NYHETSBREV

# Prof. Skogestad er vår internasjonale kybernetiker

Han har sitt daglige virke ved Institutt for kjemisk prosessteknologi, men setter kybernetiske spor også globalt.



Godt grep om destillasjonstårn: Regulering av kolonner har gått som en rød tråd gjennom Sigurds profesjonelle liv.

# Process systems group

**Sigurd Skogestad**

Trondheim, 18 Oct. 2024

- About myself
- About the group

"The goal of my research is to develop simple yet rigorous methods to solve problems of engineering significance"

Chemical Engineering

**Sigurd Skogestad** Professor

*Department of Chemical Engineering, Norwegian University of Science and Technology (NTNU), N7491 Trondheim, Norway*

**Start here...**

- About me - CV - Powerpoint presentations - How to reach me - *Email: skoge@ntnu.no*
- Teaching: Courses - Master students - Project students
- Research: My Group - Research - Ph.D. students - Academic tree

*"The overall goal of my research is to develop simple yet rigorous methods to solve problems of engineering significance"*

*"We want to find a self-optimizing control structure where close-to-optimal operation under varying conditions is achieved with constant (or slowly varying) setpoints for the controlled variables (CVs). The aim is to move more of the burden of economic optimization from the slower time scale of the real-time optimization (RTO) layer to the faster setpoint control layer. More generally, the idea is to use the model (or sometimes data) off-line to find properties of the optimal solution suited for (simple) on-line feedback implementation"*

**"News"...**

- 27 Nov. 2023: Welcome to the SUBPRO Symposium at the Britannia Hotel in Trondheim
- Aug. 2023: Tutorial review paper on "Advanced control using decomposition and simple elements". Published in Annual reviews in Control (2023). [paper] [tutorial workshop] [slides from Advanced process control course at NTNU]
- 05 Jan. 2023: Tutorial paper on "Transformed inputs for linearization, decoupling and feedforward control" published in JPC. [paper]
- 13 June 2022: Plenary talk on "Putting optimization into the control layer using the magic of feedback control", at ESCAPE-32 conference, Toulouse, France [slides]
- 08 Dec. 2021: Plenary talk on "Nonlinear input transformations for disturbance rejection, decoupling and linearization" at Control Conference of Africa (CCA 2021), Magaliesburg, South Africa (virtual) [video and slides]
- 27 Oct. 2021: Plenary talk on "Advanced process control - A newe look at the old" at the Brazilian Chemical Engineering Conference, COBEQ 2021, Gramado, Brazil (virtual) [slides]
- 13 Oct. 2021: Plenary talk on "Advanced process control" at the Mexican Control Conference, CNCA 2021 (virtual) [video and slides]
- Nov. 2019: Sigurd receives the "Computing in chemical engineering award from the American Institute of Chemical Engineering (Orlando, 12 Nov. 2019)
- June 2019: Best paper award at ESCAPE 2019 conference in Eindhoven, The Netherlands
- July 2018: PID-paper in JPC that verifies SIMC PI-rules and gives "Improved" SIMC PID-rules for processes with time delay (taud=theta/3)
- June 2018: Video of Sigurd giving lecture at ESCAPE-2018 in Graz on how to use classical advanced control for switching between active constraints
- Feb. 2017: Youtube vidoes of Sigurd giving lectures on PID control and Plantwide control (at University of Salamanca, Spain)
- 06-08 June 2016: IFAC Symposium on Dynamics and Control of Process Systems, including Biosystems (DYCOPS-2016), Trondheim, Norway. Videos and proceedings from DYCOPS-2016
- Aug 2014: Sigurd recieves IFAC Fellow Award in Cape Town
- 2014: Overview papers on "control structure design and "economic plantwide control"
- OLD NEWS

**Books...**

- Book: S. Skogestad and I. Postlethwaite: MULTIVARIABLE FEEDBACK CONTROL-Analysis and design. Wiley (1996; 2005)
- Book: S. Skogestad: CHEMICAL AND ENERGY PROCESS ENGINEERING CRC Press (Taylor&Francis Group) (Aug. 2008)
- Bok: S. Skogestad: PROSESSTEKNIKK- Masse- og energibalanser Tapir (2000; 2003; 2009).

**More information ...**

- **Publications** from my Google scholar site
- **Download publications** from my official publication list ........ or look HERE if you want to download our most recent and upublished work
- Proceedings from conferences - some of these may be difficult to obtain elsewhere
- Process control library - We have an extensive library for which Ivar has made a nice on-line search
- Photographs that I have collected from various events (maybe you are included...)
- International conferences - updated with irregular intervals
- SUBPRO (NTNU center on subsea production and processing) [ Annual reports ] [ Internal ]
- Nordic Process Control working group - in which we participate
- 5-year Master program in Chemical and Biochemical Engineering at NTNU (MTKJ) - Sigurd Skogestad is Program Leader 2019-2025.
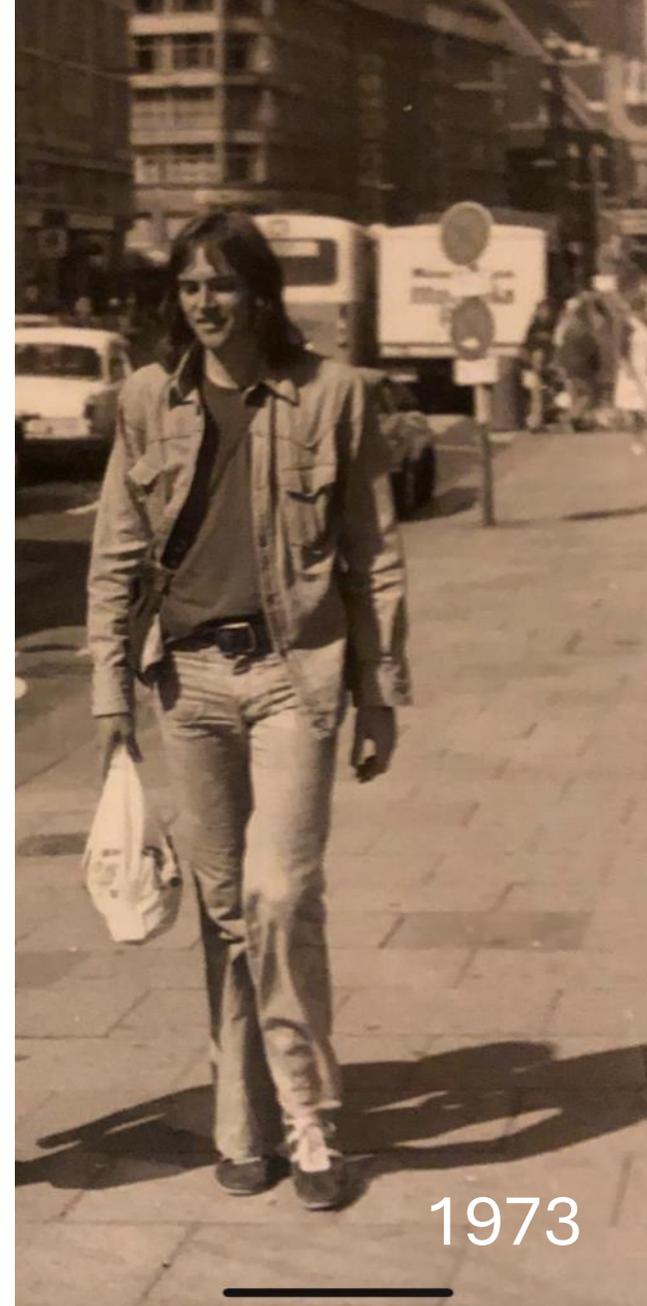
# About Sigurd Skogestad

- 1955: Born in Flekkefjord, Norway
- 1974-1978: MS (Siv.ing.) studies in chemical engineering at NTNU
- 1979: Military service (FFI)
- 1980-1983: Worked at Norsk Hydro F-senter (process simulation)
- 1983-1987: PhD student at Caltech (supervisor: Manfred Morari)
- 1987-present: Professor of chemical engineering at NTNU
- 1994-95: Visiting Professor UC Berkeley
- 2001-02: Visiting Professor UC Santa Barbara
- 1999-2009: Head of ChE Department, NTNU
- 2015-..: Director SUBPRO (Subsea research center at NTNU)

**Non-professional interests:**
- mountain skiing (cross country)
- orienteering (running around with a map)
- grouse hunting

1973

# EXPERIENCE IN NORSK HYDRO WITH CUBIC EQUATIONS OF STATE

SIGURD SKOGESTAD

Norsk Hydro, Research Centre, N3901 Porsgrunn, Norway

## ABSTRACT

The paper presents some specific applications of cubic equations of state (EOS) in Norsk Hydro and points out some aspects of such equations that one should be aware of when using them or when developing new equations. Is is emphasized that the use of EOS to calculate vapor-liquid equilibrium is inherently empirical. Activity coefficients predicted for some systems by the Soave-Redlich-Kwong (SRK) equation of state are presented. The limitations of the van Laar equation for activity coefficients which may be derived from SRK at infinite pressures does not necessarily apply at finite pressures. The shortcomings of the SRK equations of state are pointed out and suggestions are given on how to develop an extended SRK-equation.

# 1983-87: PhD student at Caltech

Supervisor: Manfred Morari

1. PID (IMC)
2. Distillation
3. Robust control



STUDIES ON ROBUST CONTROL

OF

DISTILLATION COLUMNS

*Thesis by*

Sigurd Skogestad

California Institute of Technology

Pasadena, California

1987

(Submitted January 26, 1987)

IMPLICATIONS OF INTERNAL MODEL CONTROL FOR PID CONTROLLERS

Manfred Morari
Sigurd Skogestad

Daniel F. Rivera

California Institute of Technology
Department of Chemical Engineering
Pasadena, California 91125

University of Wisconsin
Department of Chemical Engineering
Madison, Wisconsin 53706

# Internal Model Control. 4. PID Controller Design

**Daniel E. Rivera, Manfred Morari,* and Sigurd Skogestad**

*Chemical Engineering, 206-41, California Institute of Technology, Pasadena, California 91125*

For a large number of single input–single output (SISO) models typically used in the process industries, the Internal Model Control (IMC) design procedure is shown to lead to PID controllers, occasionally augmented with a first-order lag. These PID controllers have as their only tuning parameter the closed-loop time constant or, equivalently, the closed-loop bandwidth. On-line adjustments are therefore much simpler than for general PID controllers. As a special case, PI- and PID-tuning rules for systems modeled by a first-order lag with dead time are derived analytically. The superiority of these rules in terms of both closed-loop performance and robustness is demonstrated.
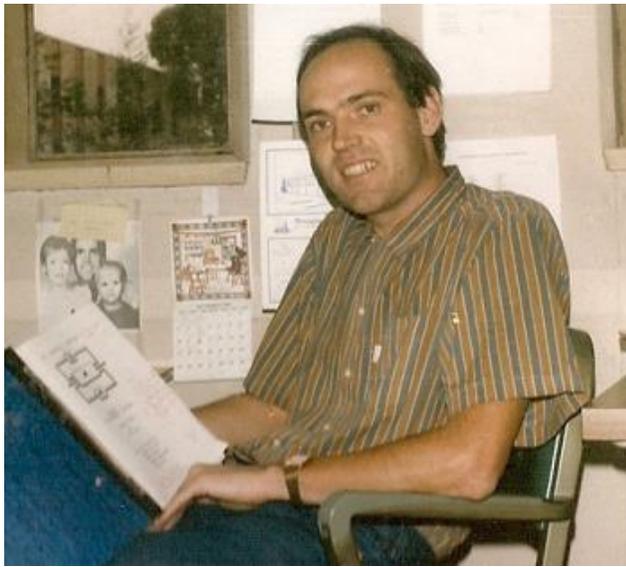
**Sigurd at Caltech (1984)**

How we design a control system for a complete chemical plant?

- Where do we start?
- What should we control? and why?
- etc.
- etc.

# Economic Plantwide Control of the Ethyl Benzene Process

**Rahul Jagtap, Ashok S Pathak, and Nitin Kaistha**

Dept. of Chemical Engineering, Indian Institute of Technology Kanpur, Kanpur 208016, Uttar Pradesh, India

A1: Benzene
A2: Ethylene
B: Ethylbenzene (product)
C: Diethylbenzene (undersired, recycled to extinction)

$A1 + A2 \rightarrow B$
$B + A2 \rightarrow C$
$C + A1 \rightarrow 2B$
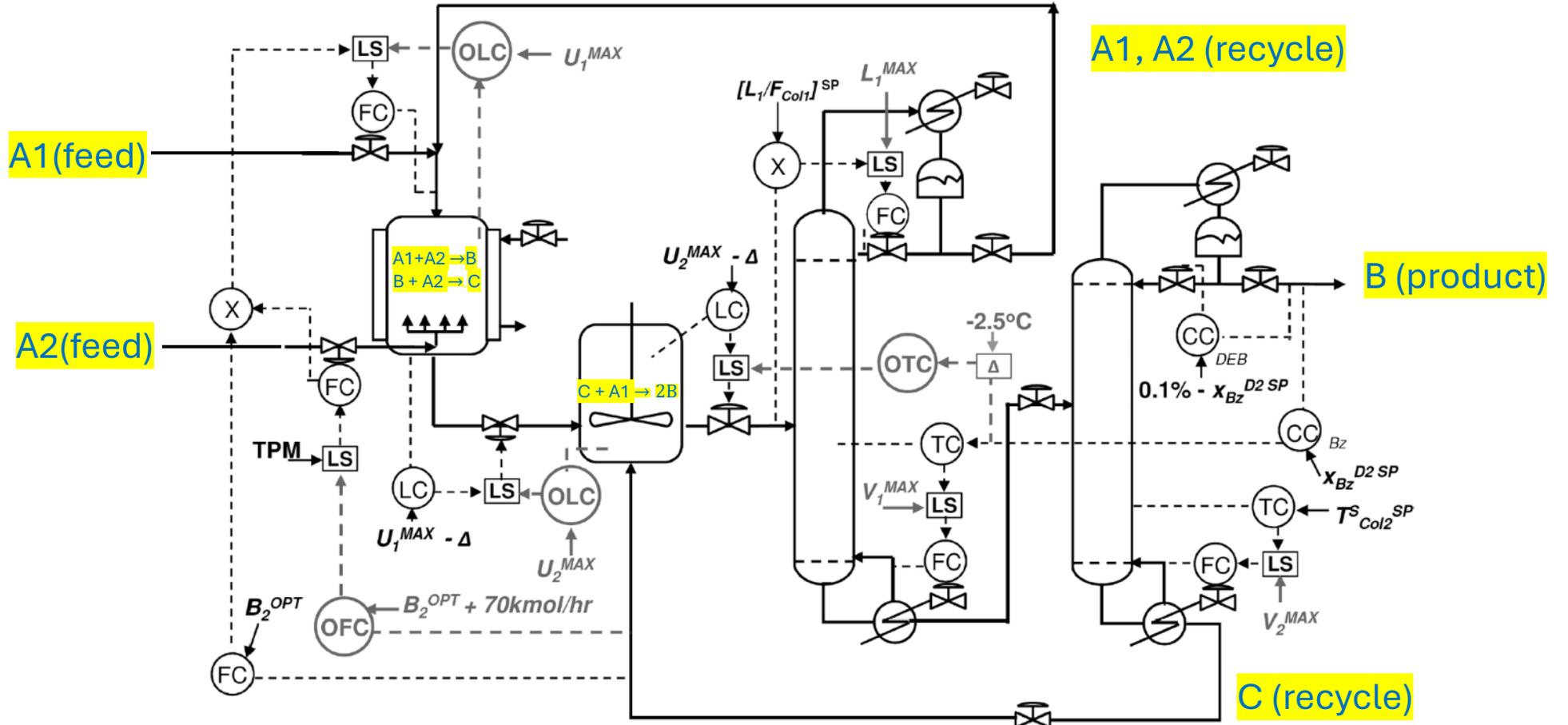


Figure 7. CS2 with overrides for handling equipment capacity constraints.

# Control system structure*

Alan Foss ("Critique of chemical process control theory", AIChE Journal,1973):

*The central issue to be resolved ... is the determination of control system structure*:
**Which variables should be measured, which inputs should be manipulated and which links should be made between the two sets?**



*Current terminology: Control system architecture

# Since 1987: Professor at NTNU

# Robust control



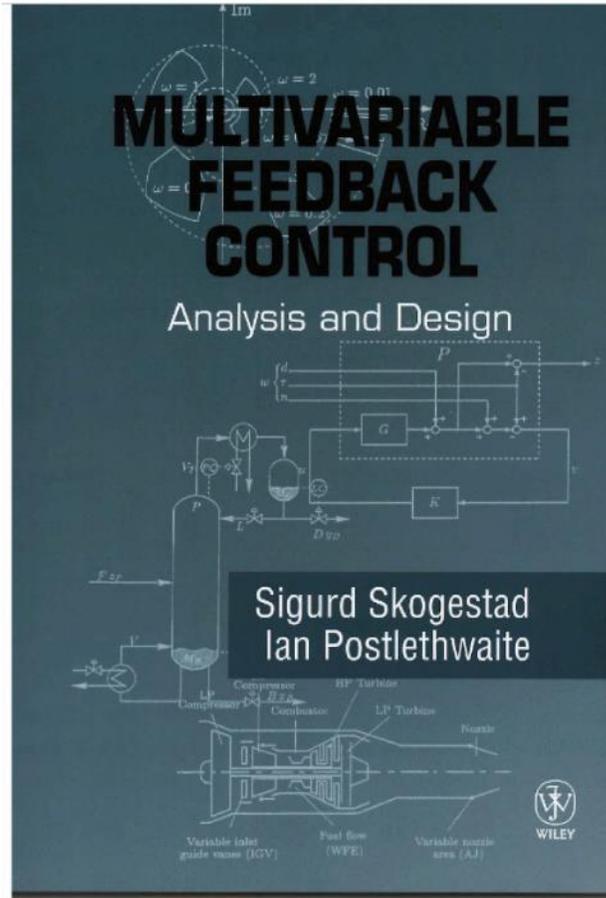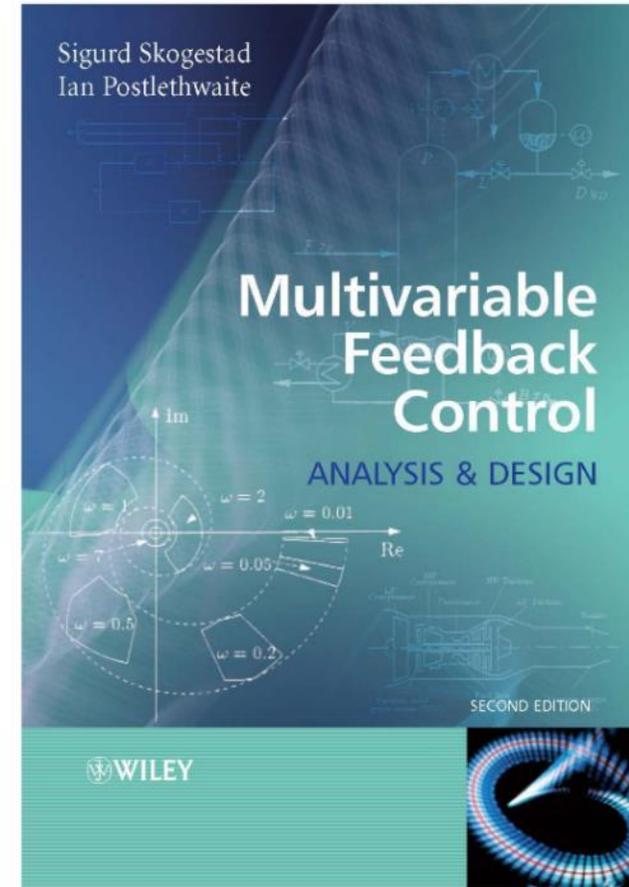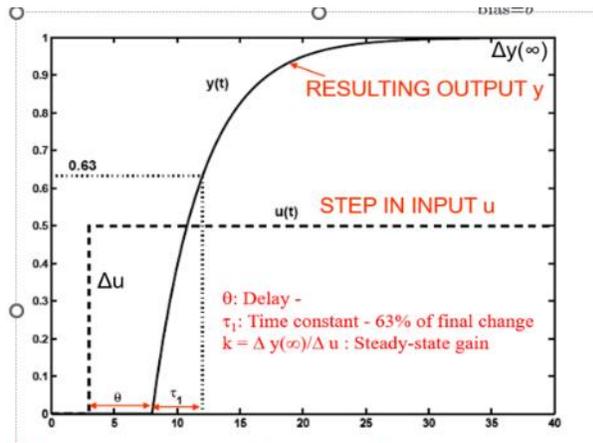Berkeley, Dec. 1994



1996



2005

# SIMC PID tuning rule (2001,2003)



$$g(s) = \frac{k}{(\tau_1 s + 1)(\tau_2 s + 1)} e^{-\theta s}$$

$$K_c = \frac{1}{k} \frac{\tau_1}{\tau_c + \theta}$$

$$\tau_I = \min\{\tau_1, 4(\tau_c + \theta)\}$$

$$\tau_D = \tau_2$$

Tuning parameter:

$$\tau_c \geq \theta$$

$$= \lambda$$

[19] S. Skogestad, Probably the best simple PID tuning rules in the world. AIChE Annual Meeting, Reno, Nevada, November 2001

## Simple analytic rules for model reduction and PID controller tuning☆

Sigurd Skogestad*

Department of Chemical Engineering, Norwegian University of Science and Technology, N-7491 Trondheim, Norway

**Abstract**

The aim of this paper is to present analytic rules for PID controller tuning that are simple and still result in good closed-loop behavior. The starting point has been the IMC-PID tuning rules that have achieved widespread industrial acceptance. The rule for the integral term has been modified to improve disturbance rejection for integrating processes. Furthermore, rather than deriving separate rules for each transfer function model, there is a just a single tuning rule for a first-order or second-order time delay model. Simple analytic rules for model reduction are presented to obtain a model in this form, including the "half rule" for obtaining the effective time delay.

# Distillation
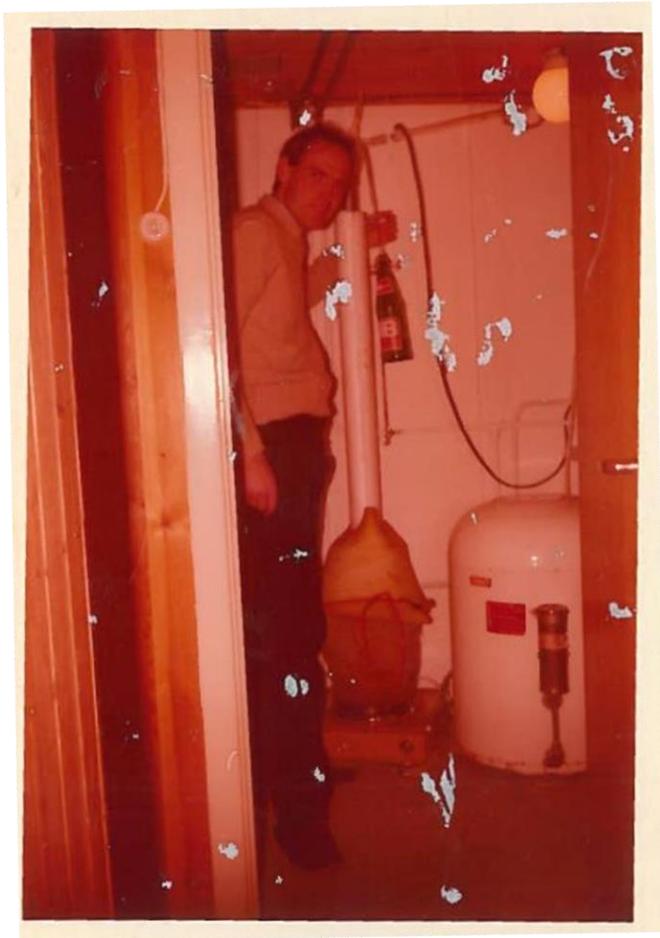


At home doing moonshine distillation (1979)

# THE DOS AND DON'TS OF DISTILLATION COLUMN CONTROL

S. Skogestad*

**Department of Chemical Engineering, Norwegian University of Science and Technology, Trondheim, Norway.**

**Abstract:** The paper discusses distillation column control within the general framework of plant-wide control. In addition, it aims at providing simple recommendations to assist the engineer in designing control systems for distillation columns. The standard LV-configuration for level control combined with a fast temperature loop is recommended for most columns.

# Chemical Engineering
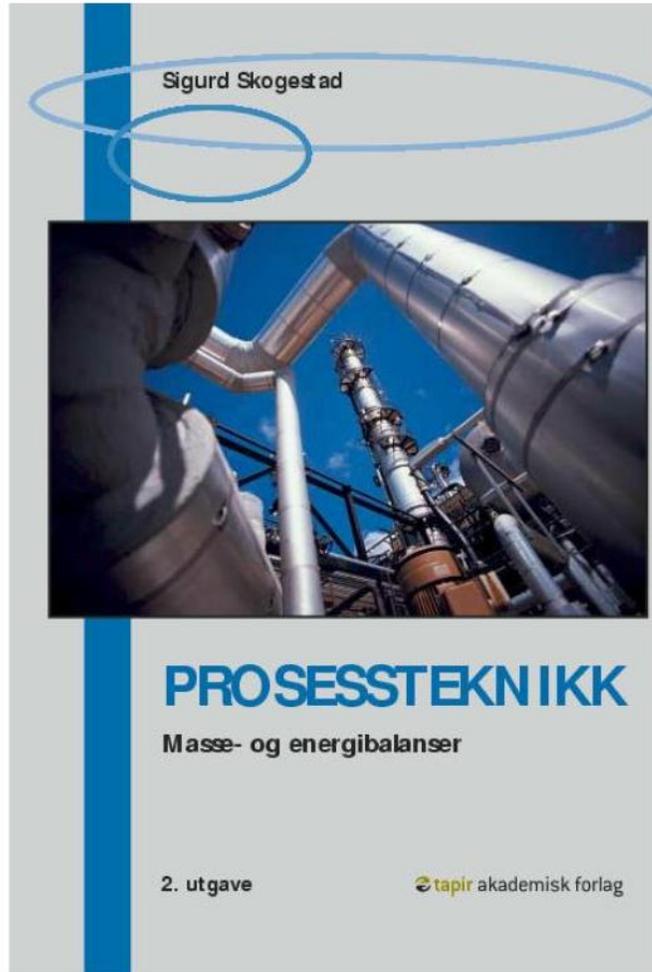


2000, 2003, 2009



2000
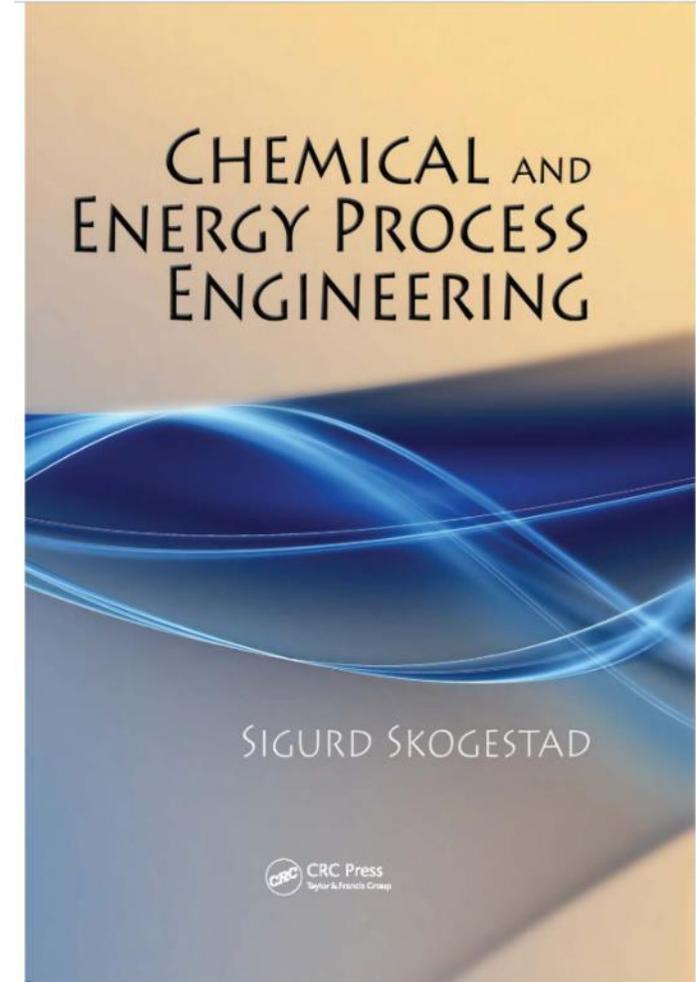


2009

# My main theme: **Use the Magic of feedback**

- **Why use feedback control (data-based) rather than feedforward control (model-based) ?**

- **Reduce uncertainty and change dynamics**

  - The three main process control inventions:
    - Integral action
    - Cascade control
    - Ratio control
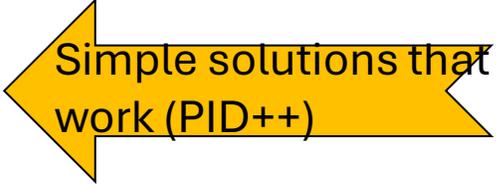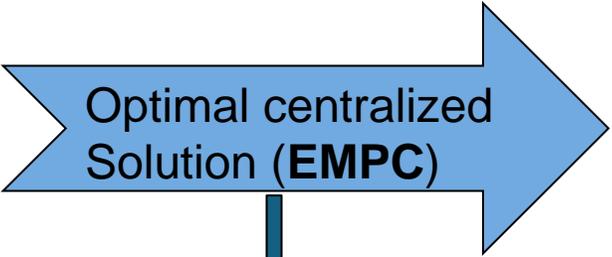
# PSE Group at NTNU

# Chemical Engineering and Process Systems Engineering
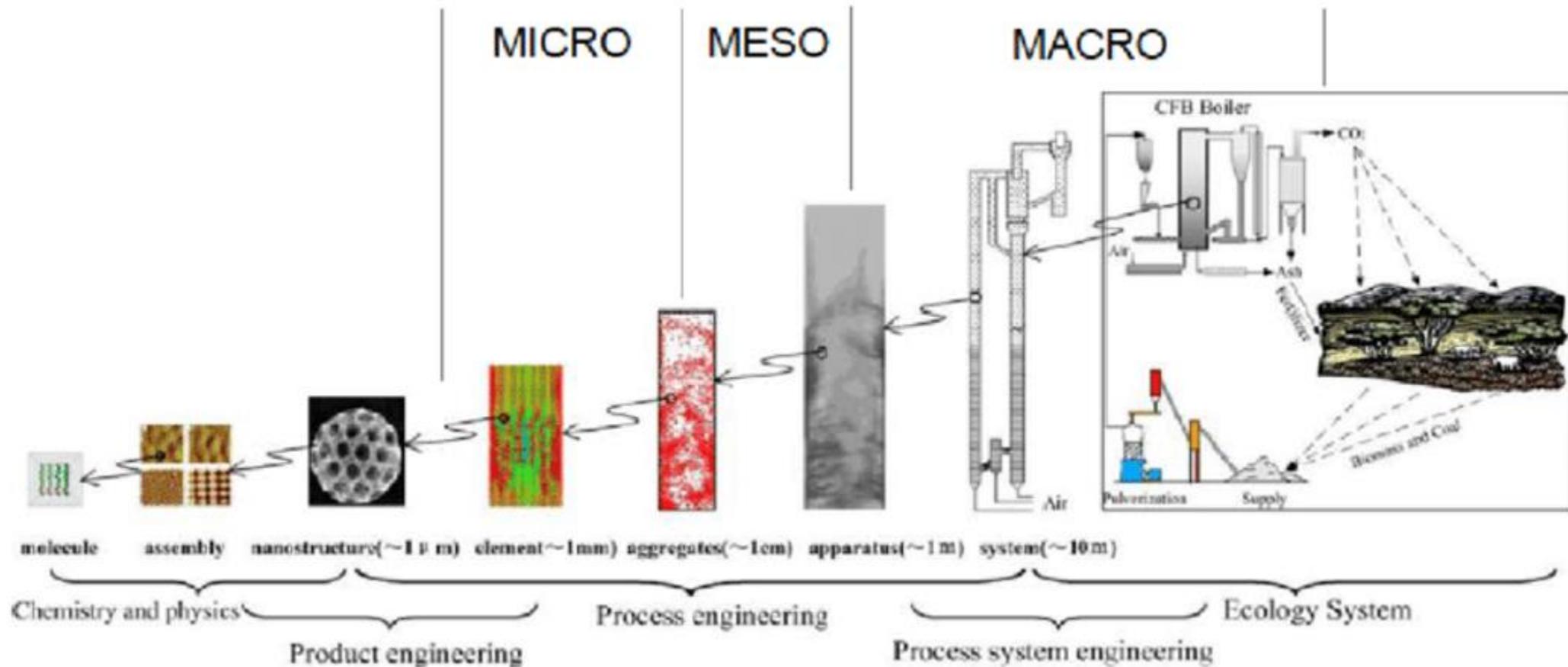


Main areas PSE:
- Process modelling and simulation
- Process design/synthesis
- Process control
- Process optimization
- Process AI

# PSE group at NTNU. History until 1999



- Odd Andreas Asbjørnsen (dosent 1963, Professor 1970-1975)
  - Siv.ing. Mechanical Engineering, Dr.Tech. 1962
  - Started teaching process control for our students in 1955 (with Terjesen)
  - Visiting Professor Alan Foss, UC Berkeley (1969-70)
  - Arild Nybraathen (siv.ing. 1967, not mentioned in 50-year history)
    - Teaching process control in 1977
    - Wrote a nice booklet on process control

- Terje Hertzberg (dosent 1977, Professor 1985-2007)
  - Siv.ing. 1963, dr.ing. 1975,

- Sigurd Skogestad (Professor oil & gas 1987)
  - Siv,ing. 1978, PhD Caltech 1987

- Kristian Lien (1.am. 1987. Professor 1991-1999)
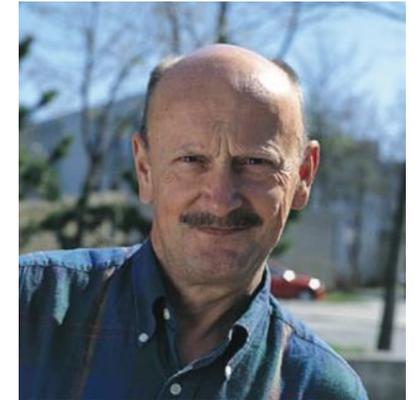
# 1999

**Systems Group members at the beginning of 1999**

Academic staff

- Professor Sigurd Skogestad
- Professor Terje Hertzberg
- Professor II Kristian Lien (Energos)

 PhD-students (the first 8 working with Sigurd, the last with Terje) (year of graduation in parenthesis):

- Ivar Halvorsen (2001)
- Audun Faanes (2003),
- Katrine Hilmen (2000)
- Pål Flatby (discontinued)
- Marius Govatsmark  (2003)
- Truls Larsson  (2000)
- Tore Lid (2007)
- Bernd Wittgens (1999)
- Ingvild Løvik (2001)

In addition, three external members were invited to the weekly group meetings:

- Petter Lundström (Sintef)
- Thor Mejdell (Sintef)
- Professor Morten Hovd (Cybernetics NTNU)

# PSE Academic/Teaching staff 2000-2024

- Terje Hertzberg (Professor 1977-2007; Prof. Emer. to 2016)
- Sigurd Skogestad (Professor 1987)
- Tore Haug-Warberg, (1.am. Thermodynamics 2002; 2017 to Env & Reactor Group)
- Heinz Preisig (Professor (2003-2021, Professor Researcher since 2021)
- Nadav Bar (1.am. Systems Biology 2008,  Professor 2017)
- Johannes Jäschke (1.am. 2014,  Professor 2022)
- Idelfonso Nogueira (1.am. 2022)
- Krister Forsman, Perstorp (Professor II 2012)
- Ivar Halvorsen, SINTEF  (Professor II 2017)

**Associated PSE Professors**
- Magne Hillestad, Professor from 2007 (Environmental & Reactor Group)
- Truls Gundersen, Professor at Energy and Process Engineering from 1996 to 2023.
- Thomas A.  Adams, Professor at Energy and Process Engineering from 2022.

# 57 Graduated PhD students in Systems Group since 1998

| | | |
|---|---|---|
| 1998 | Christiansen, Atle C, | |
| | Havre, Kjetil | |
| 1999 | Hauan, Steinar | Lien* |
| | Wittgens, Bernd | |
| 2000 | Larsson, Truls | |
| | Hilmen, Eva Katrine | |
| 2001 | Halvorsen, Ivar J. | |
| | Løvik, Ingvild | Hertzberg |
| 2003 | Govatsmark, Marius S. | |
| | Faanes, Audun | |
| 2004 | Engelien, Hilde | |
| | Skouras, Stathis | |
| 2005 | Alstad, Vidar | |
| | Storkaas, Espen | |
| 2006 | Siepmann, Volker | Haug-Warberg |
| 2007 | Araujo, Antonio B. | |
| | Lid, Tore | |
| | Zenith, Federico | |
| 2008 | Jensen, Jørgen B. | |
| | Sivertsen. Heidi | |
| | Løvfall, Bjørn Tore | Haug-Warberg |
| 2009 | Bergheim (Aske), Elvira | |
| | Linhart, Andreas | |
| 2010 | Dones, Ivan | Preisig |
| | Manum, Henrik | |
| | Berglihn, Olaf | Haug-Warberg |
| 2011 | Strandberg, Jens Petter | |
| | Jäschke, Johannes | |
| | Jacobsen, Magnus G. | |
| | Panahi, Mehdi | |

| | | |
|---|---|---|
| 2012 | Yelchuru, Ramprasad | |
| 2013 | Dwivedi, Deeptanshu | |
| | Jahanshahi, Esmaeil | |
| 2014 | Ghadrdan, Maryam | |
| 2015 | Doni Jayavelu, Naresh | Bar |
| 2016 | de Oliveira, Vinicius | |
| | Skancke, Jørgen | Bar |
| 2018 | Straus, Julian | |
| | Grimholt, Chriss | |
| | Das, Tamal | Jäschke |
| 2019 | Krishnamoorthy, Dinesh | |
| | Birgen, Cansu | Preisig |
| | Reyes-Lua, Adriana | |
| | Verheyleweghen, Adriaen | Jäschke |
| | Bikmukhametov, Timur | Jäschke |
| 2021 | Thombre,Mandar | Jäschke |
| | Lira Parada, Pedro | Bar |
| 2022 | Nikparvar, Bahareh | Bar |
| 2023 | Zotica, Cristina | |
| | Tuveri, Andrea | Bar |
| | Dos Santos, Allyne | |
| 2024 | Adhau, Saket | |
| | Turan, Evren | Jäschke |
| | Krog, Halvor | Jäschke |
| | Bernardino, Lucas | |
| | Mdoe, Zawadi | Jäschke |
| | Dirza, Risvan | |

*Supervisor is Skogestad unnless stated

# 57 Graduated PhD students in Systems Group since 1998

| Year | Name | Supervisor |
|------|------|------------|
| 1998 | Christiansen, Atle C, | |
| | Havre, Kjetil | |
| 1999 | Hauan, Steinar | Lien* |
| | Wittgens, Bernd | |
| 2000 | Larsson, Truls | |
| | Hilmen, Eva Katrine | |
| 2001 | Halvorsen, Ivar J. | |
| | Løvik, Ingvild | Hertzberg |
| 2003 | Govatsmark, Marius S. | |
| | Faanes, Audun | |
| 2004 | Engelien, Hilde | |
| | Skouras, Stathis | |
| 2005 | Alstad, Vidar | |
| | Storkaas, Espen | |
| 2006 | Siepmann, Volker | Haug-Warberg |
| 2007 | Araujo, Antonio B. | |
| | Lid, Tore | |
| | Zenith, Federico | |
| 2008 | Jensen, Jørgen B. | |
| | Sivertsen. Heidi | |
| | Løvfall, Bjørn Tore | Haug-Warberg |
| 2009 | Bergheim (Aske), Elvira | |
| | Linhart, Andreas | |
| 2010 | Dones, Ivan | Preisig |
| | Manum, Henrik | |
| | Berglihn, Olaf | Haug-Warberg |
| 2011 | Strandberg, Jens Petter | |
| | Jäschke, Johannes | |
| | Jacobsen, Magnus G. | |
| | Panahi, Mehdi | |

| Year | Name | Supervisor |
|------|------|------------|
| 2012 | Yelchuru, Ramprasad | |
| 2013 | Dwivedi, Deeptanshu | |
| | Jahanshahi, Esmaeil | |
| 2014 | Ghadrdan, Maryam | |
| 2015 | Doni Jayavelu, Naresh | Bar |
| 2016 | de Oliveira, Vinicius | |
| | Skancke, Jørgen | Bar |
| 2018 | Straus, Julian | |
| | Grimholt, Chriss | |
| | Das, Tamal | Jäschke |
| 2019 | Krishnamoorthy, Dinesh | |
| | Birgen, Cansu | Preisig |
| | Reyes-Lua, Adriana | |
| | Verheyleweghen, Adriaen | Jäschke |
| | Bikmukhametov, Timur | Jäschke |
| 2021 | Thombre, Mandar | Jäschke |
| | Lira Parada, Pedro | Bar |
| 2022 | Nikparvar, Bahareh | Bar |
| 2023 | Zotica, Cristina | |
| | Tuveri, Andrea | Bar |
| | Dos Santos, Allyne | |
| 2024 | Adhau, Saket | |
| | Turan, Evren | Jäschke |
| | Krog, Halvor | Jäschke |
| | Bernardino, Lucas | |
| | Mdoe, Zawadi | Jäschke |
| | Dirza, Risvan | |

11 female (19.3 %)

*Supervisor is Skogestad unless stated

# Academic offspring since 1980 (Professors)

- Truls Gundersen (1982). NTNU
- Bjørn Kvamme (1984). Un. Bergen
- Magne Hillestad (1986). NTNU
- Elling Jacobsen (1991). KTH, Sweden
- Morten Hovd (1992). Cybernetics NTNU
- Eva Sørensen (1994). University College London
- Antonio Araujo Brandao (2007). Campina Grande, Brazil
- Johannes Jäschke (2011). IKP NTNU
- Mehdi Panahi (2011). Mashhad, Iran
- Dinesh Krishnamoorthy Kallur (2019). Eindhoven (NTNU from May 2025)

# Current System group members (Oct. 2024)

- **Nadav Bar, Professor**
  - Giacomo Sartori, PhD Candidate
  - Vitor Neves, PhD Candidate
  - Lipe Carmel, PhD Candidate
  - Chinmay Patwardhan, PhD Candidate
  - Yiwen Li, PhD Candidate
  - Fabienne Roessler, PhD Candidate
  - + 2 Master students

- **Idelfonso Nogueira, Associate Professor**
  - Carine Rebello, PhD Candidate
  - Erbet Costa, PhD Candidate
  - Vinicius Santana, Postdoc
  - Patrick Lima, PhD Candidate
  - Bruno Rodrigues, PhD Candidate
  - Robson Pessoa, PhD Candidate
  - Igor Iwakiri, PhD Candidate
  - Luis Oliveira, PhD Candidate (Un. Porto)
  - Luana Queiroz, PhD Candidate (double degree Un. Porto)
  - Fernando Lima, PhD Candidate (double degree UFRJ, Rio)
  - Gustavo Caldas, PhD Candidate (double degree UFRJ, Rio)

  + 12 Master students

- **Johannes Jäschke, Professor**
  - Simen Bjorvand, PhD Candidate
  - Jonas Fraihat, PhD Candidate
  - Lucas Cammann, PhD Candidate
  - Rafael de Oliveira, Postdoc
  - Marius Fredriksen, PhD Candidate
  - Eden Ngowi, PhD Candidate
  - Archand Kumaraswamy, PhD Candidate
  - + 2 Master students

- **Heinz Preisig, Professor**
  - Alberto Rodriguez Fernandez, Researcher
  - Robert Pujan, PhD student

- **Sigurd Skogestad, Professor**
  - David Perez Pineira, PhD Candidate
  - Enrico Pizzi, Visiting PhD candidate from DTU

  + 3 Master students

- **Krister Forsman, Professor 2**
- **Ivar Halvorsen, Professor 2**

- **Christopher Sørmo, Head Engineer**
- **Pål Aune, Project Coordinator**

# Current research interests

# Sigurd Skogestad



- Control architecture (plantwide control)
- Self-optimizing control
- Stabilization of fluid flow
- Moving optimization into the control layer
- Advanced control using standard elements
- Wastewater treatment, including fish farming

Conclusion: **Use the Magic of feedback**
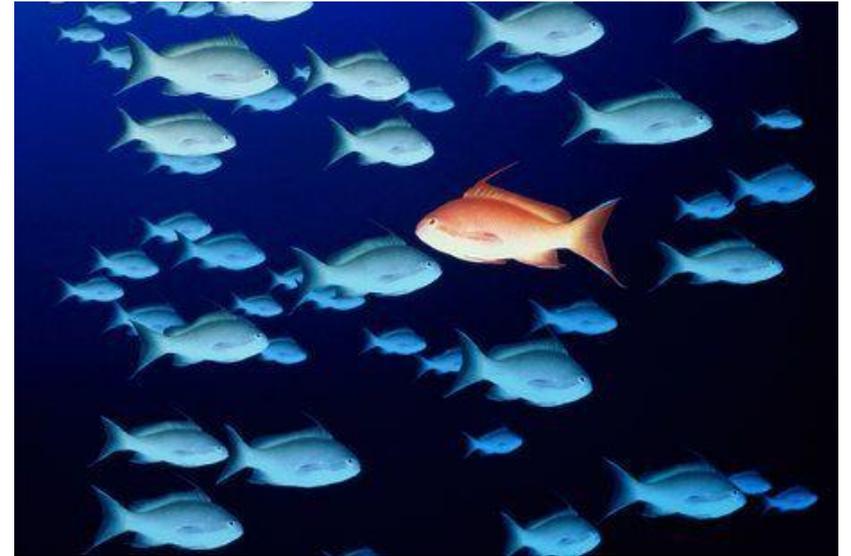
# Heinz Preisig

Activities:

- Digitalisation / knowledge graphs

- Fundamental process modelling

- Integrated bio processes

- Fuel cells

Projects:

- DigiPass — a CSA project for the European Commission on digital passports for material-related products

- VIPCOAT — anti-corrosion paints with Airbus and AkzoNobel as the main industrial partners

- NanoLodge — an Indian-Norwegian project with NFR on integrated bioprocesses combining membrane separation with fermentation and esterification.

- Mediate — project on modelling fuel cells.

# Nadav Bar



Head of the Microbial Feedback Control (MFC) laboratory,

- Microbial bioprocessing technology

- Optimal control of bioprocesses

- Estimation theory

- Dynamic and adaptive modeling of microbial processes

- Automation, algorithms and electronics of biotechnology
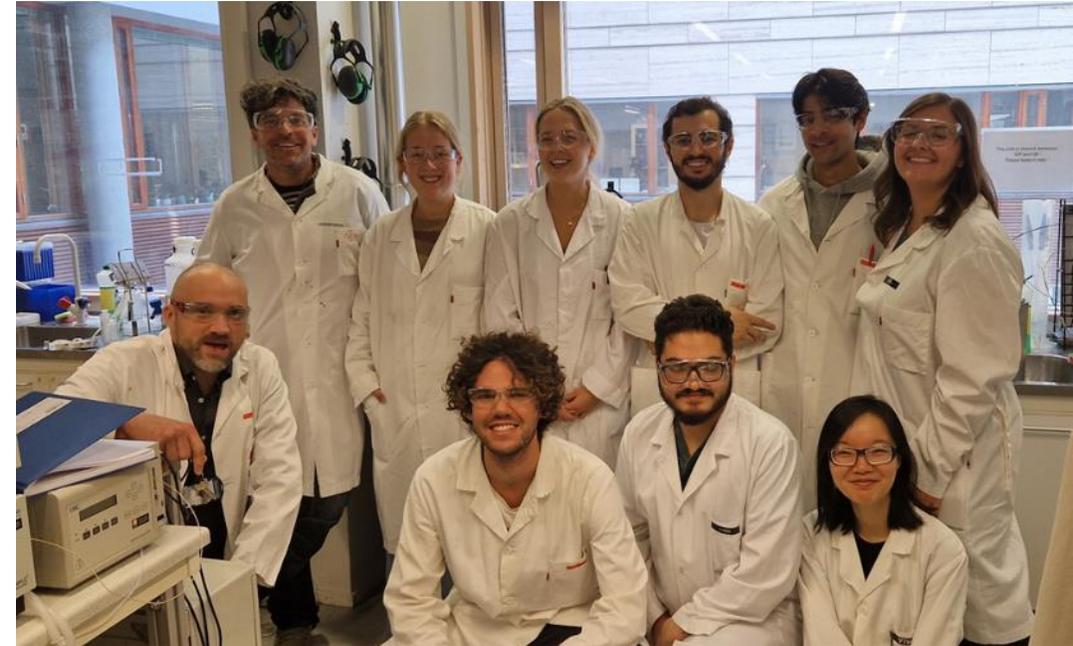
# Johannes Jäschke

- Model Predictive Control
- Estimation of unmeasured variables (soft-sensing, virtual measurements)
- Optimal operation of degrading systems
- Optimization algorithms for Systems with nonsmoothness

Applications

- Hydrocarbon production (SUBPRO Zero - Substantial Bridge Program Towards Zero Emissions).
- Green hydrogen production

Conclusion: No Magic – Just better methods for optimization, estimation and control

# Idelfonso Nogueira

- AI-Driven Process Systems Engineering
- Control & Meta-heuristic Optimization
- Domain-informed AI
- First-principles Modelling
- Sensory Engineering

Conclusion: Guiding AI/ML with purpose unlocks its potential where it truly matters.

# Thank you from the PSE group!

- We can simulate and compute everything!
  - We even do experiments when necessary

- No problem too small, no problem too large!