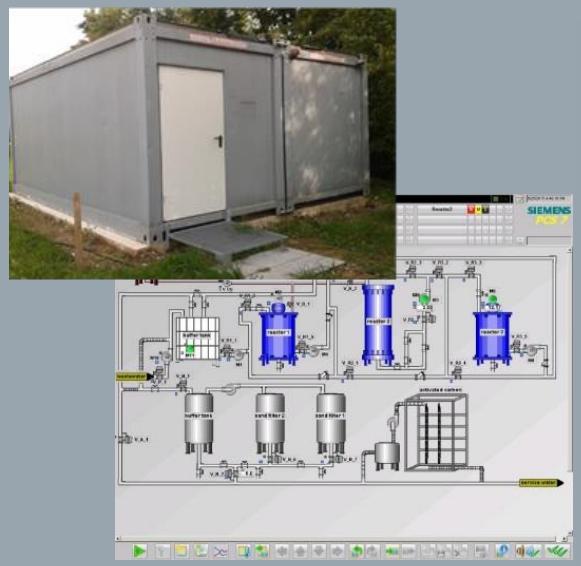
Start-Up of a decentralized pilot plant for the anaerobic treatment of domestic wastewater

Laura Fröba, Marisela Vega, Frauke Groß, Antonio Delgado 16.09.16



Objective of the study

- autarc wastewater treatment of small settlements and megacities
- industrial scale (capacity: 200 m³/ d; PE 2000)
- saving drinking quality water by using service water (saving potential about 60%)

domestic wastewater

COD:	200 mg/l
NH4-N:	40 mg/l
TN:	50 mg/l
TP:	5 mg/l
E.coli:	10^6 cfu/100ml

anaerobic

domestic wastewater → **service water**

decentral – **easy to use**

self-defined limit values
(AbwV 2016, BayBadeGewV 2008)

COD:	75 mg/l
NH4-N:	10 mg/l
TN:	13 mg/l
TP:	1 mg/l
E.coli	900 cfu/ 100 ml

lab scale
0,014 m³/ d
✓

→ pilot scale
2 m³/ d
20 PE

→ industrial scale
200 m³/ d
2000 PE

Pilot plant for treating domestic wastewater

- **three stage biological process**
  - C-reduction: anaerobic digestion
    reactor 1 (R1) and 2 (R2)
  - N-reduction: anaerobic Ammonium Oxidation (Anammox)
    reactor 3 (R3)
- **pre-heating step** due to mesophilic conditions (30°C-40°C)
- **reactors:** **R1 + R3**: anaerobic sequencing batch reactor
  (1300 liters each) **R2:** fixed bed reactor


buffer tank


reactor 1


reactor 2


reactor 3


sand filter

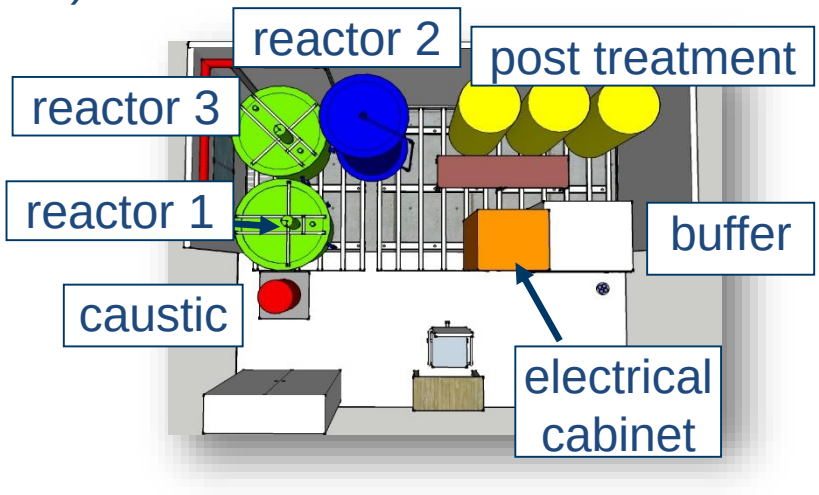

activated carbon

pre-heating → anaerobic digestion → Anammox → post-treatment

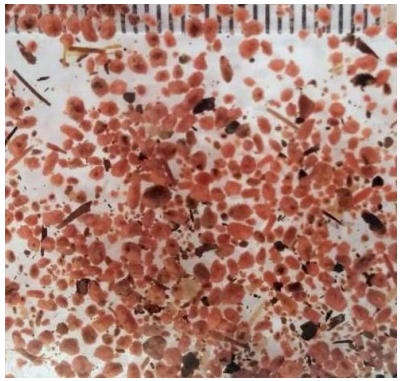
Pilot plant for treating domestic wastewater

- **installation in office container (28 m², H: 2.50 m)**

→ flexible, modular and space efficient (decentral)



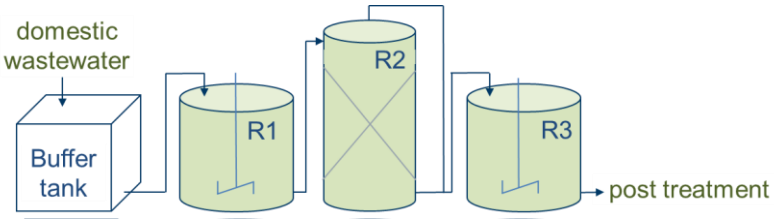
- reactors were innoculated each with 60 liters of seeding sludge
  - R1+R2: **sludge coming from a two-stage anaerobic digestion plant** (Obermichelsbach, GE)
  - R3: **sludge coming from a Deammonification (DEMON)-System** (Fulda, Gläserzell, GE)



Start-Up of the pilot plant

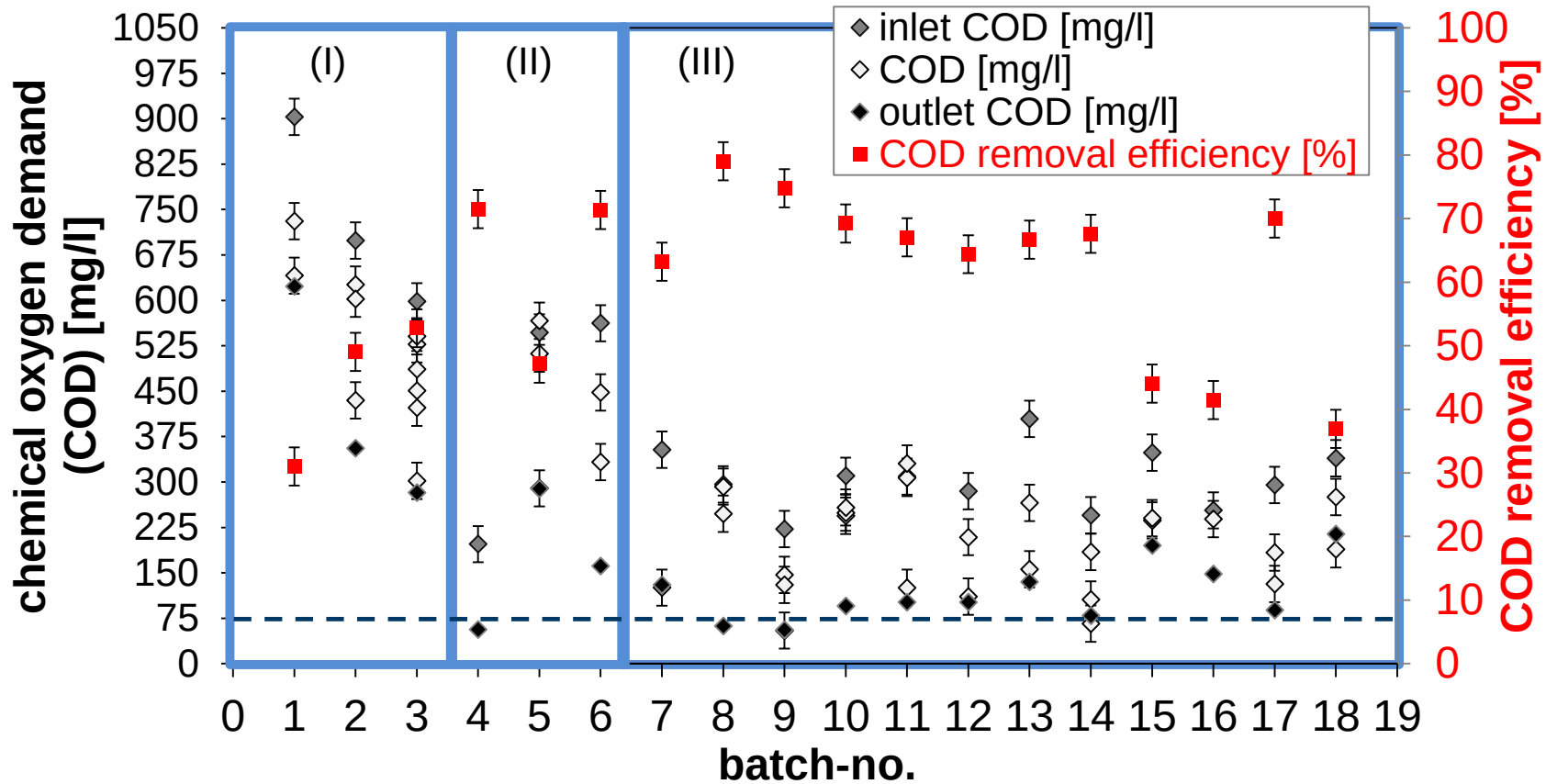
- start-up procedure (MWW: municipal wastewater, SWW: synthetic wastewater)

<table>
<tr><th>reactor 1</th><th>reactor 2</th><th>reactor 3</th></tr>
<tr><td>adaptation phase
100% MWW</td><td>adaptation phase
100% MWW + organic acids
(acetic acid: propionic acid: butyric acid in 2:1:1)</td><td rowspan="2">adaptation phase
100% SWW
(1000 liters of tab water added with ammonia sulfate (40mg/l) and sodium nitrite (50mg/l))</td></tr>
<tr><td colspan="2">stepwise interconnection of R1 and R2
to 33%, 50%, 75% and 100%
→ 100%: no addition of organic acids to R2</td></tr>
<tr><td colspan="3">stepwise interconnection of anaerobic digestion (outlet of R2) and R3
to 20%, 50%, 80% and 100%
→ 100%: - no addition of ammonia sulfate to R3
- adjsutment of nitrite-nitrogen (NO2-N) to ammonia-nitrogen (NH4-N) ratio</td></tr>
</table>



- testing of the three-stage pilot plant for 200 days of operation after start-up
  → feeding of 100% MWW
  → additive: sodium nitrite (R3)

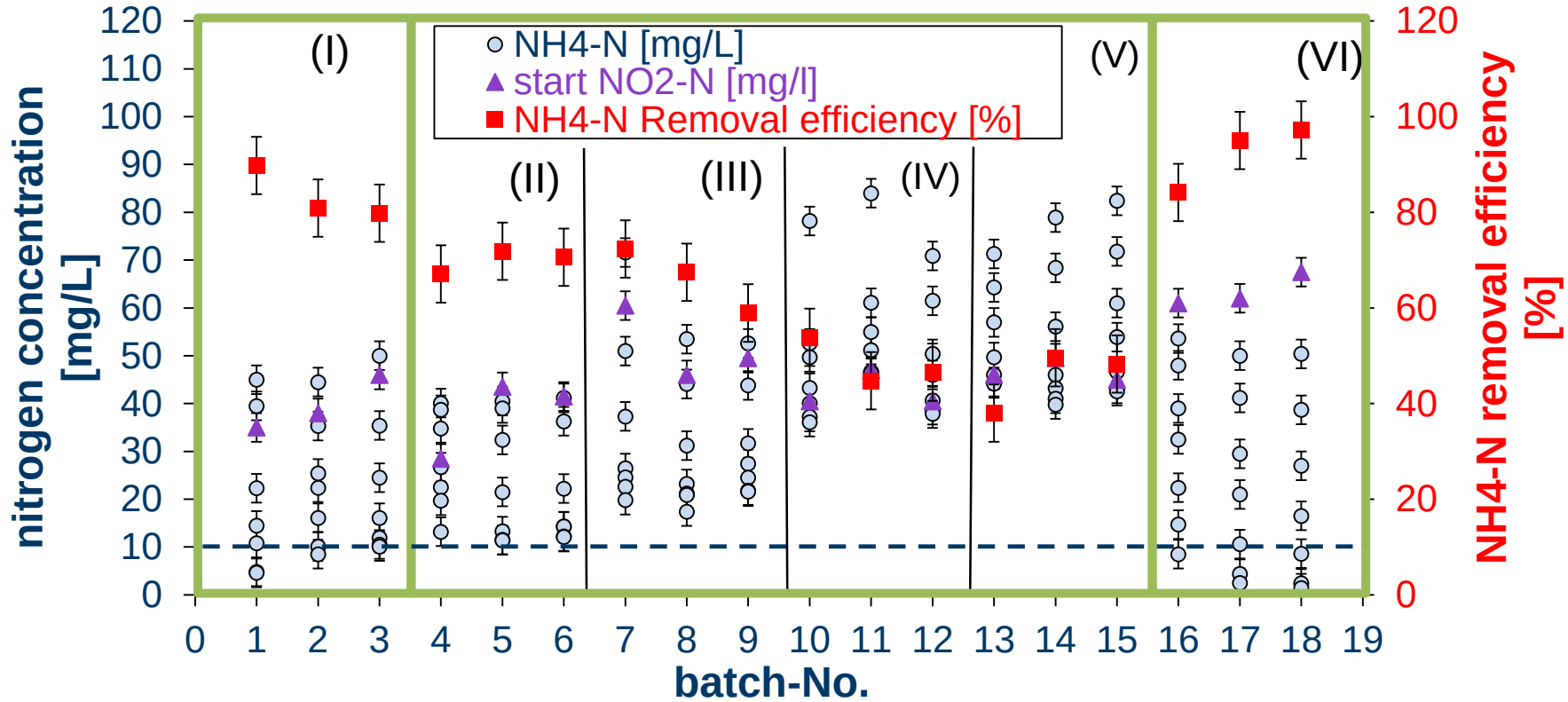
Start-Up of the two-stage anaerobic digestion (R1 + R2)



→ Start-up of two-stage anaerobic digestion was successful

→ Self-defined service water limit value of 75 mg/ l could almost be reached

Start-Up of the Anammox-stage (R3)



(I): 100% SWW, **(II):** 20% MWW **(III):** 50% MWW, **(IV):** 80% MWW, **(V):** 100% MWW

→ start-up of the Anammox-stage was successful

→ self-defined service water limit value of 10 mg/ l could be reached

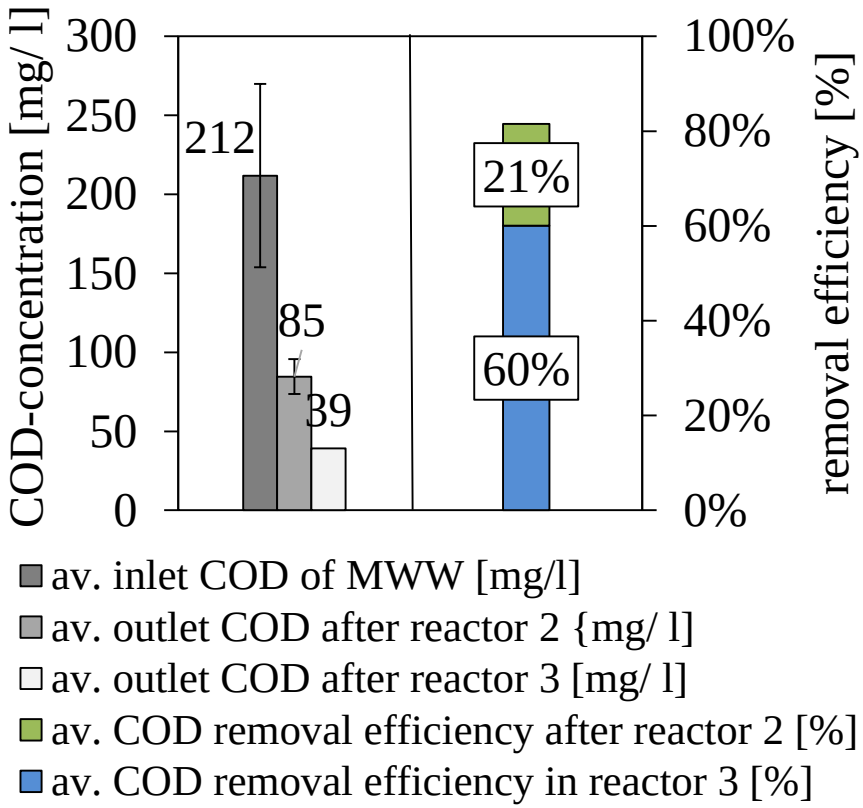
→ **Optimum substrate to feed ratio of the Anammox-stage in pilot scale: 1.14 mg/ l**

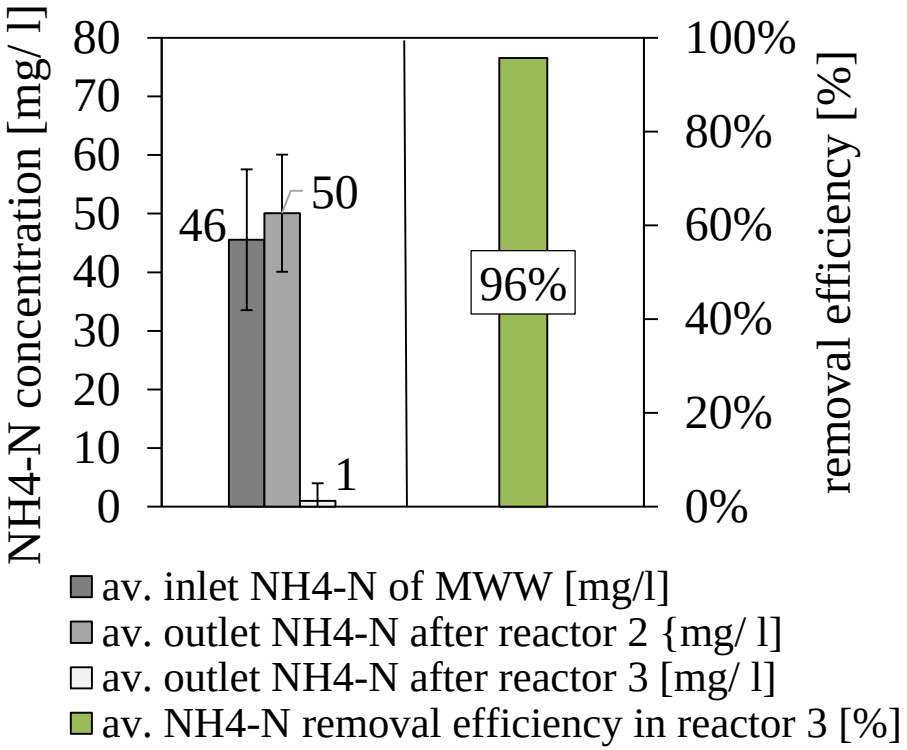
Degradation performance after 200 days of operation

Self-defined service water limit values:

COD: 75 mg/ l

NH4-N: 10 mg/ l





→ further optimization of 2-stage anaerobic digestion needed

→ with Anammox-stage limit value is guaranteed

Conclusion

- **start-up of the two-stage anaerobic digestion (R1 + R2)**
  - for a temperature range of 34°C to 38°C
  - without automated pH-control
  - final average COD removal efficiency: 62%
- **start-up of the Anammox-stage (R3)**
  - for a temperature range of 28°C to 35°C
  - optimum NO2-N to NH4-N ratio: 1.14
  - final average NH4-N removal efficiency: 92%
- **after testing the pilot plant for 200 days of operation**
  - total COD removal efficiency is 81%
    - → self-defined service water limit value of 75 mg/l could always be reached with R3 connected in downstream
  - total NH4-N removal efficiency is 96%
    - → self-defined service water limit value of 10 mg/l could always reached only by R3

→ **two-stage anaerobic digestion is limiting process-step, thus further optimization is needed to increase the plant´s capacity**

Acknowledgements:

- Hans Sauer Stiftung
- Klärwerk Erlangen
- Siemens AG
- ZWT Wasser- und Abwassertechnik GmbH
- Maschienenbau Biermann GmbH
- Webfactory GmbH

Thank you for your attention!

buffer tank

reactor 1

reactor 2

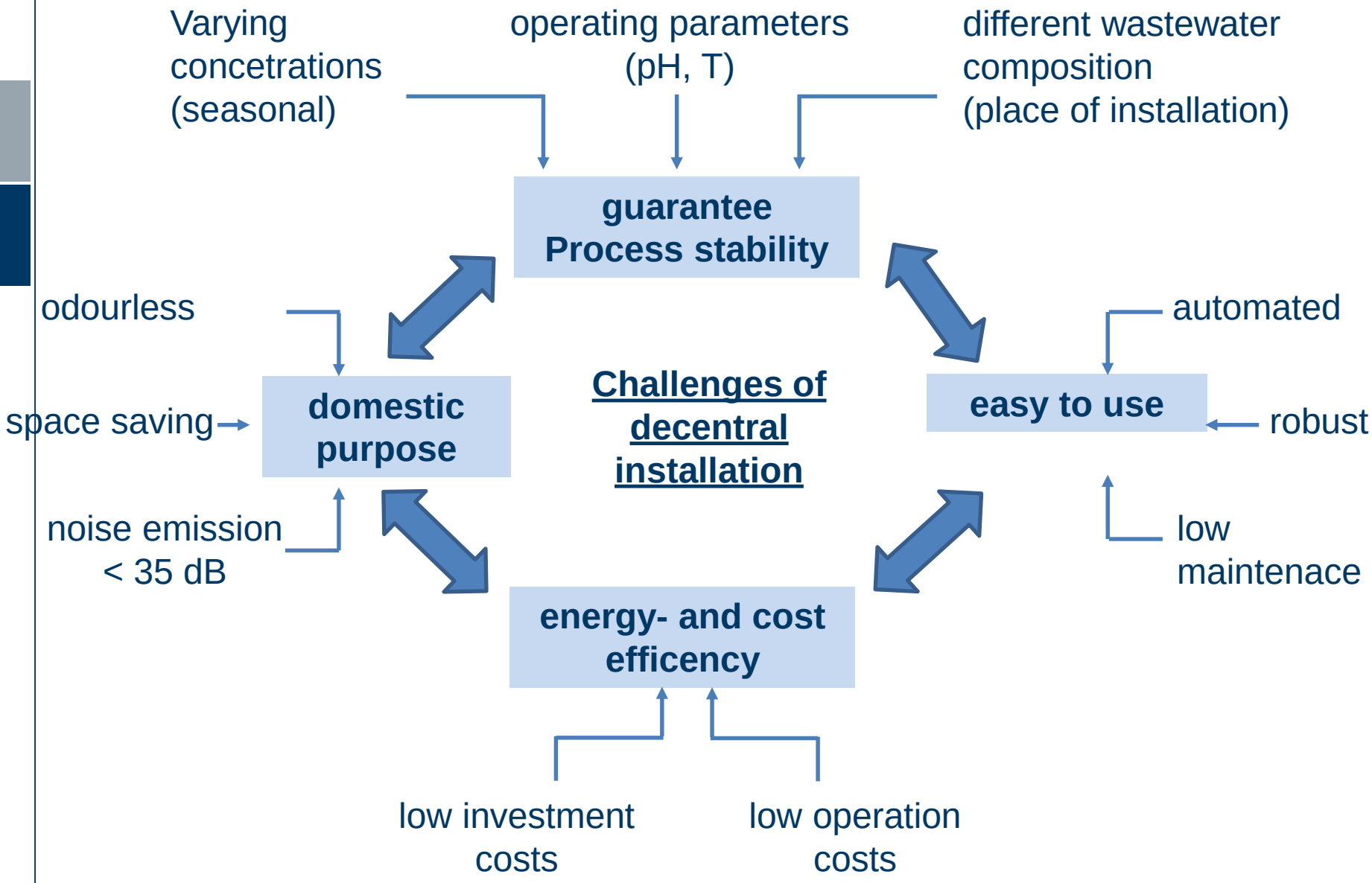
reactor 3

sand filter

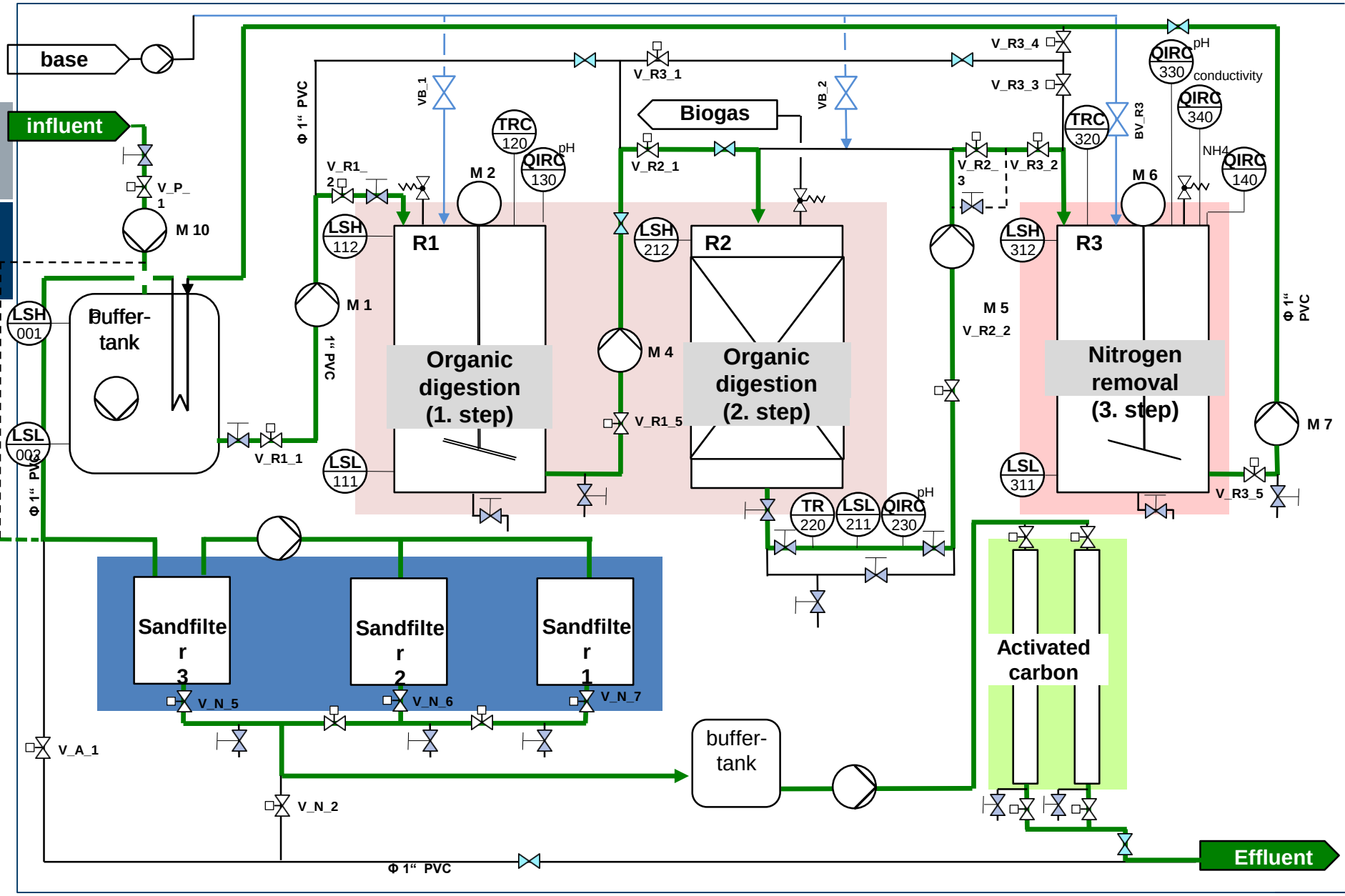
activated carbon

pre-heating → anaerobic digestion → Anammox → post-treatment

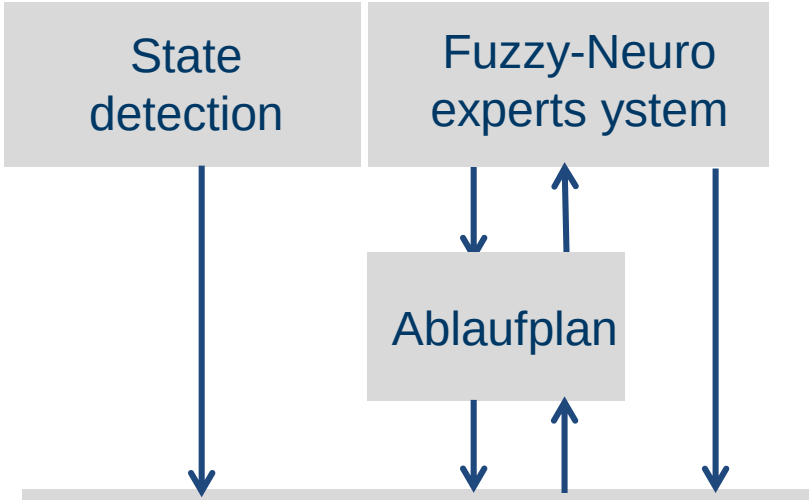
Challenges of the project



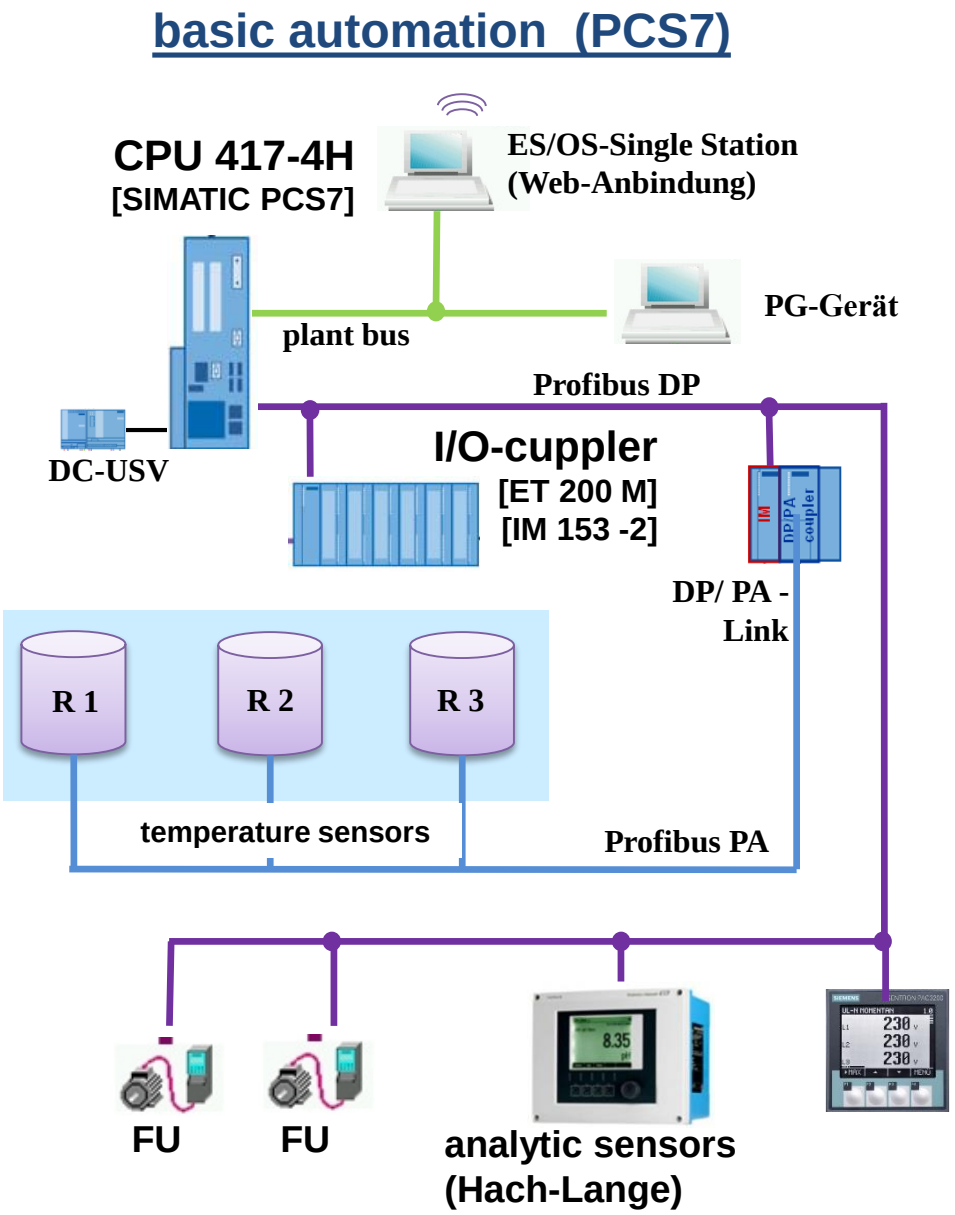
Concept of the pilot plant



Conecpt of process control



analytics	R 1	R 2	R 3
Online:			
Temperature	X	X	X
pH	X	X	X
conductivity			X
Offline:			
COD	X	X	X
NH4-N	X		X
TN			X



Methods for guaranteeing process stability

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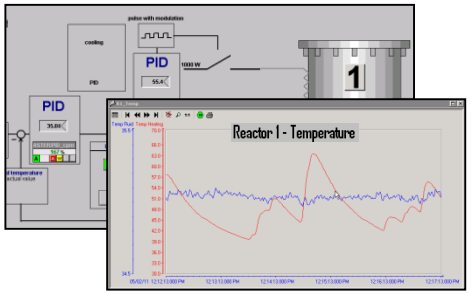
Process stability

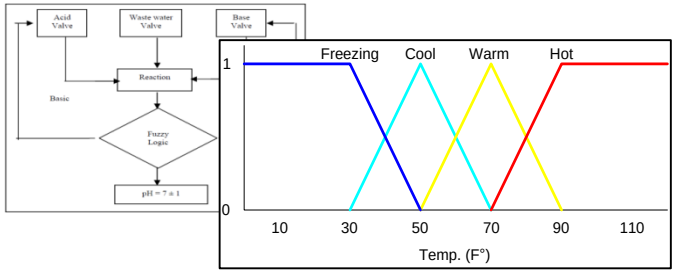
Proportional Integral Differential (PID) controller

→ For pH-control



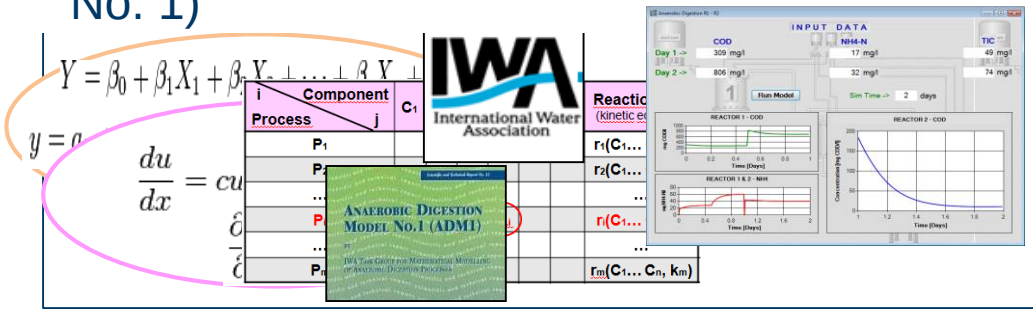
Fuzzy Logic (FL) (expert knowledge)

→ for state detection



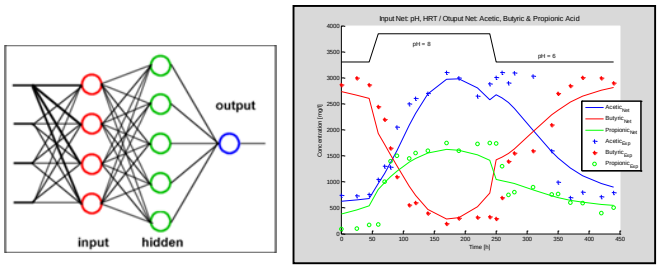
Mathematic models (differential equations)

→ Protection against overload in anaerobic digestion (Anaerobic Digestion Model No. 1)



Artificial Neuronal Nets (ANN)

→ Estimation of NH4 degradation based on ΔpH/ Δt

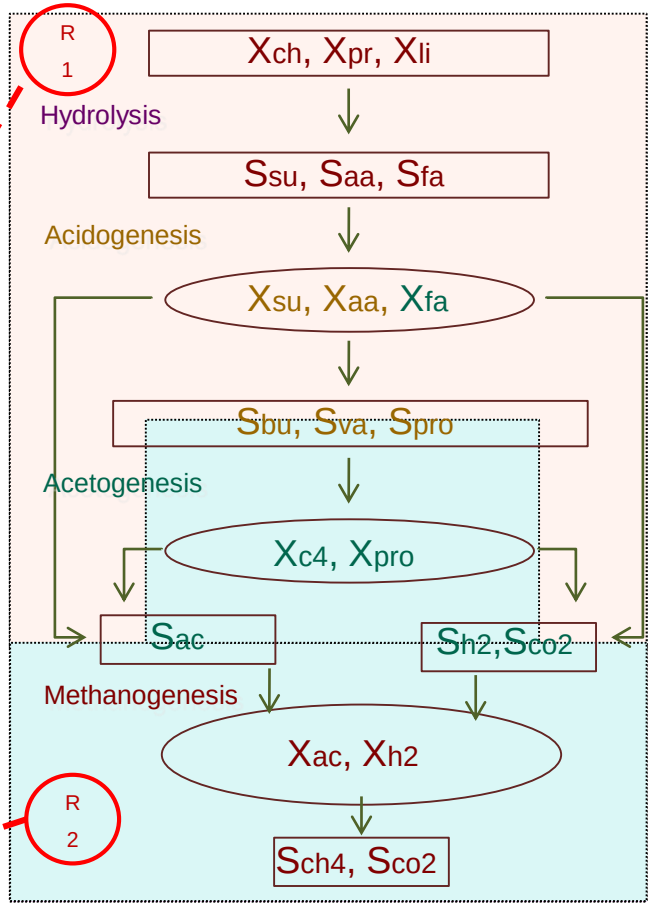


Modeling Two-stage Anaerobic Digestion

Ordinary differential equations (ODE) model:

Anaerobic Digestion Model No. 1 (ADM1)*

- Continuous stirred tank reactor configuration
- COD base unit (mg COD/L)
- 24 components: 12 soluble components ($S_i|_{i=1-12}$)
  12 particulate components ($X_i|_{i=13-24}$)
  (7 groups of microorganisms)
  - 19 biochemical processes
  - 5 physico-chemical processes
  - 4 inhibition functions



Plant specific Modifications:

- **Two-stage system**
  (hydrolysis + acidogenesis → R1
  acetogenesis + methanogenesis → R2)
- **Batch operation** with different reactors (mass balance + initial condition equations)

* Batstone, D.J., Keller, J., Angelidaki, I., Kalyuzhnyi, S.V., Pavlostathis, S.G., Rozzi, A., Sanders, W.T.M., Siegrist, H. and Vavilin, V.A. (2002). Anaerobic digestion model no. 1. Scientific and Technical Report No. 13, IWA Publishing, London.

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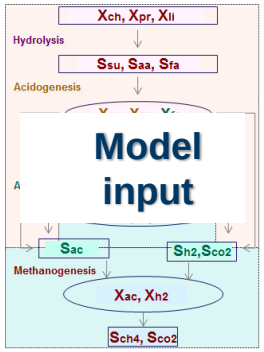
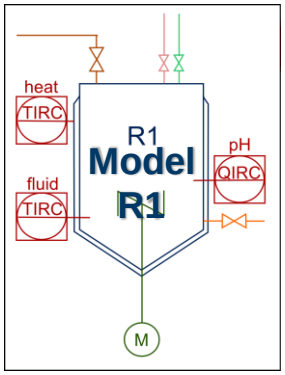
Transformation method for domestic wastewater

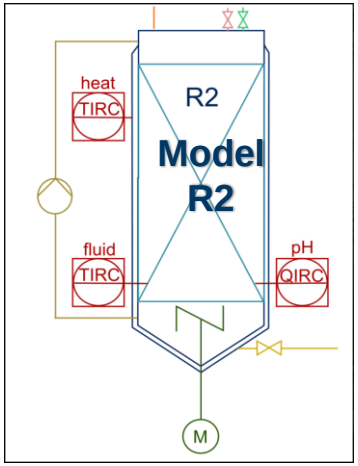
Chemical measurements:

1) COD → $^{*}0.5X_{ch} + 0.4X_{pr} + 0.1X_{li}$
2) TIC† → S_{HCO3}
3) TAN‡ → S_{NH4}

†Total inorganic carbon ‡Total ammonia-nitrogen



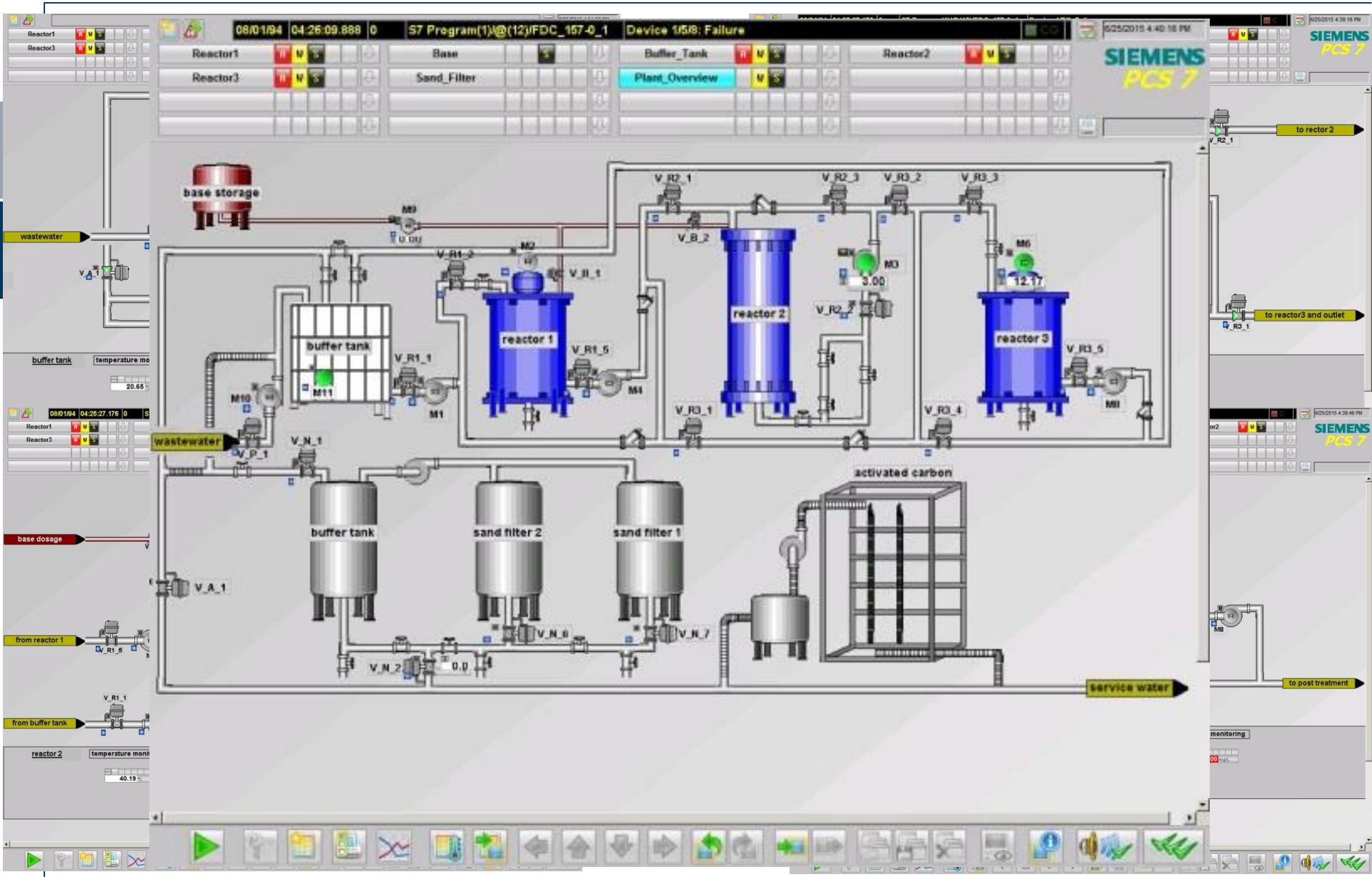




Model calibration/validation: Total COD

* Schlegel, H.G. and Fuchs, G. (2007). General Microbiology (Allgemeine Mikrobiologie), Eigth Edition. Georg Thieme Verlag, Stuttgart. P. 625.

Easy to use


08/01/94 04:26:09.888 0 S7 Program(1)\@(12)\FDC_157-0_1 Device 1/5/8: Failure
Reactor1
Reactor3
Base
Sand_Filter
Buffer_Tank
Plant_Overview
Reactor2
SIEMENS PCS 7
base storage
wastewater
buffer tank
reactor 1
reactor 2
reactor 3
activated carbon
sand filter 2
sand filter 1
service water
to rector 2
to reactor3 and outlet
to post treatment
base dosage
from reactor 1
from buffer tank
temperature mo
temperature monit
monitoring

Economic feasability study

	20 PE plant	200 PE plant
capacity	730 m³/ a	7.300 m³/ a
useful life	30 Jahre	30 Jahre
required rate of return	7 %	7 %
fixed costs	7.251 €/ a	8.967 €/ a
investment costs	103.185 €	128.300 €
amortisation costs	3.439 €/ a	4.277 €/ a
operating costs	200 €/ a	200 €/ a
average interest	3.611 €/ a	4.491 €/ a
variable costs	6.733 €/ a	24.511 €/ a
total average costs	13.983 €/ a	33.478 €/ a
wastewater costs	19,16 €/ m³	4,59 €/ m³

Wastewater costs of central wastewater treatment in Germany

Middle Franconia: 2,25 €/ m³

Brandenburg: 3,35 € /m³