Experimental Study of Scale Formation in Horizontal Tube Evaporators

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State of the Art

up to now:
- research of scale formation in full pipe flow, plate heat exchangers and vertical tube evaporators

lack of knowledge:
- scale formation on horizontal tubes

  depends on:
  - falling film flow
  - fluid flow pattern
  - heat transfer

implementation:
- multiple-effect distillation plant
  - T = const. (condensing steam)
  - phase transformation, surface evaporation
  - low heat flux

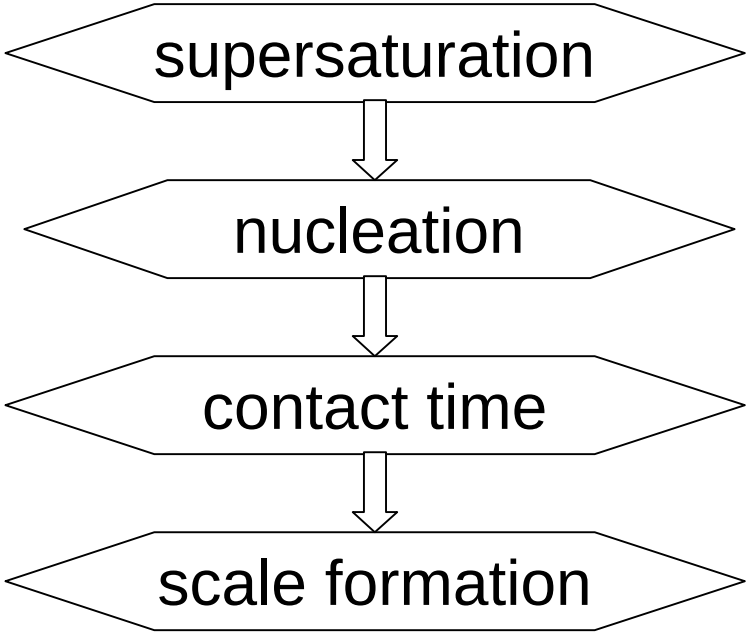
influence of:
- multi component system (seawater)

Why Do Crystalline Layers Occur?

- crystallization of inversely soluble salts:

  $CaCO_3$, $Mg(OH)_2$, $CaSO_4$
- solubility will be exceeded by increasing
  - temperature
  - concentration
  - pH value

conditions for formation of crystal layers:



Research of Scale Formation

- induction time
- fouling resistance
- scale composition
- crystal structure

depending on

- composition of test solution
- temperature
- heat flux
- trickling rate

General Idea of Implementation

- 6 horizontal tubes (one row)
- tube length: 500 mm
- tube diameter: 26.9 mm (DN 20)
- tube material: stainless steel
- exchangeable tubes (samples)
- solution is preheated to evaporation temperature on upper tubes and evaporated on lower tubes
- evaporation under vacuum conditions
- heating by condensing saturated steam in tubes
- trickling by simple distribution unit

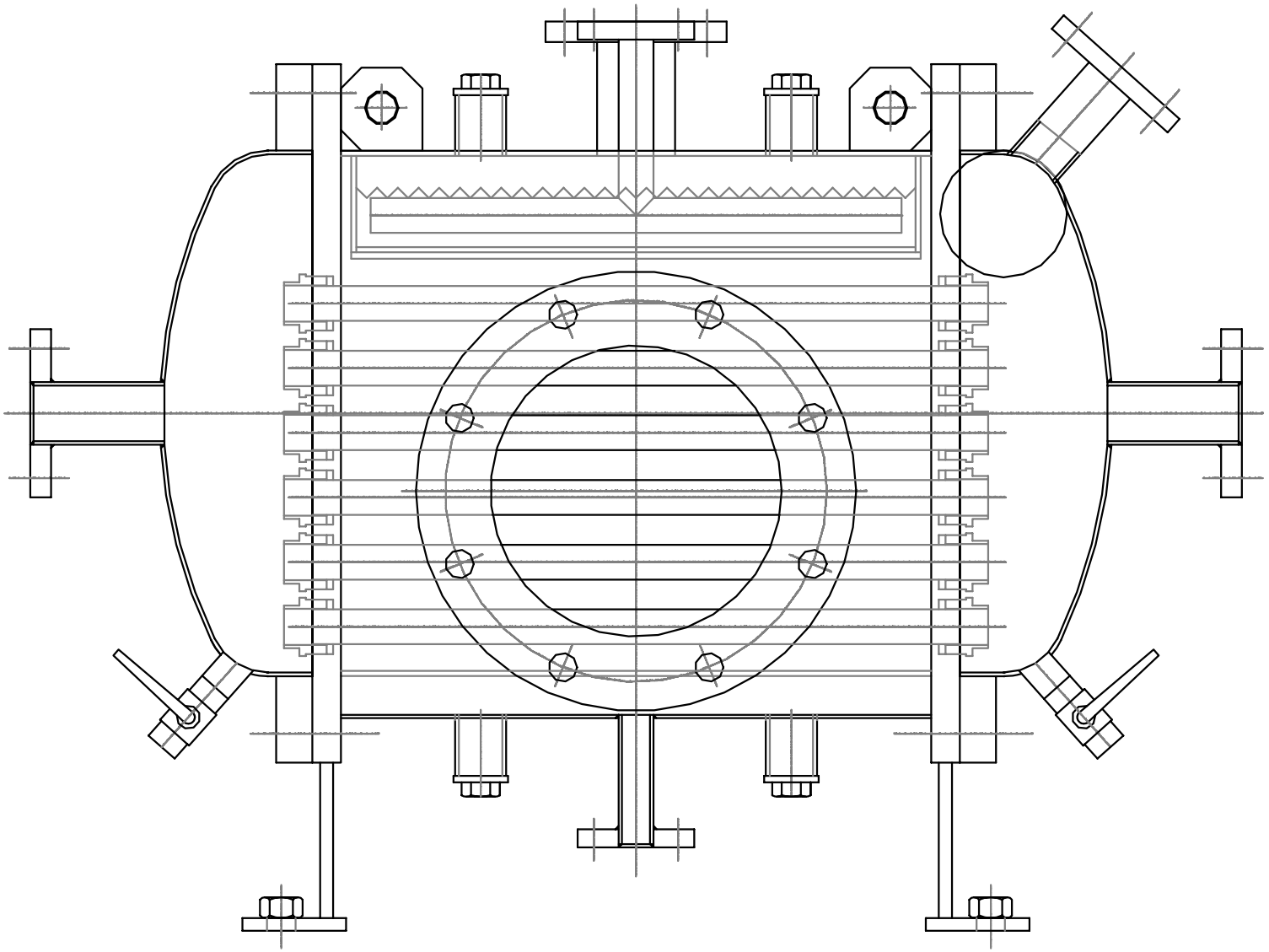


Figure 1: evaporator front view

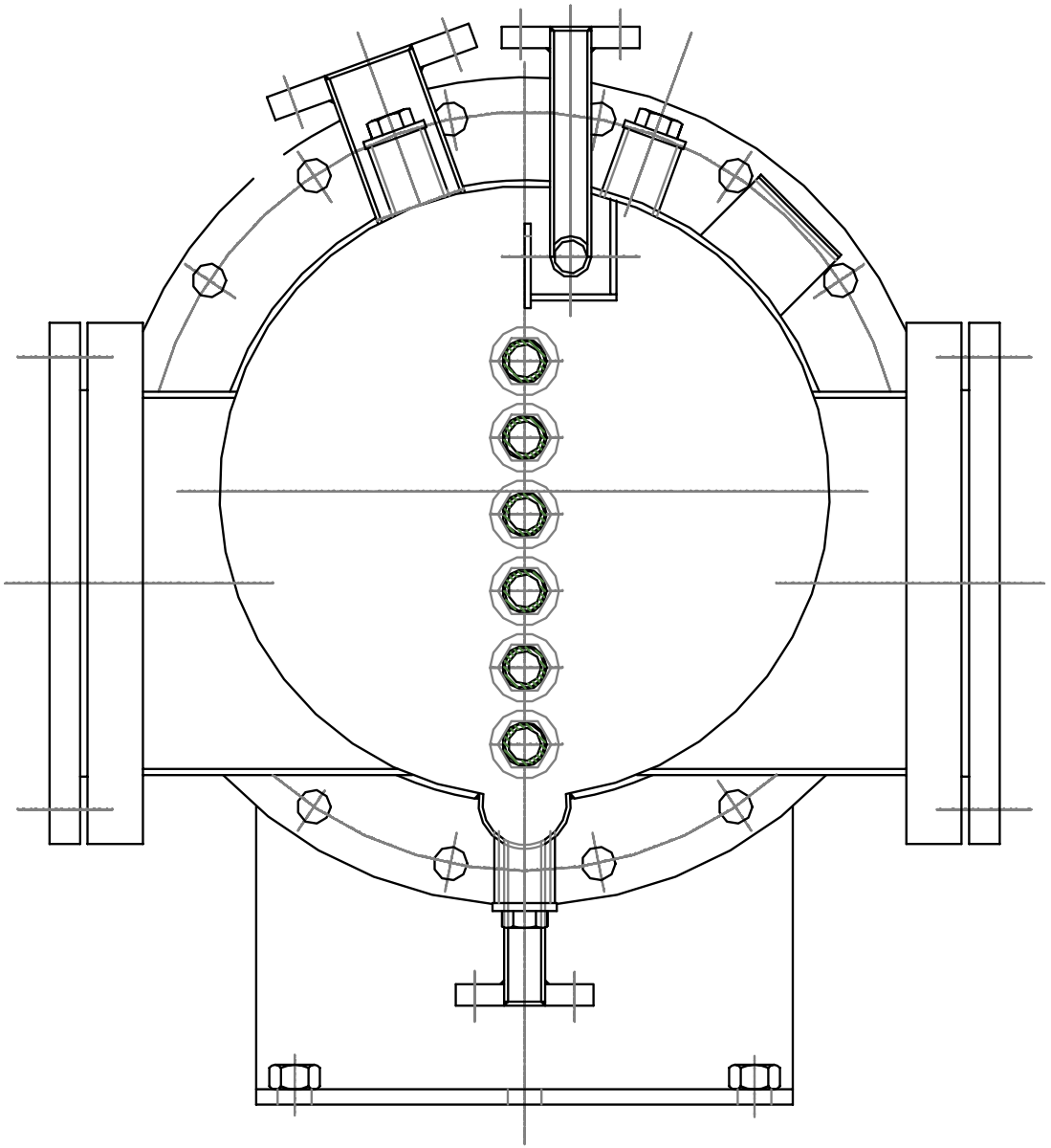
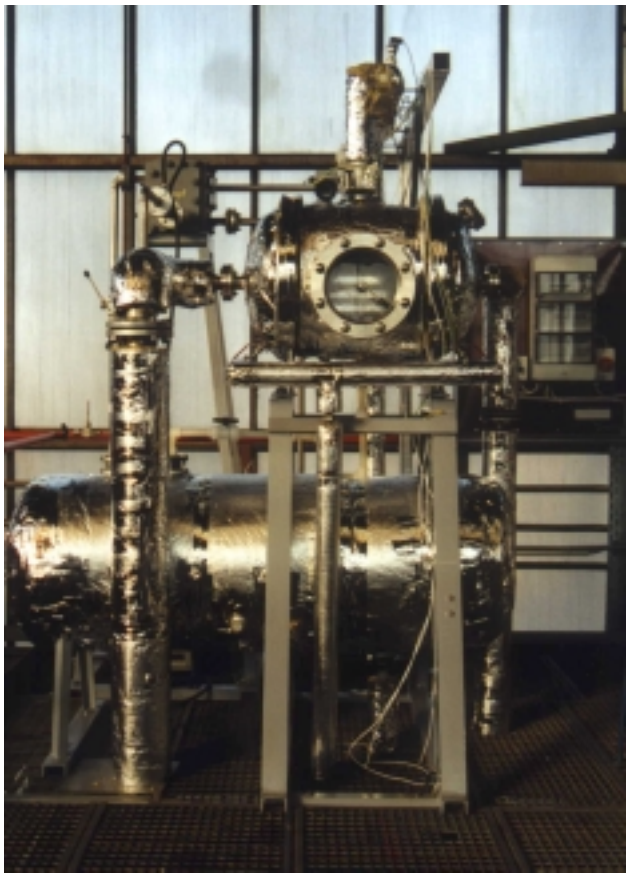
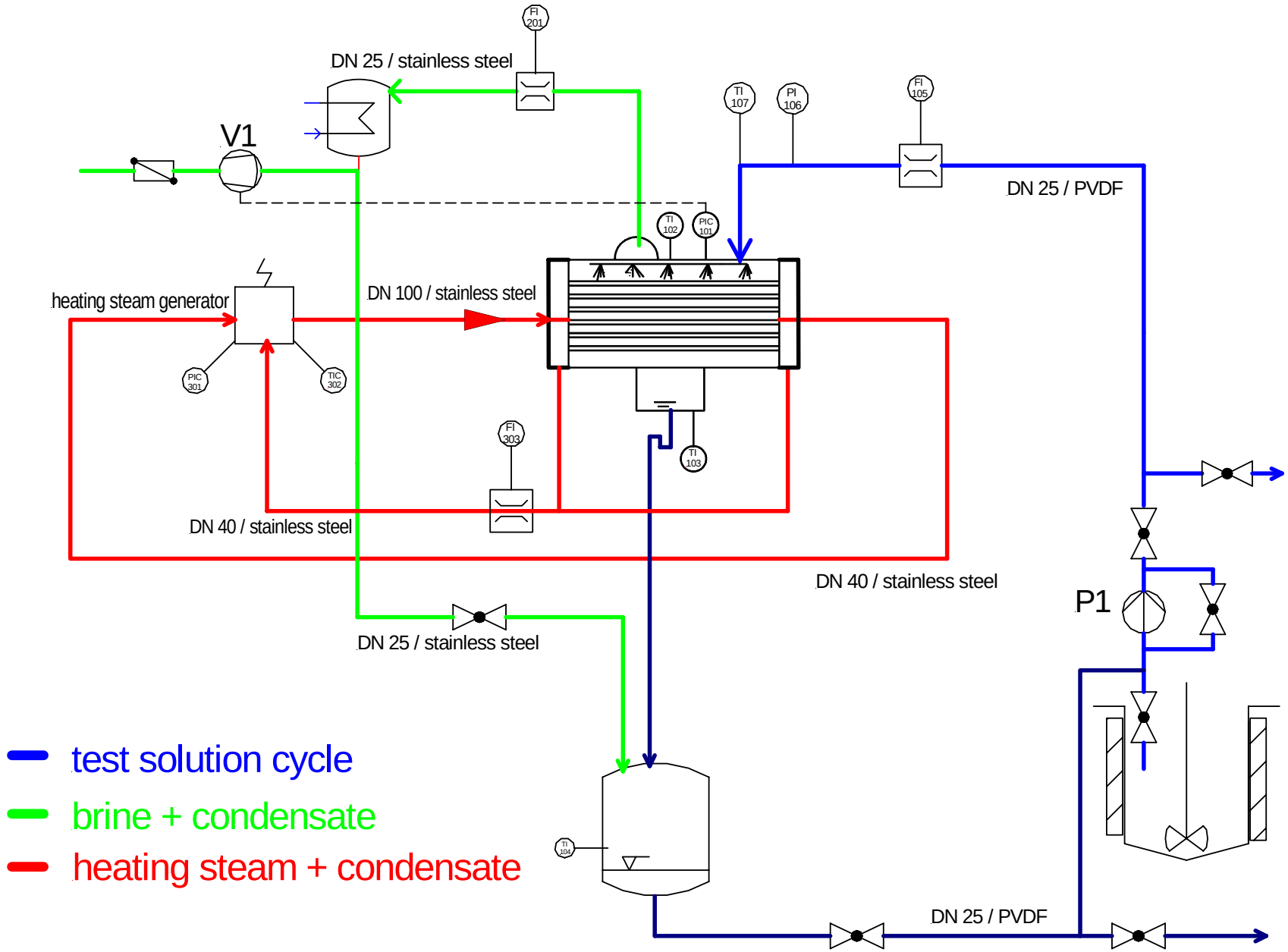


Figure 2: evaporator side view with tube row



⇐ platform 2: horizontal tube evaporator

⇑ platform 1: heating steam generator


FI 201
DN 25 / stainless steel
V1
TI 107
PI 106
FI 105
DN 25 / PVDF
TI 102
PIC 101
heating steam generator
DN 100 / stainless steel
PIC 301
TIC 302
FI 303
TI 103
DN 40 / stainless steel
DN 40 / stainless steel
P1
DN 25 / stainless steel
TI 104
DN 25 / PVDF
test solution cycle
brine + condensate
heating steam + condensate

Parameter Variation

- heating steam temperature/ pressure
- evaporation temperature/ pressure

} heat flux

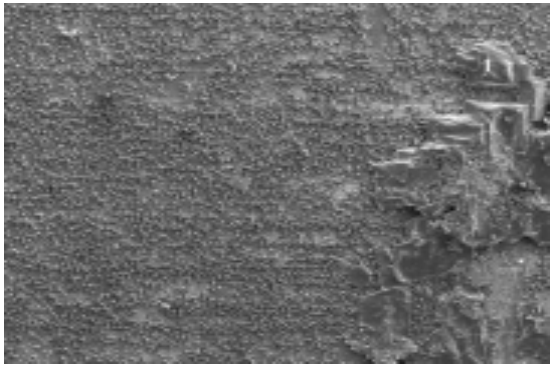
- trickling rate
- re-circulation of condensate: yes/ no
- volume of test solution ($\Rightarrow$ feed temperature)
- composition of test solution
- salinity and pH-value of test solution
- material and surface properties of heat transfer area
- experiment duration (induction time, course of scale formation)

Heat Transfer Data

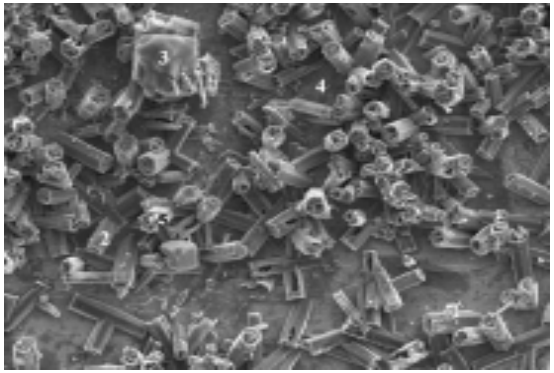
	$\Delta T = 10$ K	$\Delta T = 20$ K
Tsteam [°C]	80	90
Tevap [°C]	70	70
Q [kW]	3.7	7
k [W/m^2 K]	1000	1100

Heat transfer area : 0.254 m^2

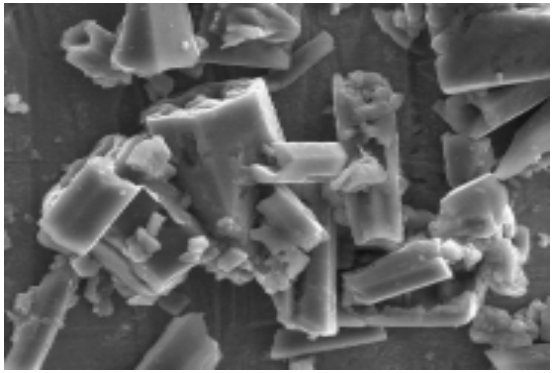
SEM Pictures of Crystal Layers



100 : 1 200 µm

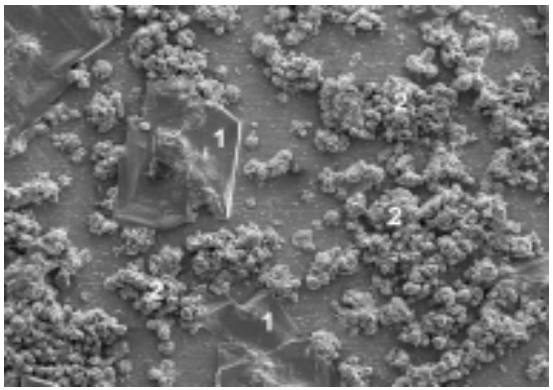


1000 : 1 20 µm

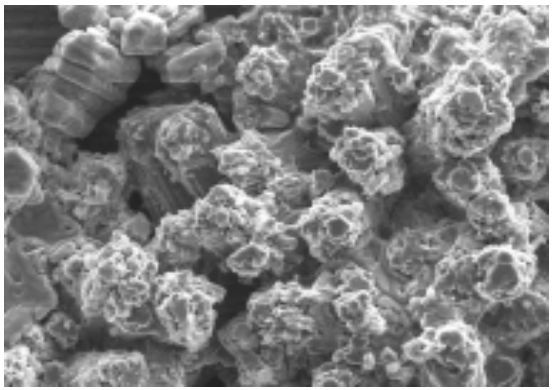


5000 : 1 5 µm

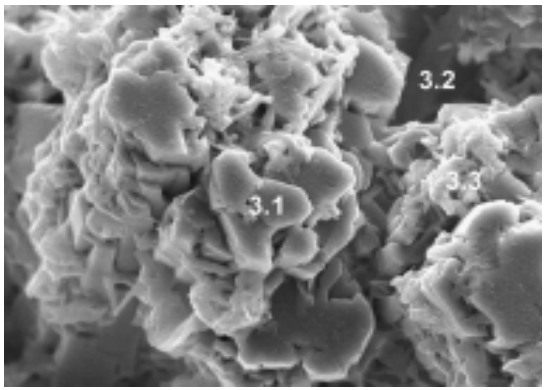
crystal structure at $\Delta T = 10$ K after 50 h



100 : 1 200 µm



1000 : 1 20 µm



5000 : 1 5 µm

crystal structure at $\Delta T = 20$ K after 50 h

Conclusions

- similar composition of scale
- different
  - scale layers
  - crystal growth
  - habiti
- not only depending on solution properties
- strongly depending on process parameters

A wide variety of parameters is necessary to realize authentic scale formation as well as to control and minimize scale formation.

$\Rightarrow$ **a test rig in pilot plant size is inevitable**