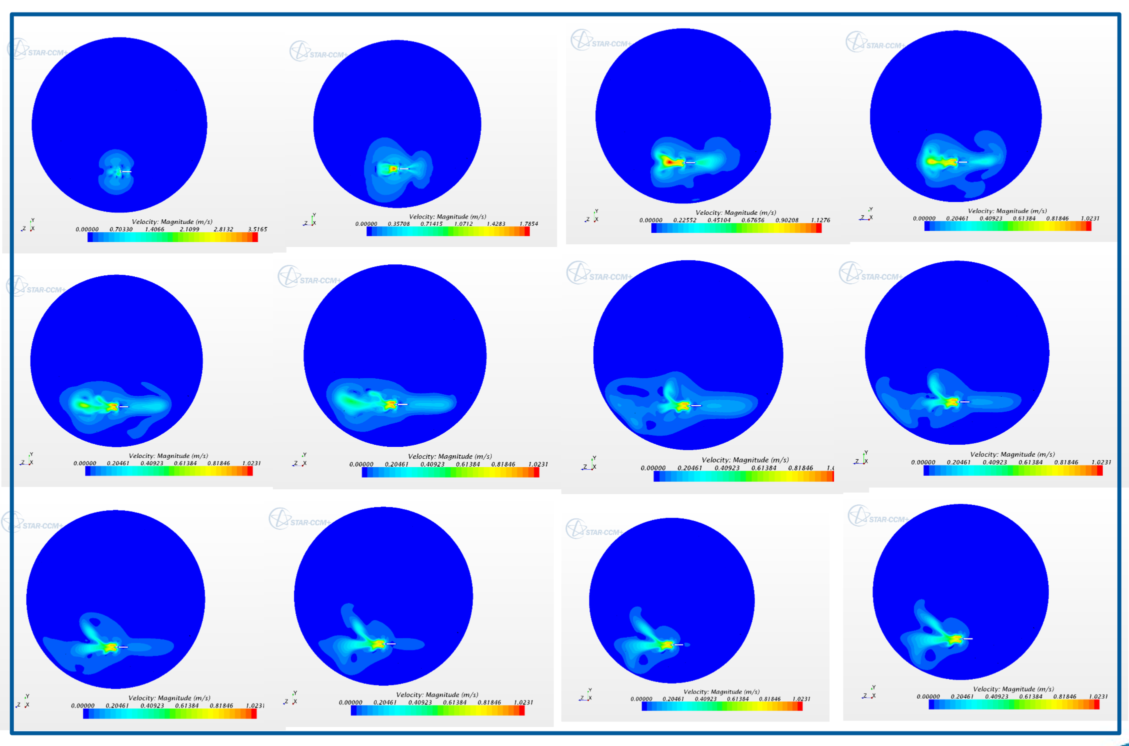
OUTPUT results for non-Newtonian fluids:



n_{model}=550 rpm $\quad n_{real}$=160rpm



n_{model}=275 rpm $\quad n_{real}$=80rpm



n_{model}=175 rpm $\quad n_{real}$=50rpm

Büche theorem:

$$\frac{P_{real}}{P_{model}} = \frac{V_{real}}{V_{model}} = \lambda^3$$

References

[1] DBFZ Deutsches Biomasseforschungszentrum (Hrsg.) (2012). Monitoring zur Wirkung des Erneuerbare-Energien-Gesetz (EEG) auf die Entwicklung der Stromerzeugung aus Biomasse. DBFZ Report Nr. 12. ISSN: 2190-7943 (Online)

[2] DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH (2015). Messmethodensammlung Biogas. Methoden zur Bestimmung von analytischen und prozessbeschreibenden Parametern im Biogasbereich. DBFZ Band 7. ISSN: 2192-1806 (Online)

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