Hochschule Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

Institute of Process Technology,
Process Automation and
Measuring Technology

IPM
HOCHSCHULE ZITTAU/GÖRLITZ

A Dynamic Simulation in Consideration of Uncertainties - Model Example of Flow Boiling

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STUDIEREN_OHNE_GRENZEN

Outline

1. Introduction
2. Mathematical description of the boiling process
3. Modeling of transitions between the different boiling stages
4. Modeling of a flow boiling example
5. Further work

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Introduction

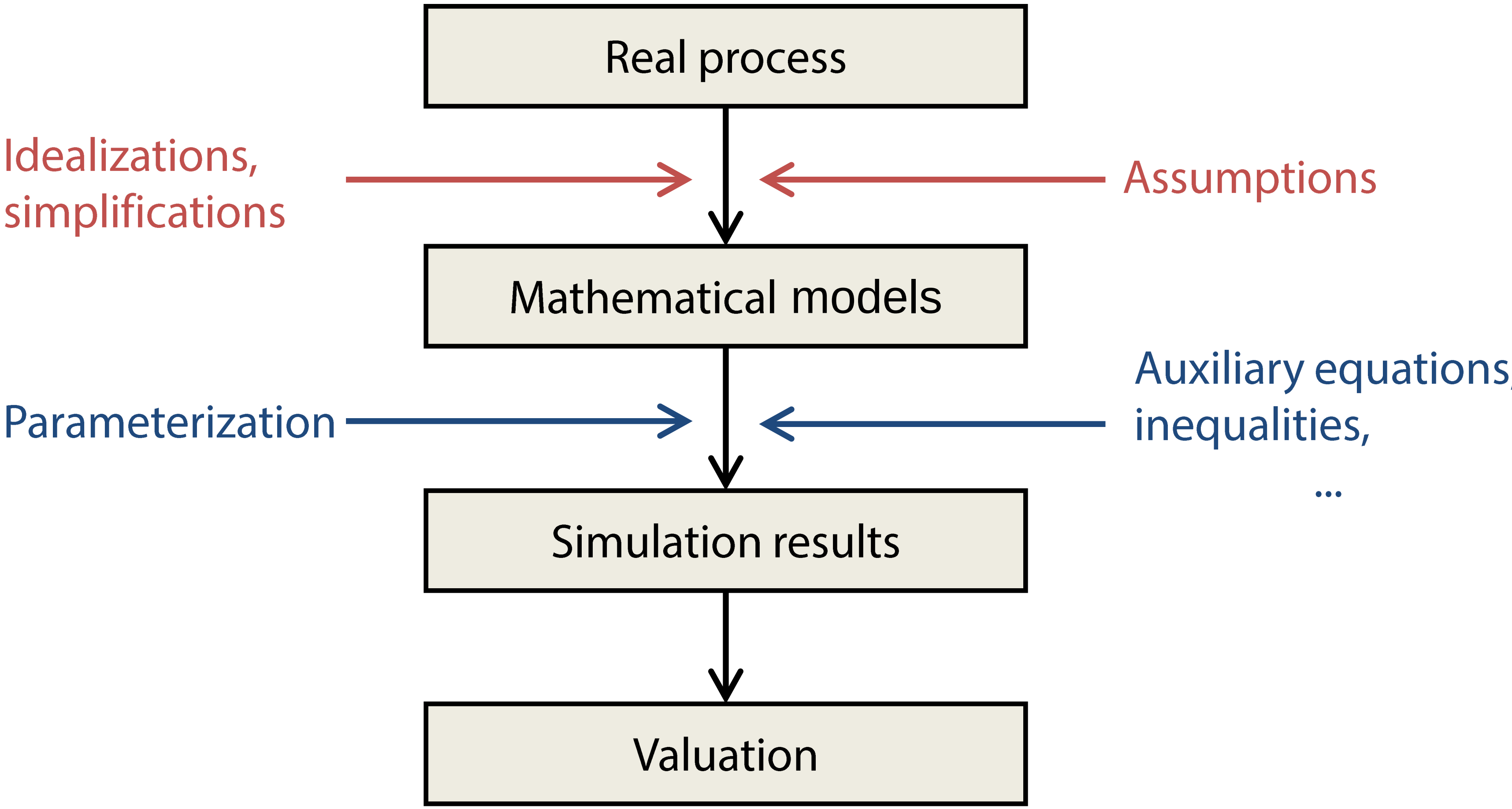


Fig.1: Analytical approach to modeling [8]

Introduction

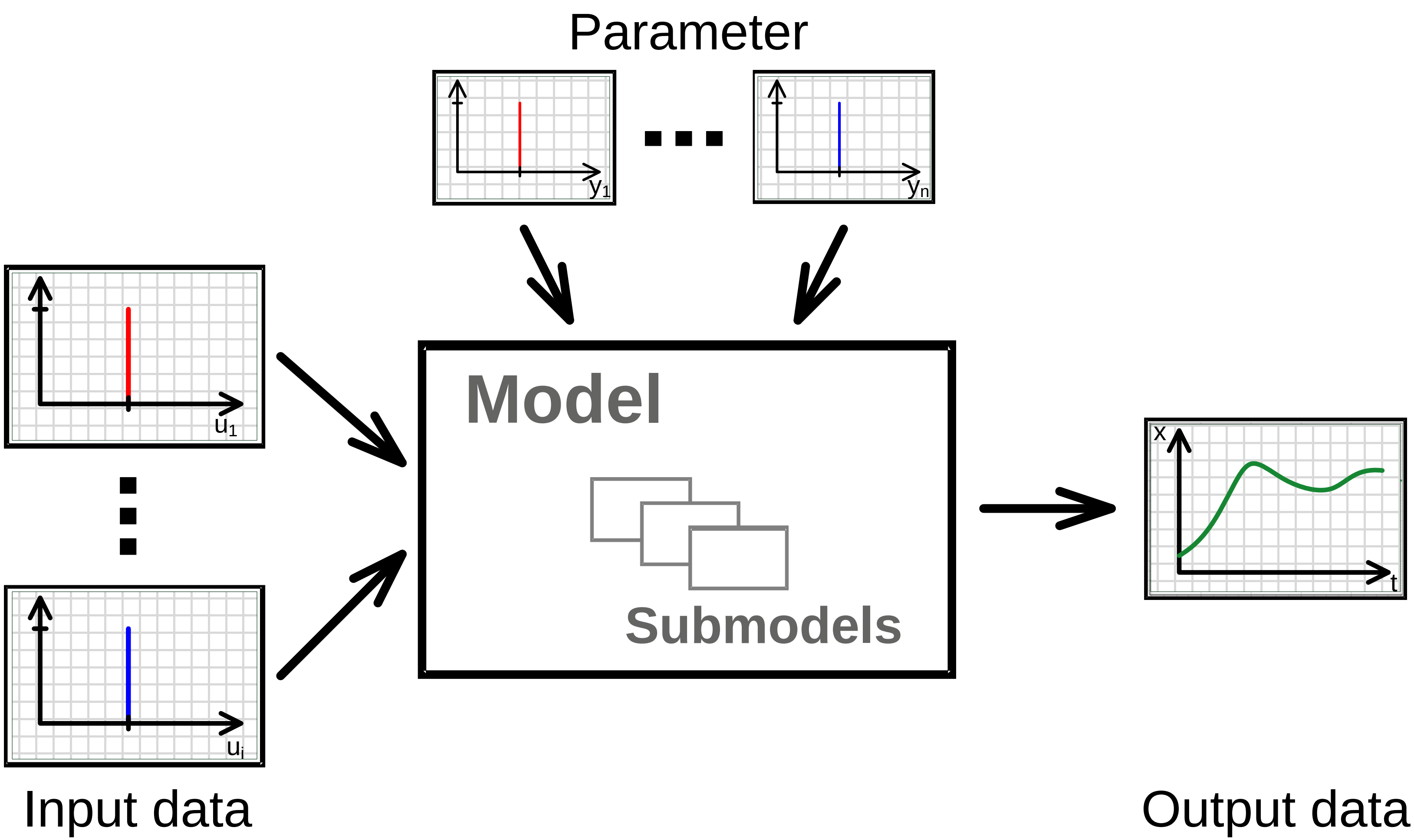


Fig.2: Model with precise input data

Introduction

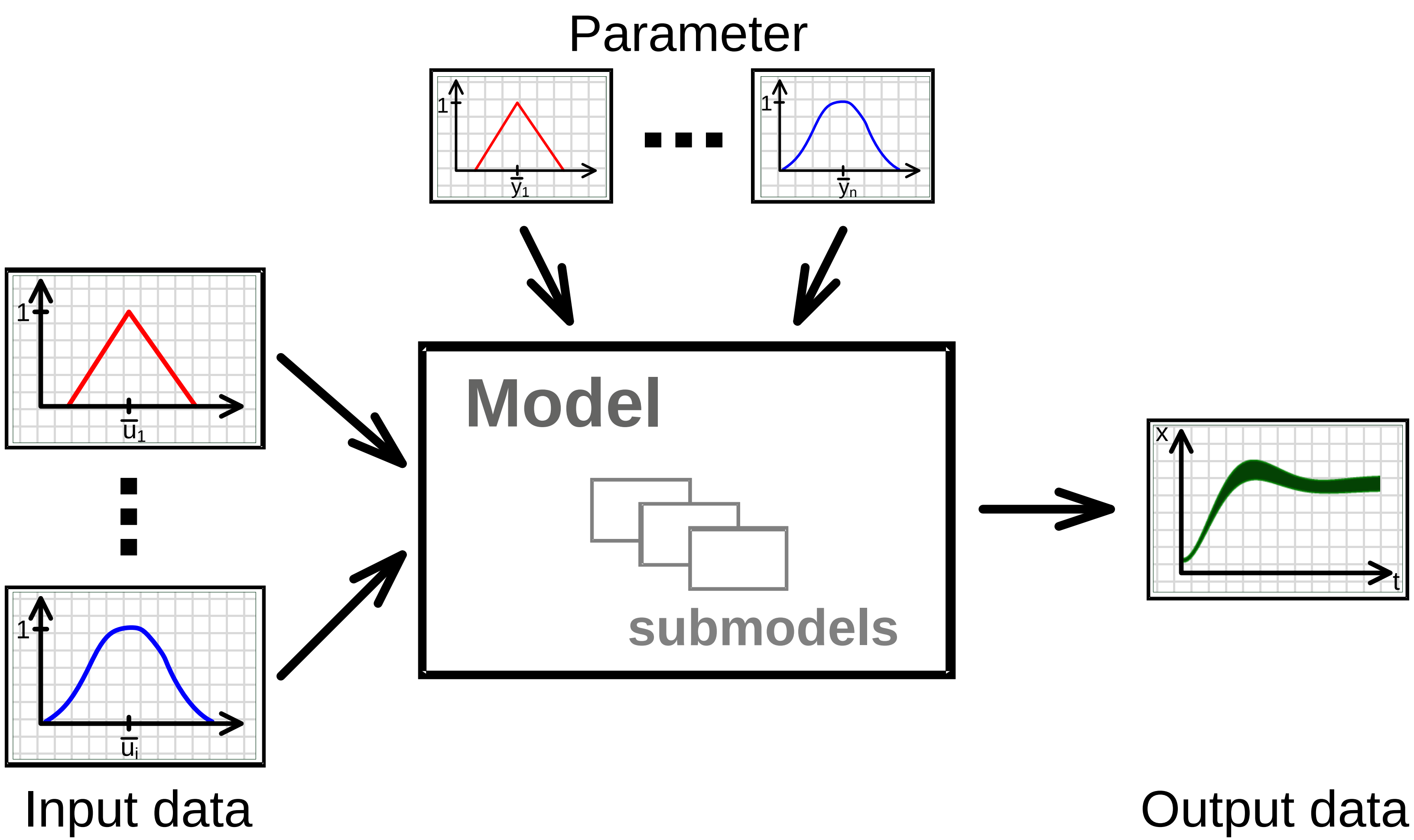


Fig.3: Model with fuzzy input data

Uncertainty

Classification of uncertainty

Parameter uncertainty
(- natural, unpredictable variation
 - lack of knowledge)

Model uncertainty
(lack of knowledge)

Sources of uncertainty

Aleatory uncertainty
(natural, unpredictable variation)

Epistemic Uncertainty
(lack of knowledge)

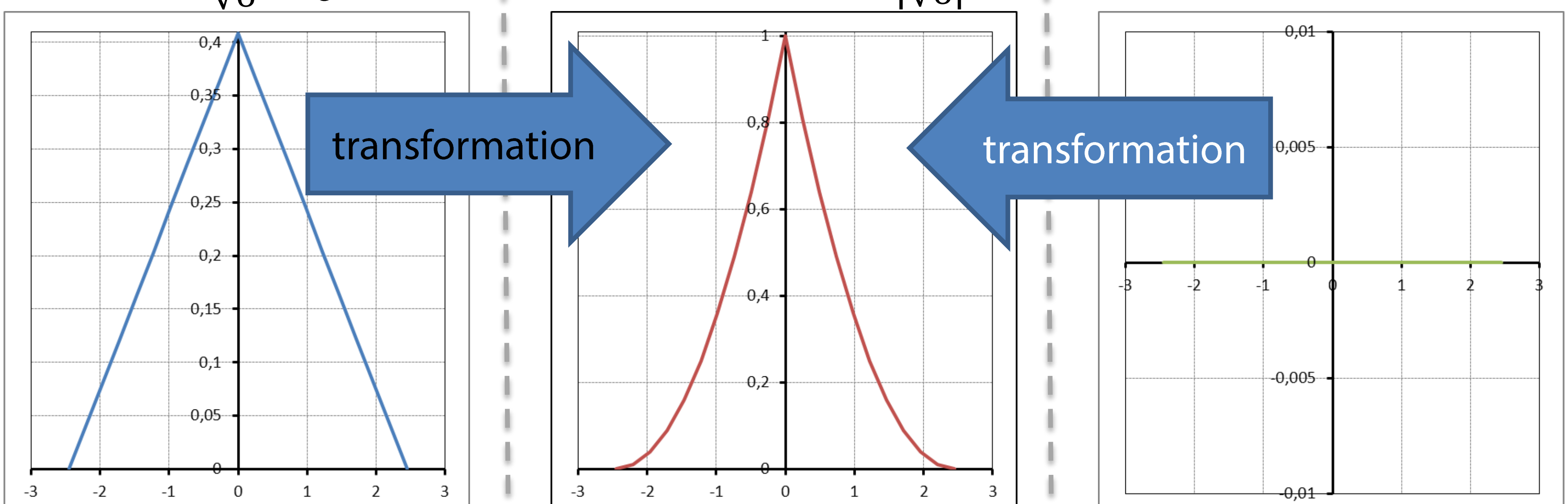
Types of uncertainty

Stochastic uncertainty
(Measurement data)

non-stochastic uncertainty
(experts)

Three possibilities to describe uncertainty mathematically:

Probability densities	Fuzzy sets (fuzzy set theory)	Intervals
Probability measure	Possibility measure (expressed by membership function)	Intervals
$p(x) = \frac{1}{\sqrt{6}} - \left\lvert\frac{x}{6}\right\rvert$	$\mu(x) = 1 + \frac{x^2}{6} - 2\left\lvert\frac{x}{\sqrt{6}}\right\rvert$	$[-\sqrt{6}, +\sqrt{6}]$



Introduction

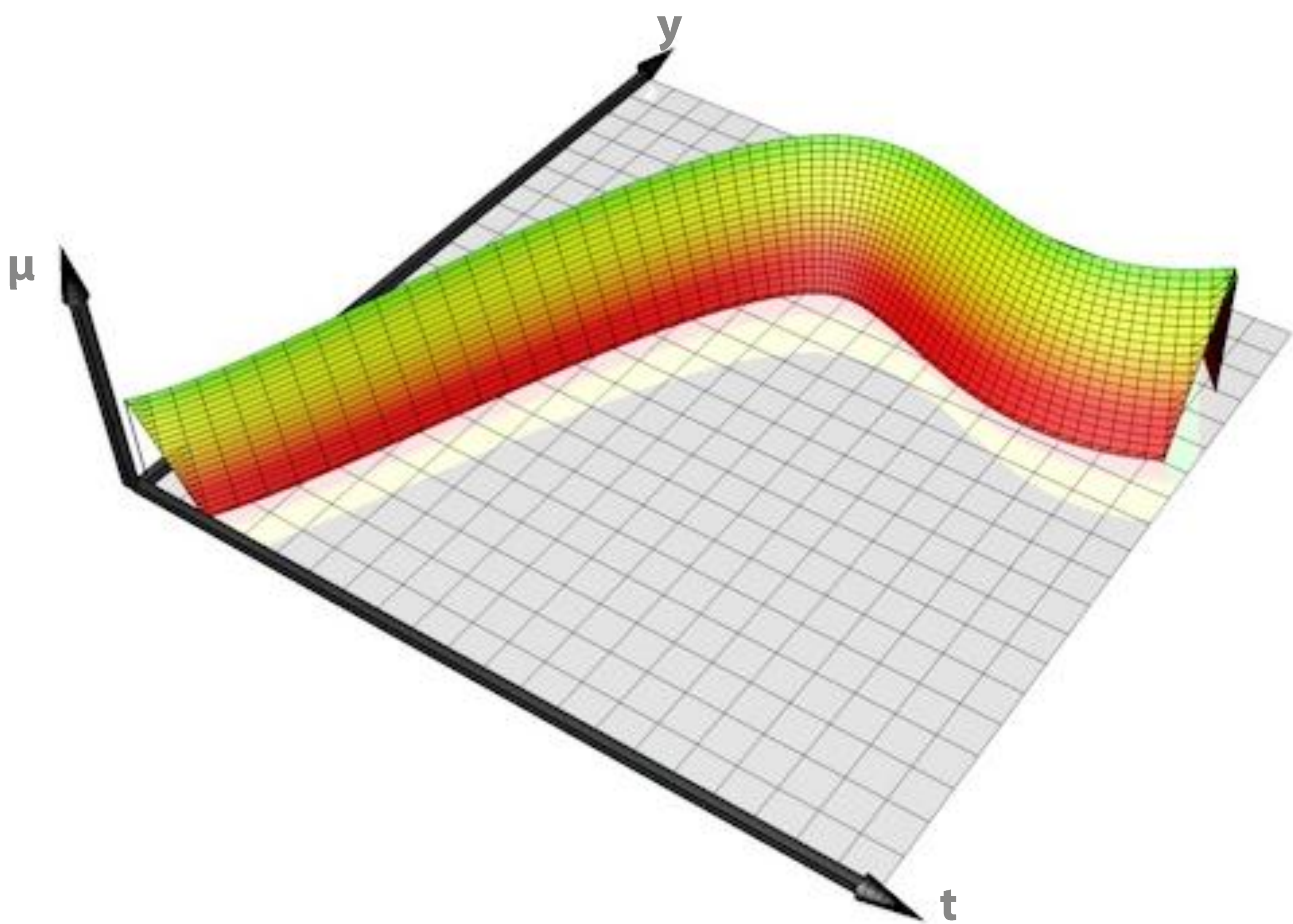


Fig.4: Temporal course of an output variable, qualitatively distributed in terms of possibility

Introduction

Motivation:

1. Certainty about the uncertainty
2. How reliable are the results?
3. How is the impact of uncertainty on the results?

Objective:

→ Integration and development of methods and procedures in the simulation system "DynStar" to take account of uncertainty / fuzziness and their propagation in nonlinear dynamic models

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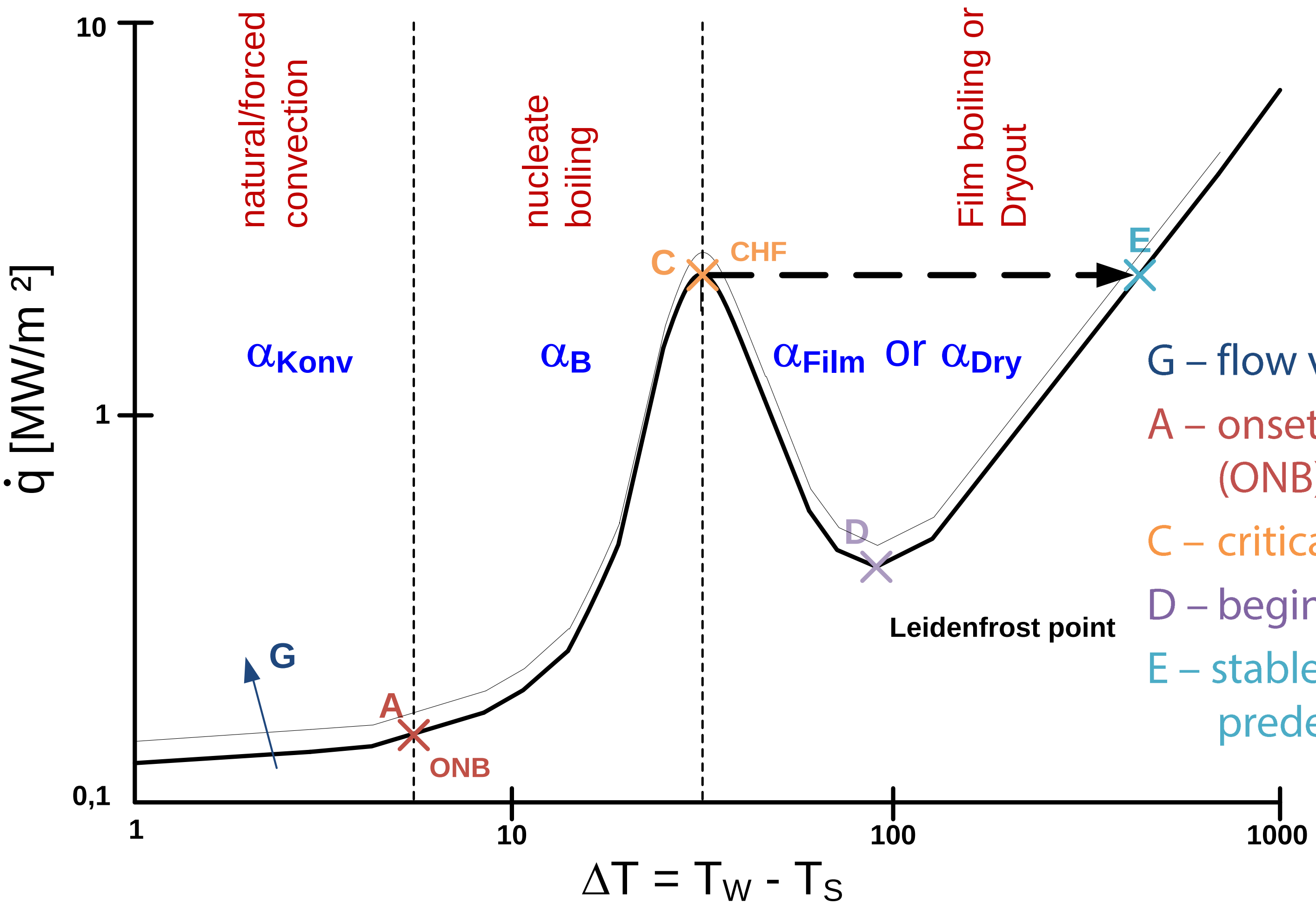
Mathematical description of the boiling process



G – flow velocity

A – onset of nucleate boiling (ONB)

C – critical heat flux (CHF)

D – beginning of film boiling

E – stable operating point with predetermined heat flux

Fig.5: Explanation of the boiling stages based on the boiling curve of Nukiyama [Maurus]

Mathematical description of the boiling process

Forced convetion α_{Konv}

$$\alpha_{Konv} = f_1(p, \dot{M}, d)$$

Depending on:
- pressure,
- mass flow,
- tube inner diameter

Nucleate boiling α_B

$$\alpha_B = f_2(p, d, \dot{q})$$

Depending on:
- pressure
- heat flux,
- tube inner diameter

Film boiling α_F

$$\alpha_F = f_3(p, h, T_W, d)$$

Depending on :
- pressure,
- wall temperature,
- tube inner diameter
- enthalpy (vapor content)

Dryout α_{Dry}

$$\alpha_{Dry} = f_4(p, h, \dot{M}, d)$$

Depending on :
- pressure,
- mass flow,
- tube inner diameter
- enthalpy (vapor content)

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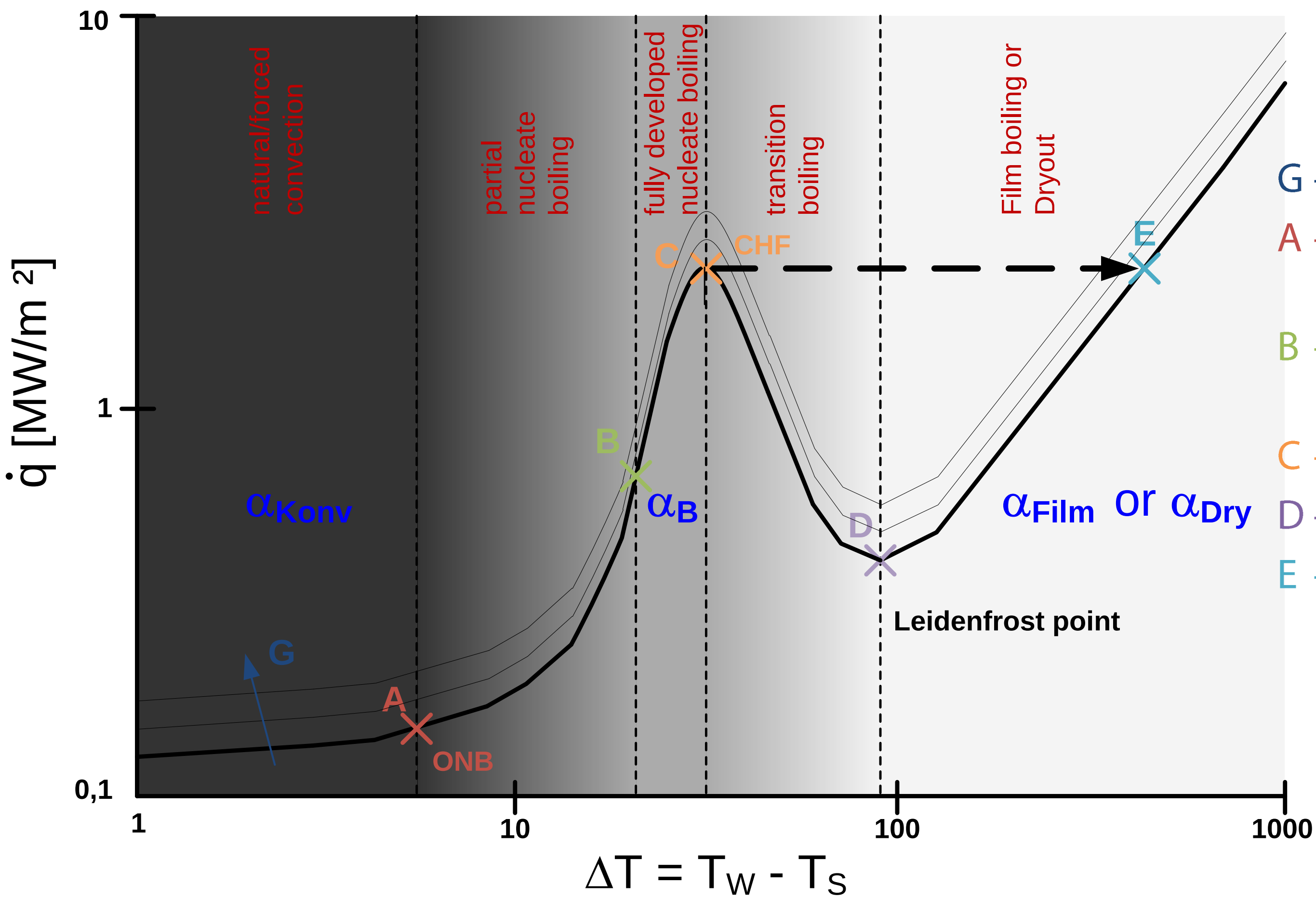
Modeling of transitions between the different boiling stages



G – flow velocity
A – onset of nucleate boiling (ONB)
B – Beginning of fully developed nucleate boiling
C – critical heat flux (CHF)
D – beginning of film boiling
E – stable operating point with predetermined heat flux

Fig.6: Explanation of the boiling stages based on the boiling curve of Nukiyama [Maurus] with smooth transitions

Modeling of transitions between the different boiling stages

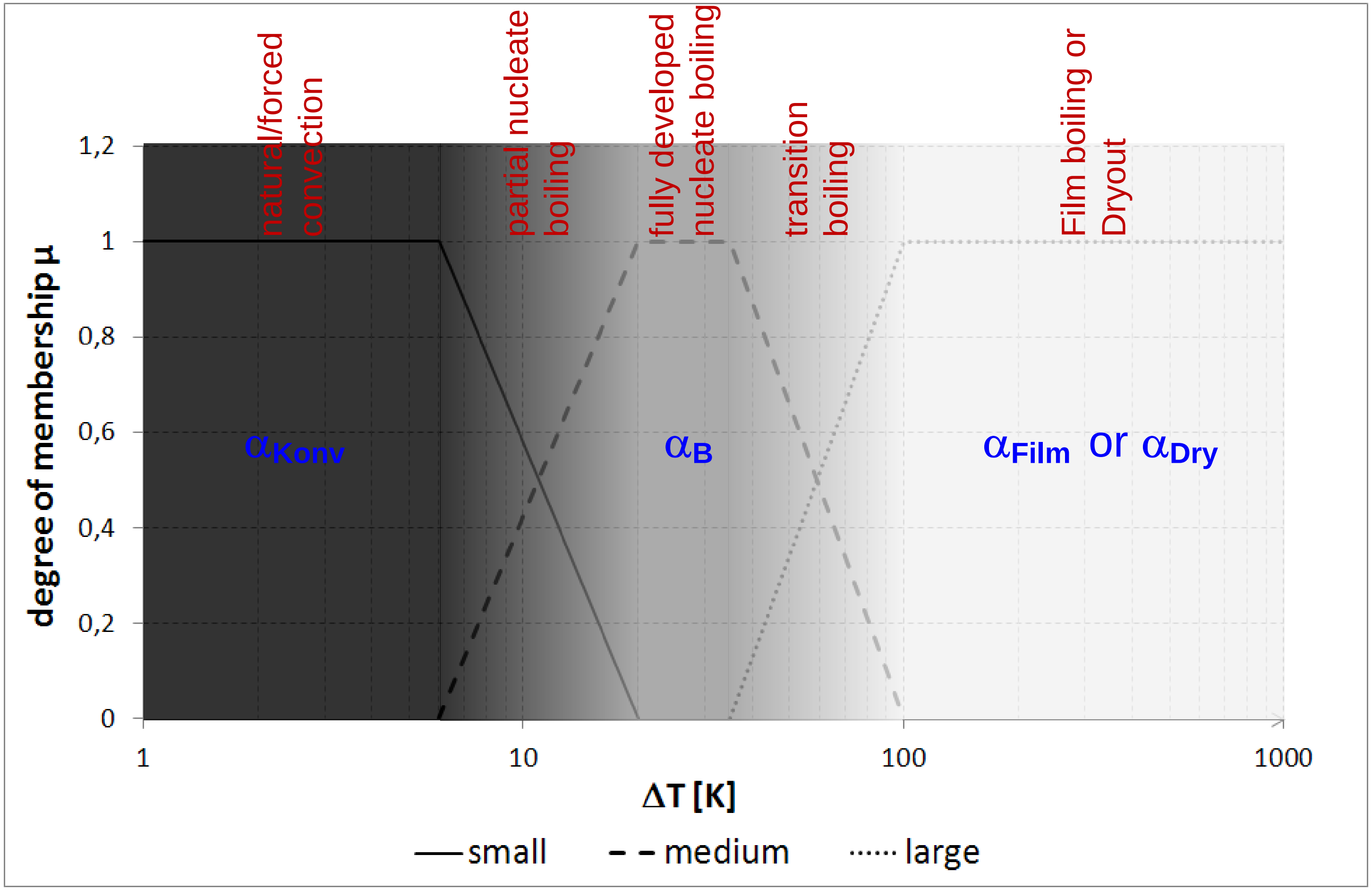


Fig.7: Linguistic variable "wall superheat ΔT"

Modeling of transitions between the different boiling stages

Which of the boiling crisis mechanisms is working?

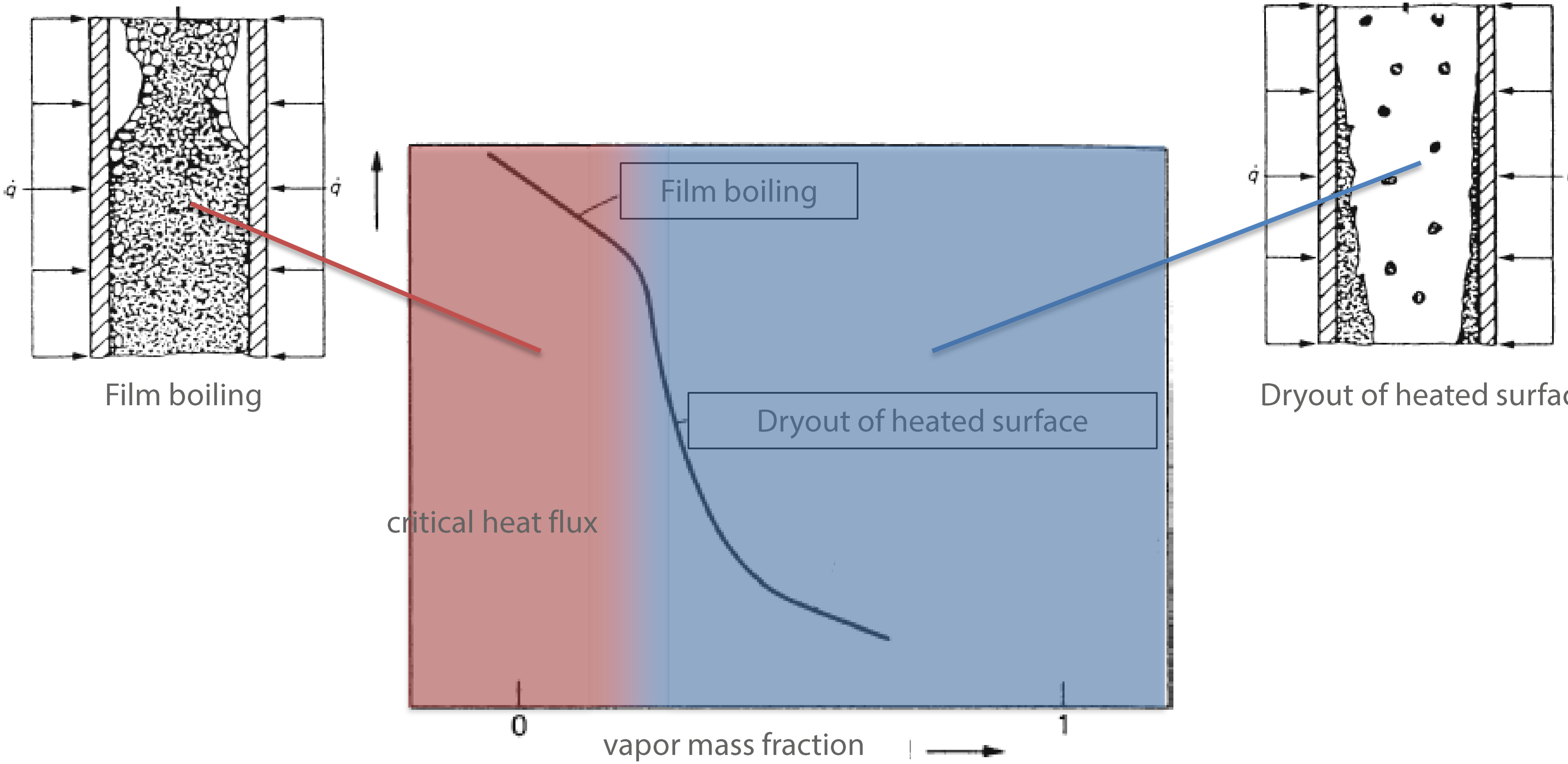


Fig.8: Typical relationship between the critical heat flux and the vapor mass fraction[1]

[1] VDI Heat Atlas section H3.5

Modeling of transitions between the different boiling stages

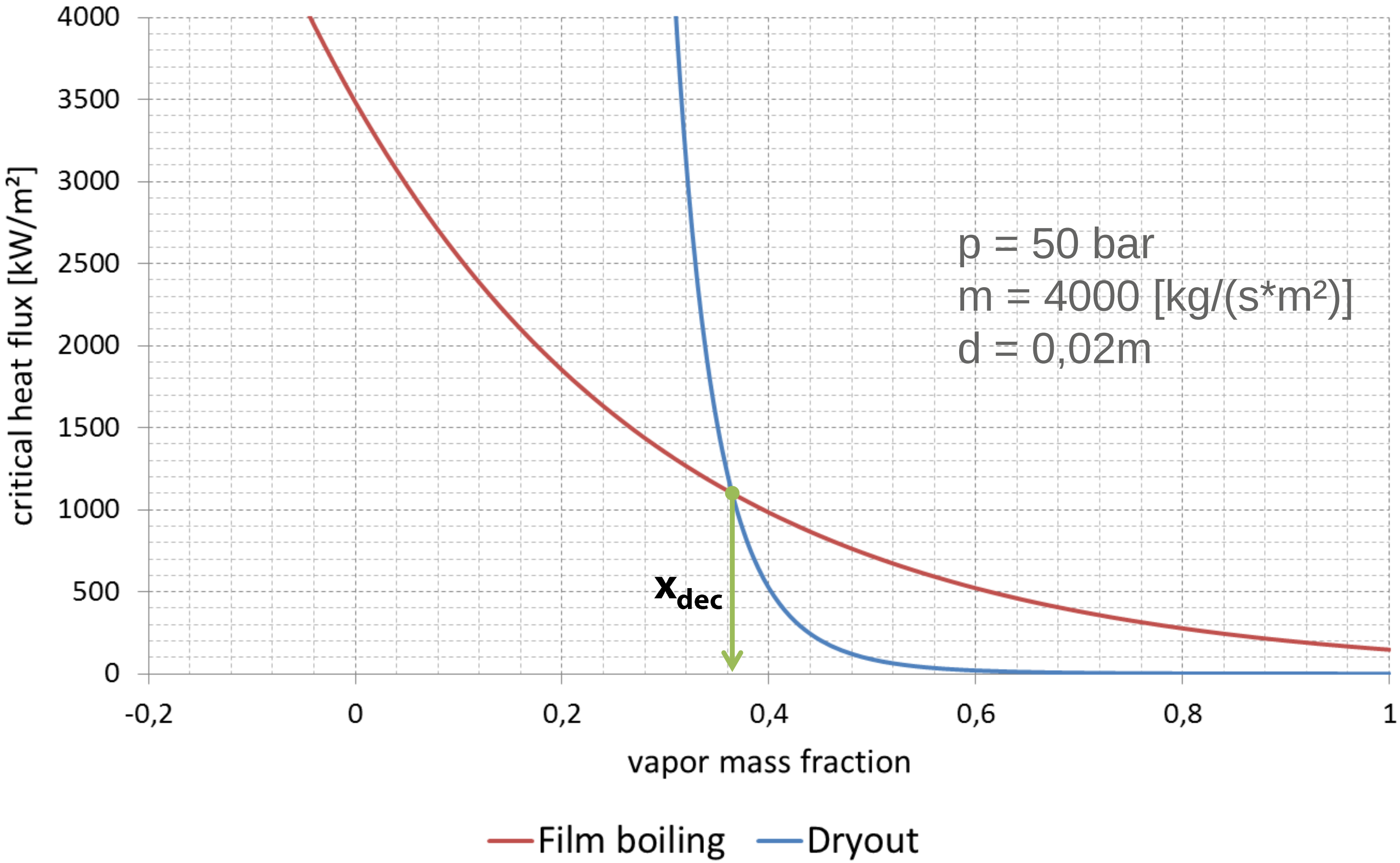


Fig.9: Critical heat flux as a function calculated from the vapor mass fraction according to VDI-heat atlas

Modeling of transitions between the different boiling stages

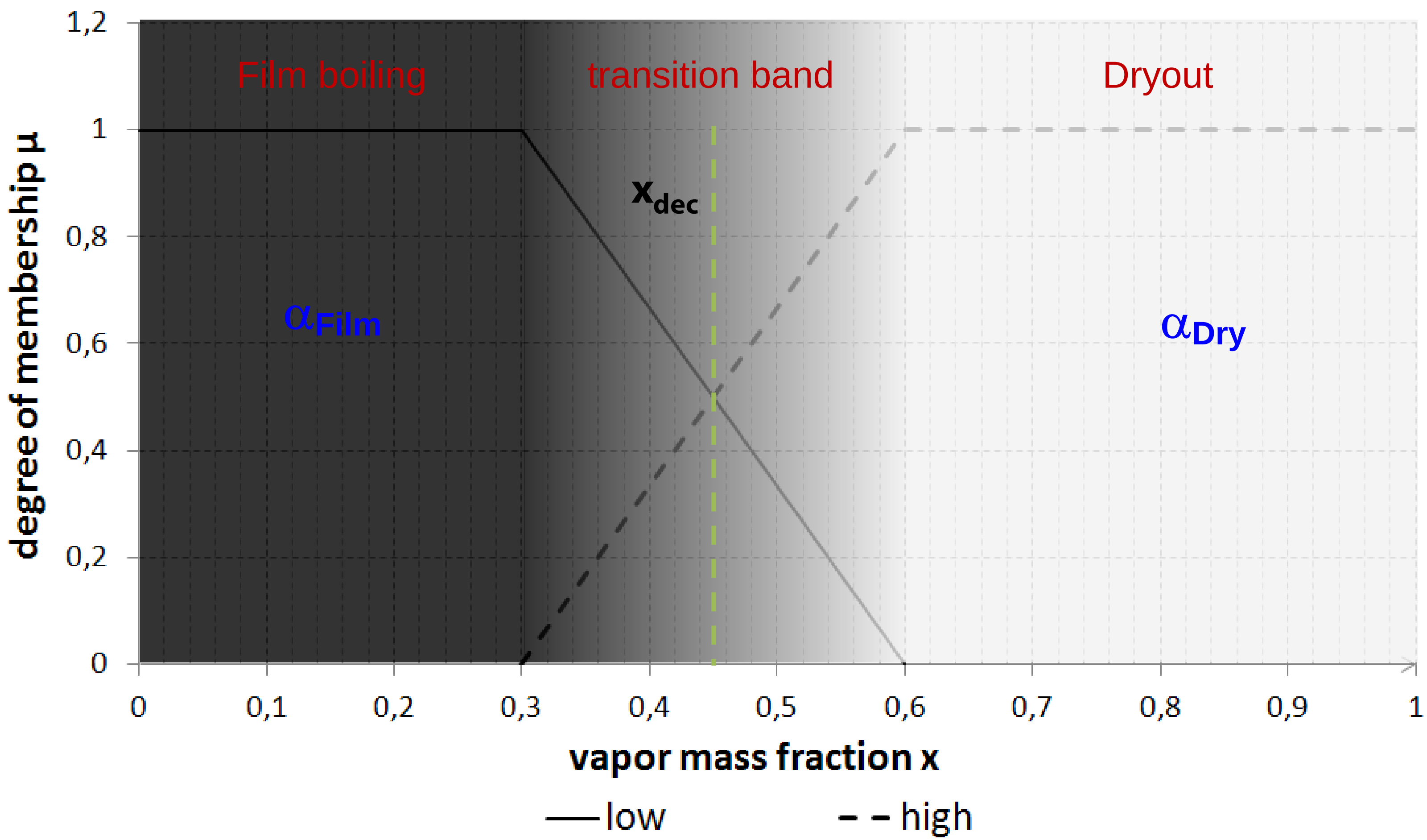


Fig.10: Linguistic variable „vapor mass fraction"

Modeling of transitions between the different boiling stages

Rule base

if	$\Delta T =$ **„small“**			then	$\alpha =$ **Forced convection (α_{Konv})**
if	$\Delta T =$ **„medium“**			then	$\alpha =$ **Nucleate boiling (α_B)**
if	$\Delta T =$ **„large“**	and	$\dot{x} =$ **low**	then	$\alpha =$ **Film boiling (α_F)**
if	$\Delta T =$ **„large“**	and	$\dot{x} =$ **high**	then	$\alpha =$ **Dryout (α_{Dry})**

Resulting heat transfer coefficient α → Aggregation of single rules

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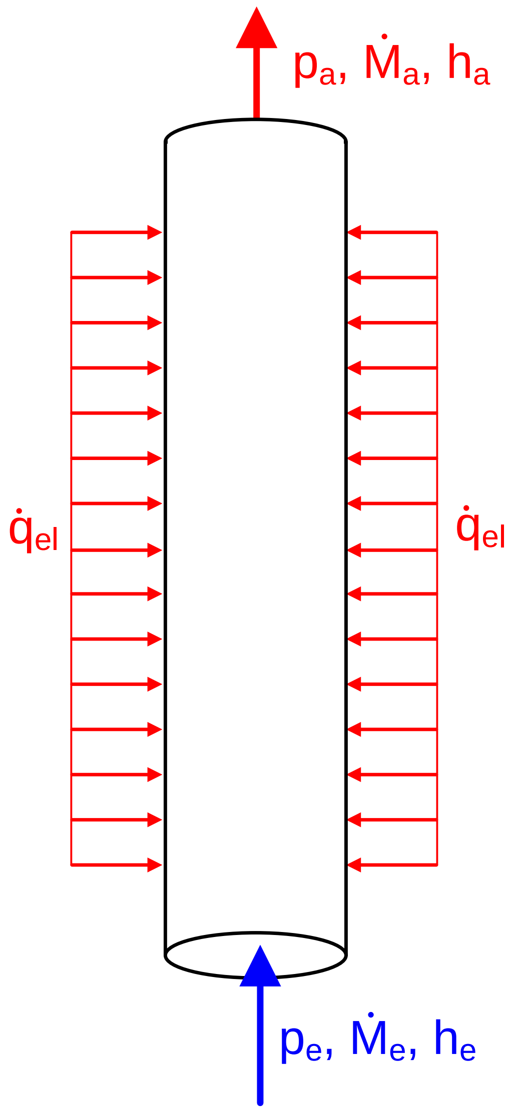
Modeling of a flow boiling example



p_e, p_a - inlet, outlet pressure

$\dot{M}_e$,$\dot{M}_a$ - inlet, outlet mass flow

h_e, h_a - Specific inlet, outlet enthalpy

m_W - Tube mass

c_W - Specific heat capacity of the wall

m - Mass of water inside the tube

T_W - Wall temperature

$\dot{q}_{el}$ - electrical heat flux

Model equations

Medium heat balance:

$$h_a \cdot \dot{M}_e + m \cdot \frac{dh_a}{dt} = \dot{M}_e \cdot h_e + \dot{q}_D(T_W, h_a)$$

Energy balance of tube:

$$m_W \cdot c_W \cdot \frac{dT_W(t)}{dt} = \dot{q}_{el} - \dot{q}_D(T_W, h_a)$$

Mechanical energy balance:

$$p_e - p_a(m, h_a) = k_1 \cdot \dot{M}_a^2 + k_2 \cdot \frac{d\dot{M}_a}{dt}$$

Mass balance:

$$\dot{M}_e - \dot{M}_a(t) = \frac{dm}{dt}$$

Unknown functions:

$$\boldsymbol{T_W(t)}, \qquad \boldsymbol{h_a(t)}, \qquad \boldsymbol{\dot{M}_a(t)}, \qquad \boldsymbol{m(t)}$$

Auxiliary equations:

$$\varrho = \frac{m}{V}$$

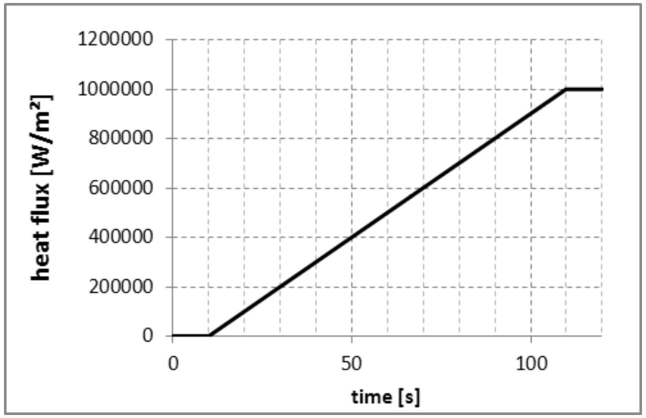
$$p_a = f(\varrho, h_a) = \tilde{f}(m, h_a)$$

$$\dot{x}_a = f(p_a, h_a)$$

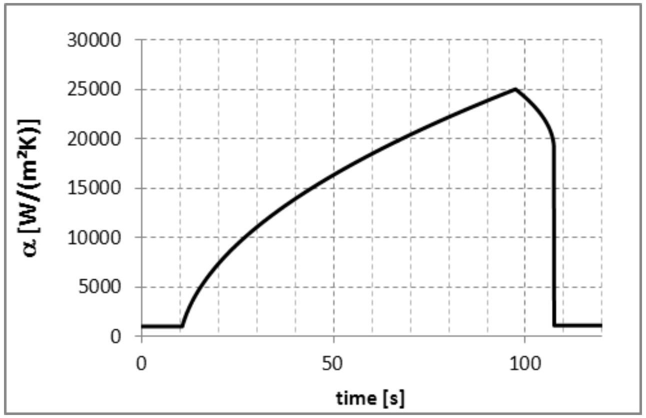
$$\dot{q}_D(T_W, h_a) = \alpha(T_W, h_a, \dot{M}_a, p_a, d, \dot{q}_{el}) \cdot (T_W(t) - T_S(p_a))$$

Modeling of a flow boiling example

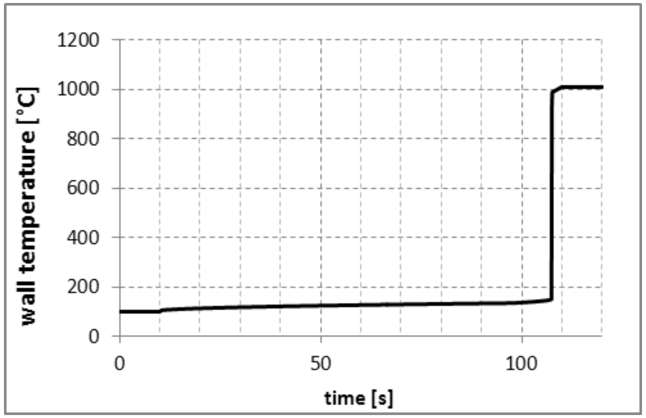
Preliminary results:

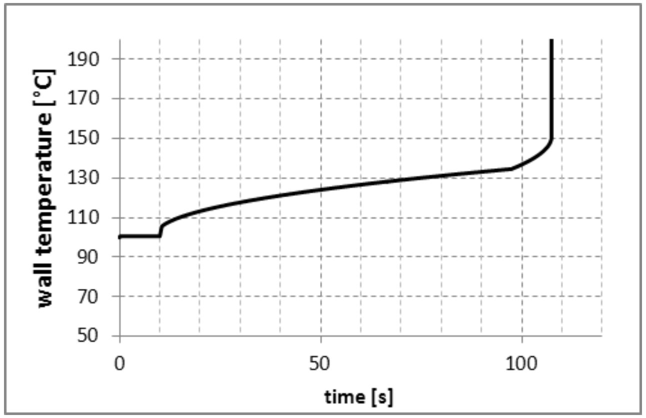


Temporal course of the prescribed heat flux



Qualitative trend of the heat transfer coefficientα





Qualitative temporal course of the wall temperature,
overview zoomed

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Further work

To do:

- Implementation in a computer algebra system
  - process model
  - Takagi-Sugeno-Fuzzy-Model (2 linguistic variables, rule base)
- Dynamic Simulation
- Uncertainty analysis for interesting parameters
- Dynamic simulation with model and parameter uncertainties
- Evaluation

→ Integration of the methods in DynStar

- Implementation of the mathematical framework (transformation, fuzzy differential equations)
- Concept development for the program implementation

Thank you for your time and interest!

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