USE OF OPENFOAM® FOR INVESTIGATION OF MIXING TIME IN AGITATED VESSELS WITH IMMERSED HELICAL COILS

Enhancement of Efficiency in Stirring Processes

Alexander Stefan, Jan Volkmer, Prof. Dr.-Ing. Heyko J. Schultz

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Background

Project

Energy-saving process technology: enhancement of electrical and thermal energy efficiency of stirring processes

Importance of stirred tank reactors
50 % of all chemical products see a stirred tank reactor at least once during the production cycle [Tatt03]

Investigated object

- **Cylindrical tank (with dished boiler end)**
- **Internals like baffles, helical coils, gassing tubes, etc**
- **Different stirrer types and stages, operating parameters**

Aims

- **Mathematical characterisation of basic operation parameters**
- **Guideline for up- and downscale**
- **Construction guideline for optimated stirred tank reactors with internals**
- **Transfer of investigation result to an existing production plant**

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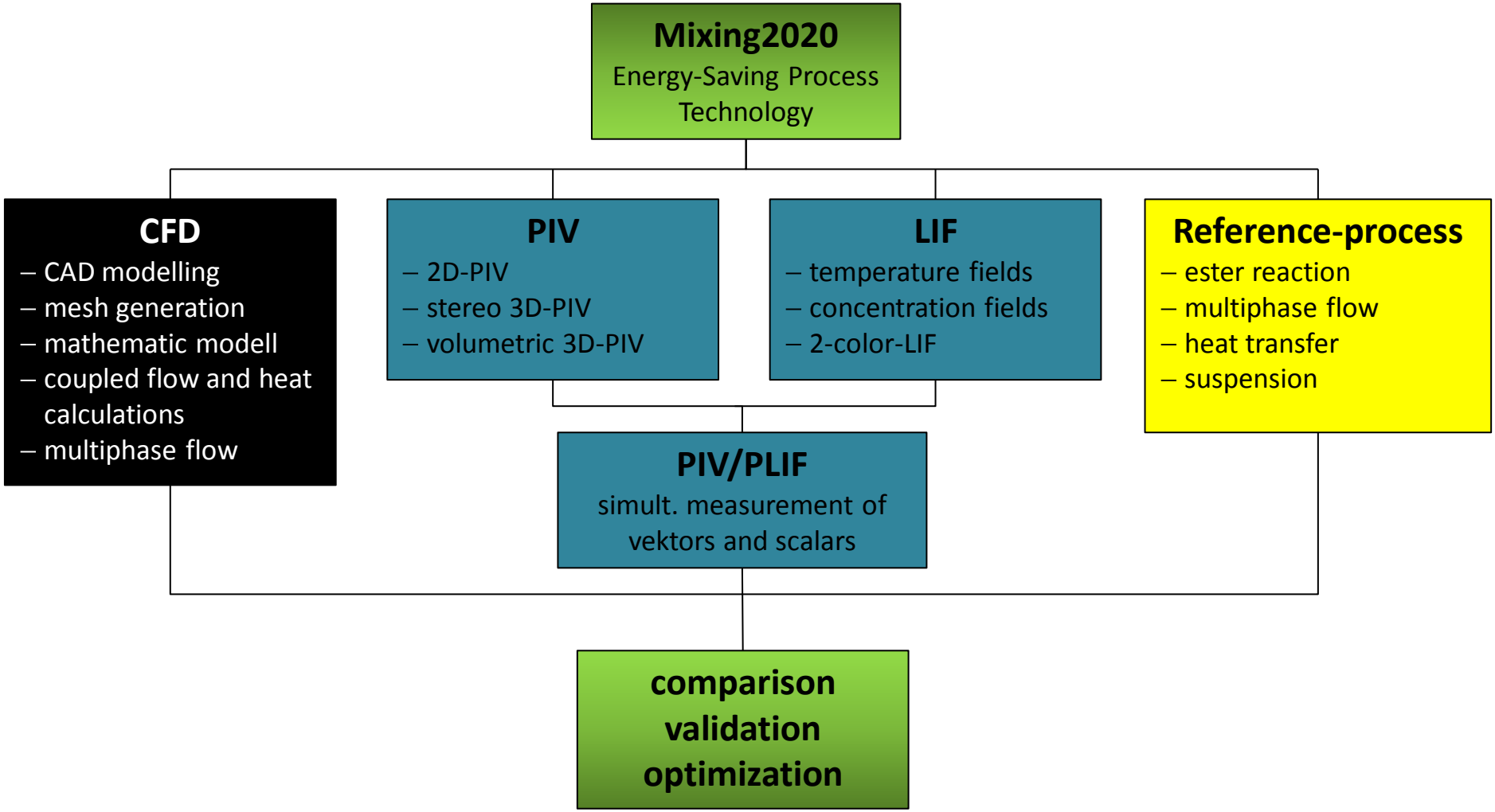
Overview



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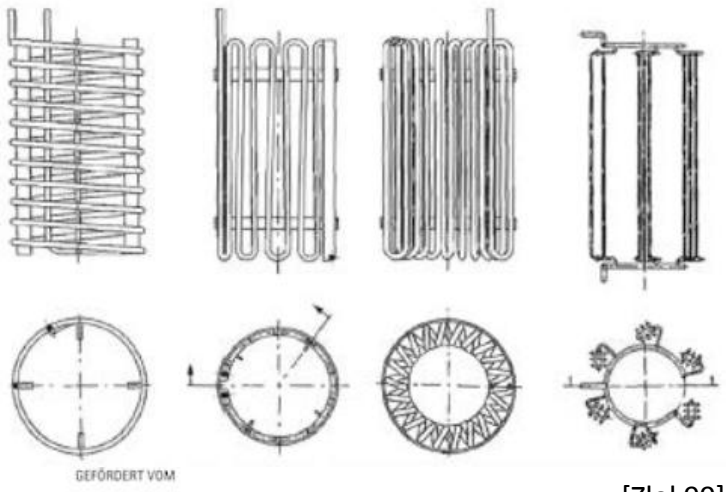
Agitated Vessels with Immersed Helical Coils

- **Importance: Most chemical products are treated at least once by a stirring process in an agitated vessel during their lifetime.**
- **Vessel design and flow conditions have a great impact on physical and chemical processes.**
- **Helical Coils in single or multiple arrangements are most common for reactor heating**

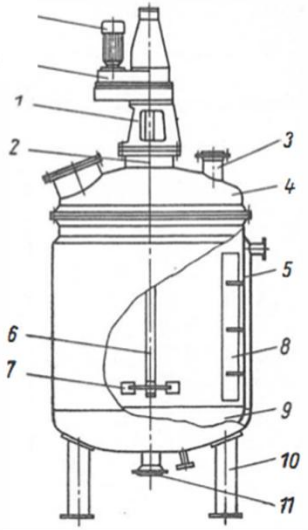


[Zlok99]

[Indi14]

Agitator
- Motor
- Gear box

Industrial Agitator



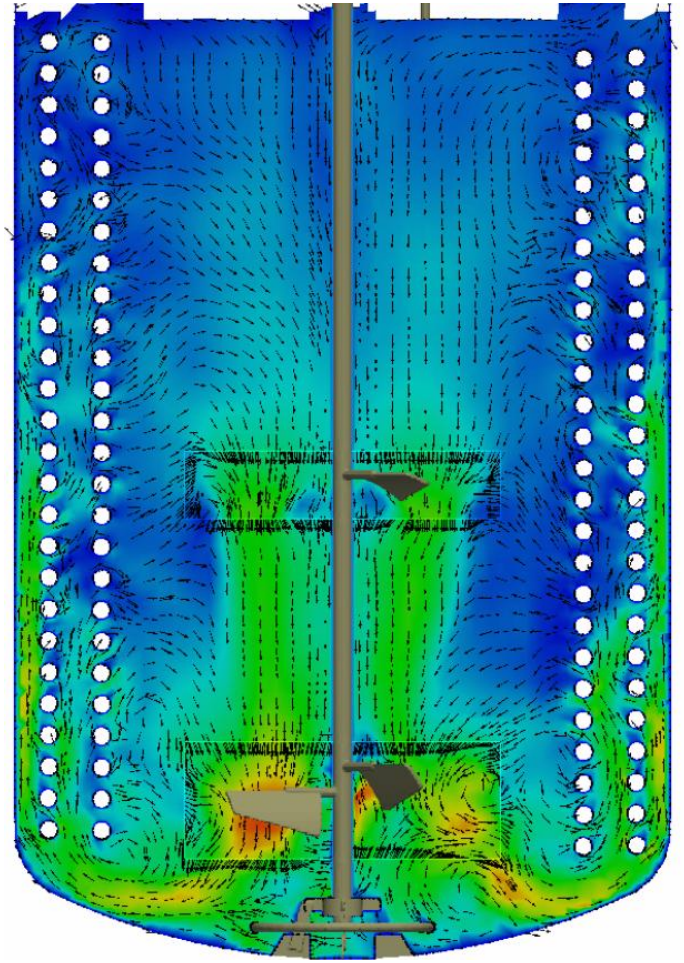
1. Storage vessel
2. Shaft seal
3. Mounting flange
4. Top
5. Heating jacket
6. Shaft
7. Impeller
8. Baffles
9. Bottom
10. Bearing
11. Drain valve

[Liep88]

Agitated Vessels with Immersed Helical Coils
Need for Review of Dimensioning

- **Coils are dimensioned to achieve designated heat transfer.**

- **Consequence:**
  - **often huge or even multiple coils needed,**
  - **huge effect on flow conditions**
  - **Opposed effect: augmented exchange area leads to flow deceleration**
    - **=> local heat transfer decrease,**
    - **=> total heat exchange less then expected,**
    - **=> bad influence on convection driven operations as mixing.**



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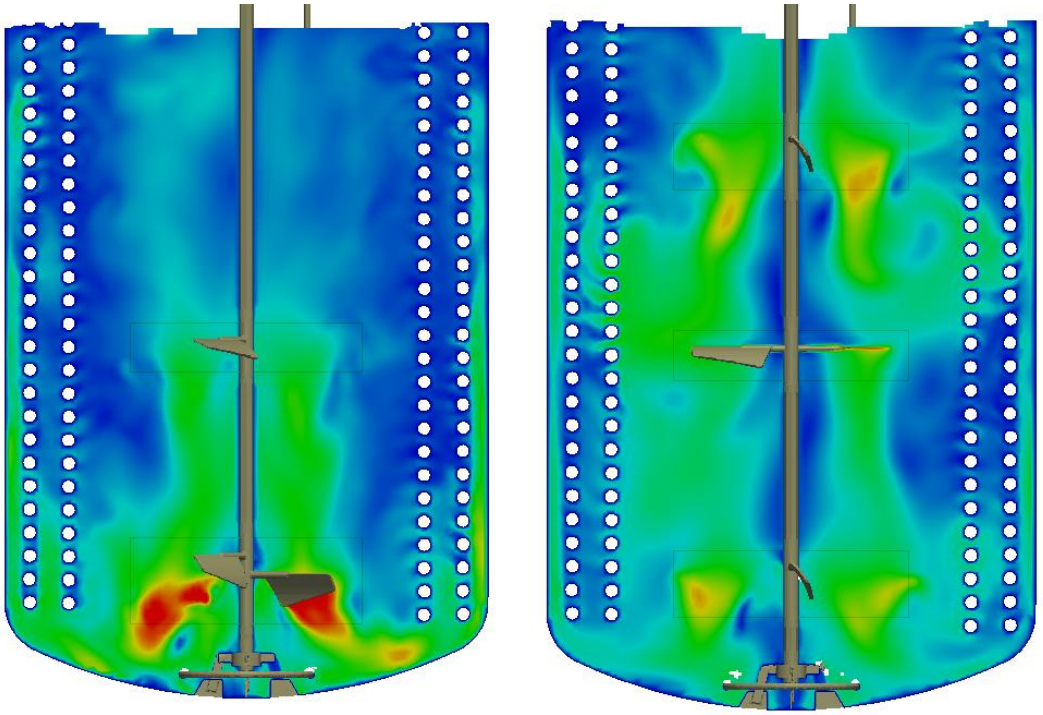
Agitated Vessels with Immersed Helical Coils
Need for Review of Dimensioning

- **Pedrosa & Nunhez (2003) found with a CFD-simulation that in a stirred tank with helical coils, only with slight modifications (here: removal of a coil at impeller height) the overall heat transfer increased 27,9 %**

- **For existing industrial plants:**
  - **constructive modifications unpopular**
  - **Possible improvement of heat transfer and velocity by stirrer position.**
  - **2D CFD-study shows 20 % improvement.**
  - **First results indicate similar potential in industrial process.**



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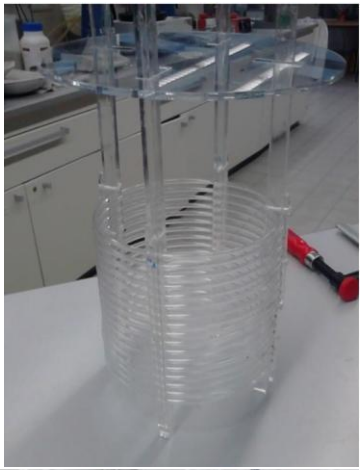
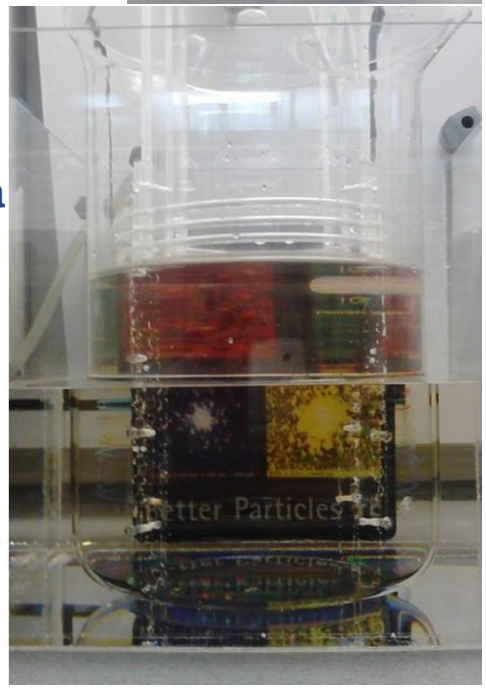
Agitated Vessels with Immersed Helical Coils

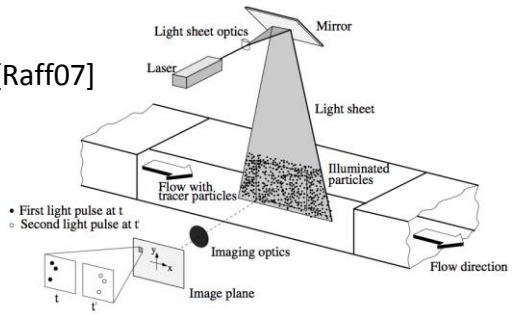
Approach of Investigation

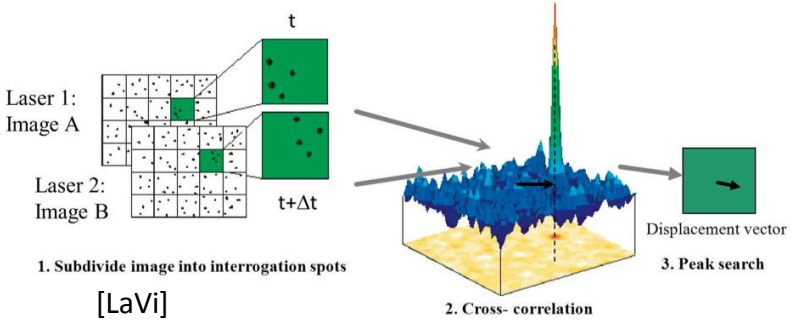
- Industrial plants mostly not accessible for measurement.
- Investigation is performed in lab scale models.
- A new measurement system
- Scale-up inaccurate and mostly not possible for multiple parameters.
- CFD capable for prediction of industrial problems, but validation necessary
- Our approach: create CFD-models in lab scale and validate with PIV/LIF-measurements.
- Scale-up CFD-model to industrial size and validate with a weak parameter like mixing time.





[Raff07]

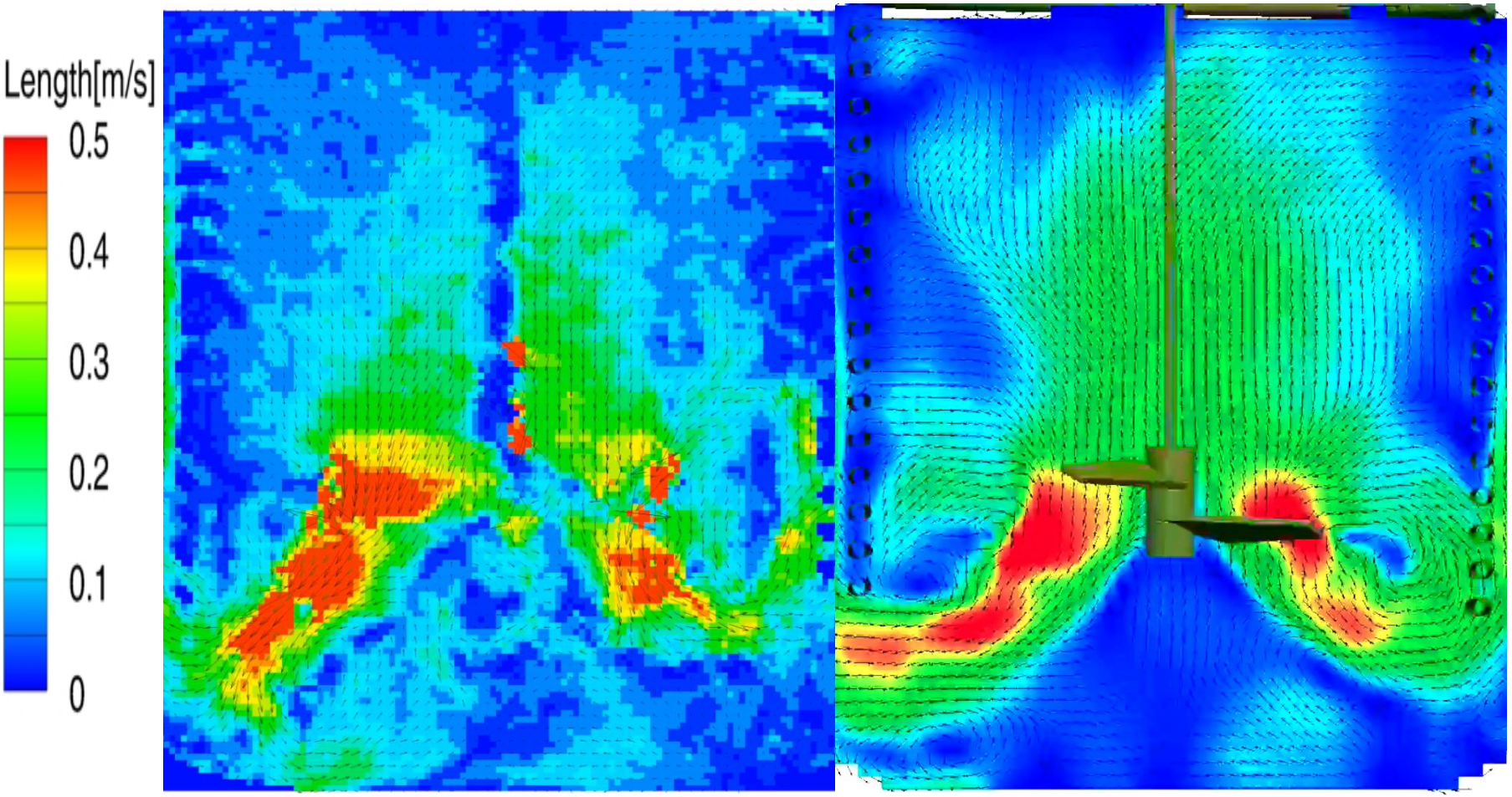




[LaVi]

[Dant12]

Agitated Vessels with Immersed Helical Coils
Validation of Flow Field



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Mixing time
Definition

- **Relative Variation:**
  σ... standard deviation x... mean value

$$v = \frac{\sigma}{\bar{x}}$$

- **Goodness of Mixture:**

$$M = (1 - v) \cdot 100\%$$

- **Measurement Approach:**
  c_0... concentration at start c_∞... c at end

$$M(t) = \frac{c_0 - c(t)}{c_0 - c_\infty}$$

- **Homogenization index:**
  t_M... mixing time n... turns

$$H = t_M \cdot n$$

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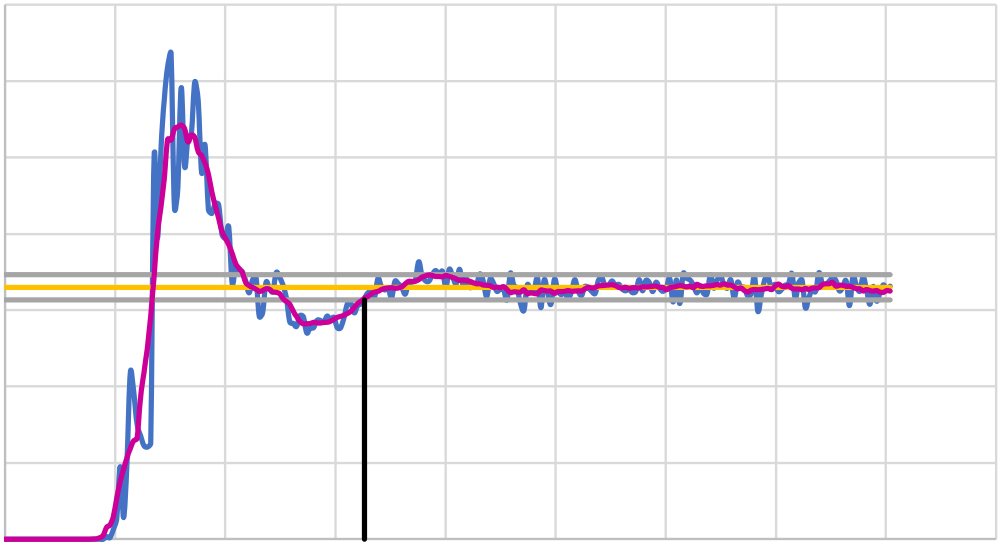
Mixing time
Determination principle

- Definition of measurement points.
- Tracking of tracer concentration.
- Backward analysis of smoothed curve.
- Definition of goodness criterion.



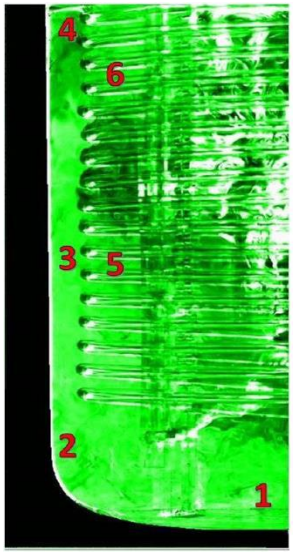


Fig.1: Exemplary concentration plot for mixing time determination.

Fig.2: Probe locations for determination of mixing time in a stirred reactor with immersed helical coils.

- Mixing time at all points is compared.
- Total mixing time is the maximal determined time at all points.
- Mixing time refers to very specific experimental setup. Hard to compare data from different experimental setups.

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Mixing time
CFD principle

- Steady state simulation via simpleFoam and RAS with MRF.
- Simulation of a stirred process via LES to quasi stationary condition.
- Introducing tracer substance as miscible liquid via VOF-approach (volume of fluid).
- Adding the DyM-Library to the twoLiquidMixingFoam solver.
- Tracking concentration alpha at six probe locations.
- Analysis as with measurement.

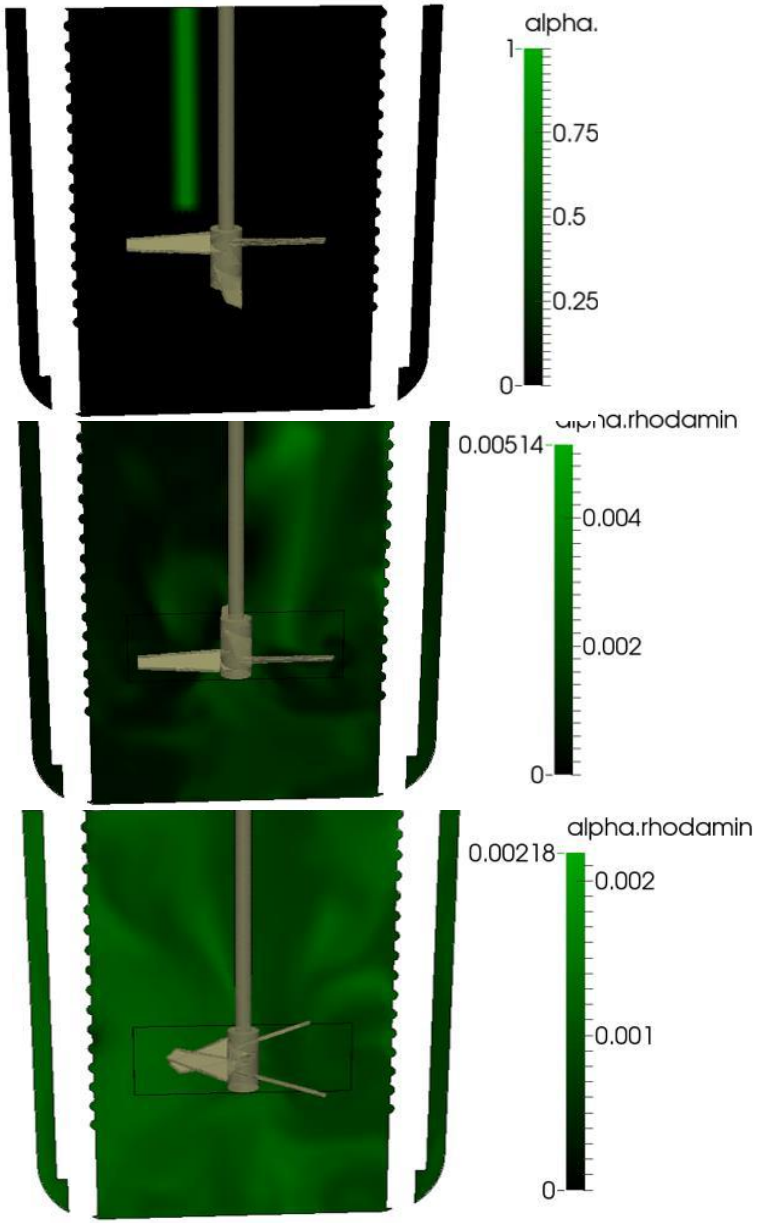

Fig.3: LES of mixing time at t=0s, 5s and 7.5s. Pitched blade stirrer, 195rpm, central inlet. Base mesh: 63^3 cells

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Mixing time Results

- **Order 1 convergence concerning mesh refinement (Fig. 3)**
- **Methodology in general corresponds to meassurements**

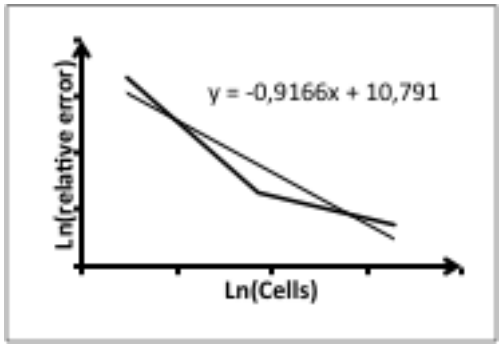

Fig.4: Convergance of successive mesh refinement.

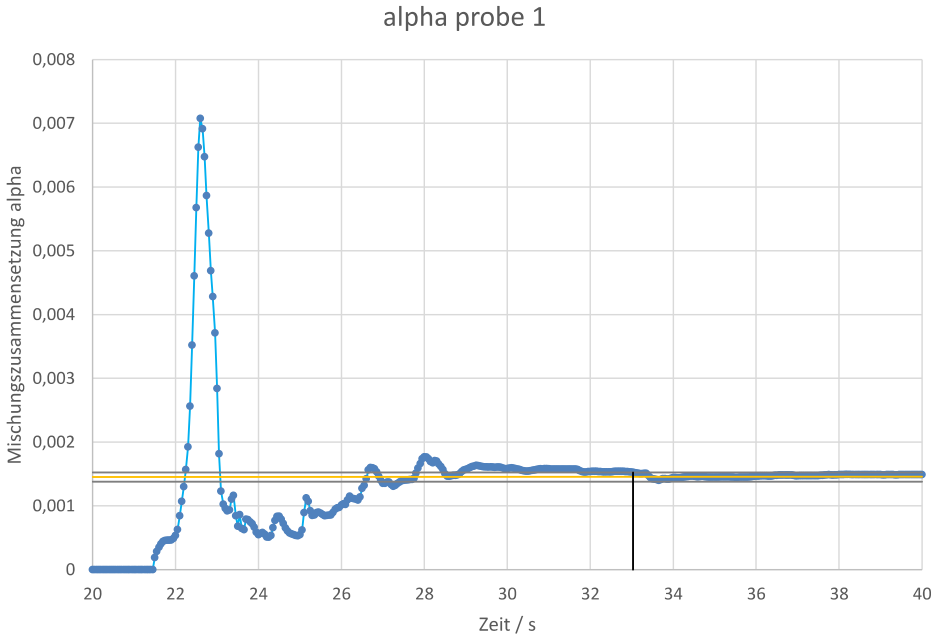

Fig.5: Concentration curve at probe location 1. Mixing time criterion: 95%

Tab.1: Mixing times for decreasing cell size

Cells	Probe0	Probe1	Probe2	Probe3	Probe4	Probe5
50^3	13,93	13,77	14,27	14,67	14,32	14,90
63^3	13,92	13,03	13,97	13,81	13,37	14,19
80^3	12,41	12,92	13,39	13,37	13,33	13,35
LIF	11,40	11,90	12,60	12,30	12,50	12,20

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Mixing time
Outlook

- **Problems:**
  - **Very large computational cost**
  - **Low convergence order**

- **Approach:**
  - **Mesh optimization (blocked?, polygonal?)**
  - **Transient, but static mesh with MRF (multiple reference frame)**
  - **Periodic conditions?**

- **Scale-Up:**
  - **Application of defined method on the industrial geometry.**
  - **Operating trail of mixing time for validation of CFD results.**
  - **Using valide CFD model as basis for further optimization.**
    - **Heat transfer**
    - **Electrical energy consumption, etc.**

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