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”

https://folk.ntnu.no/skoge/

did v2 rockets use der... | adapti | skogestad | KLM Royal Dutch Airli... | All Bookmarks

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-optimalo 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 ...

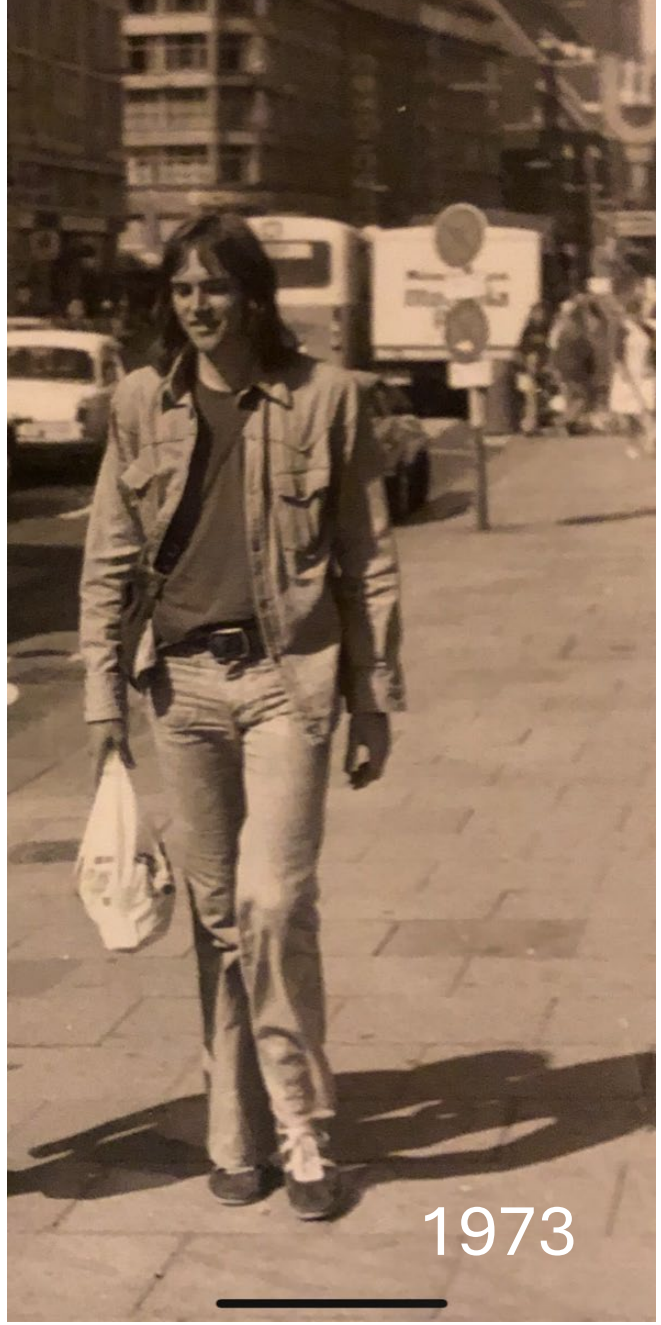
- **Publications** from my Google scholar site
- **Download publications** from my official publication list ..... or look HERE if you want to download our most recent and upublished work
- Proceedings from conferences - some of these may be difficult to obtain elsewhere
- Process control library - We 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.

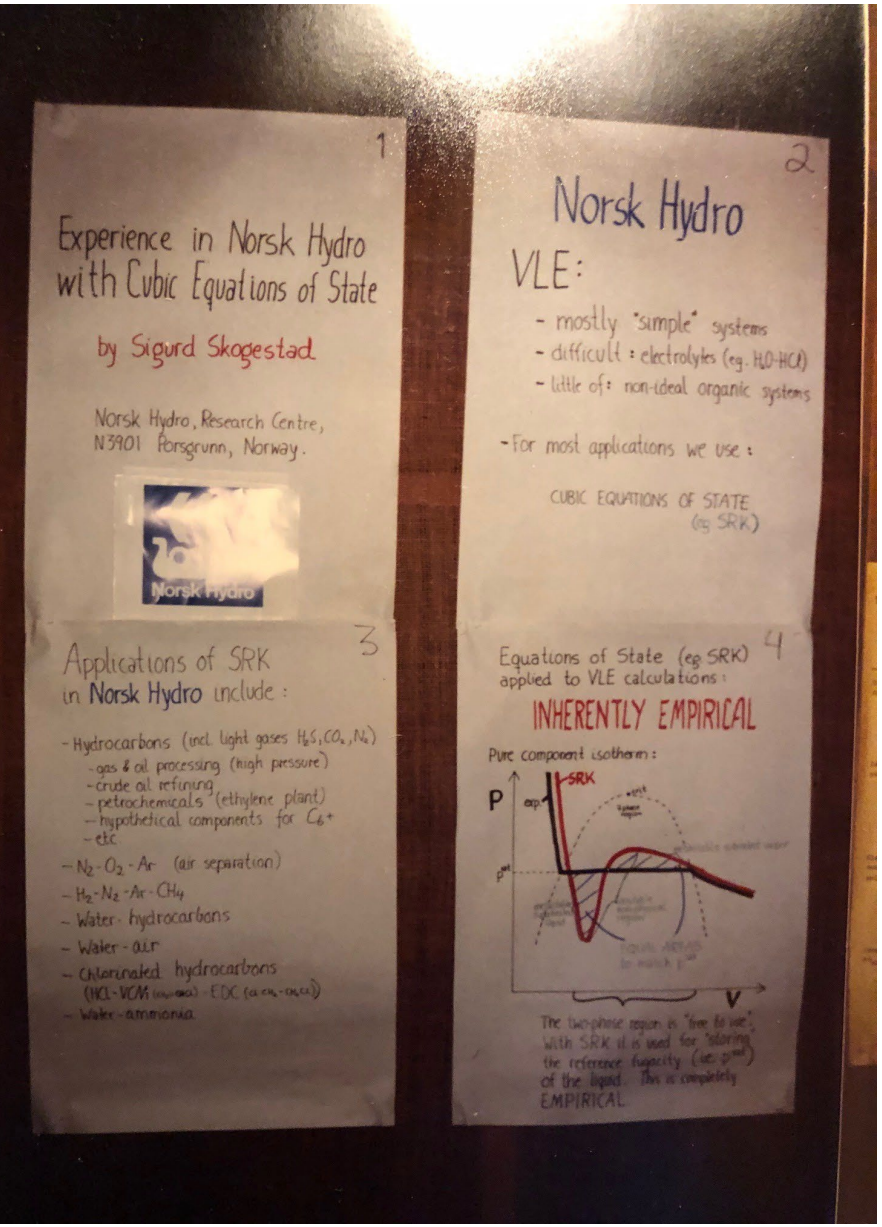
About Sigurd Skogestad

- 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**





Fluid Phase Equilibria, 13 (1983) 179—188
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

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)

AMERICAN CONTROL CONFERENCE
San Diego, California
June 6-8, 1984

IMPLICATIONS OF INTERNAL MODEL CONTROL FOR PID CONTROLLERS

Manfred Morari
Sigurd Skogestad

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

Daniel F. Rivera

University of Wisconsin
Department of Chemical Engineering
Madison, Wisconsin 53706

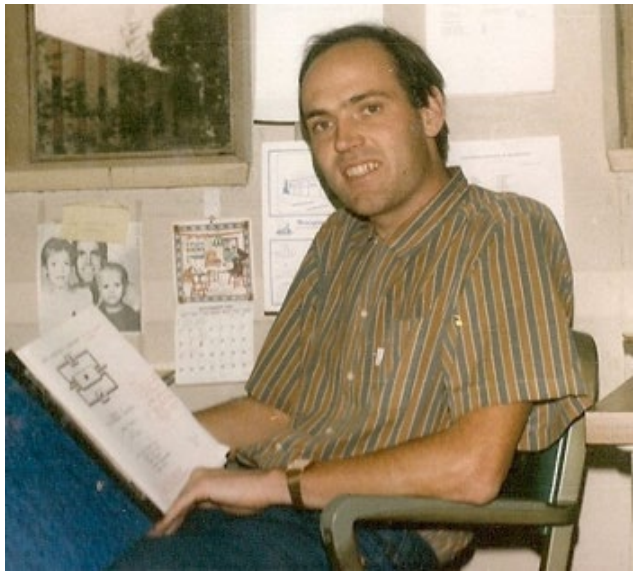
Ind. Eng. Chem. Process Des. Dev. **1986**, *25*, 252–265

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.

AIChE

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

DOI 10.1002/aic.13964
Published online December 10, 2012 in Wiley Online Library (wileyonlinelibrary.com).

A1: Benzene
A2: Ethylene
B: Ethylbenzene (product)
C: Diethylbenzene (undersired, recycled to extinction)
A1+A2 →B
B + A2 → C
C + A1 → 2B

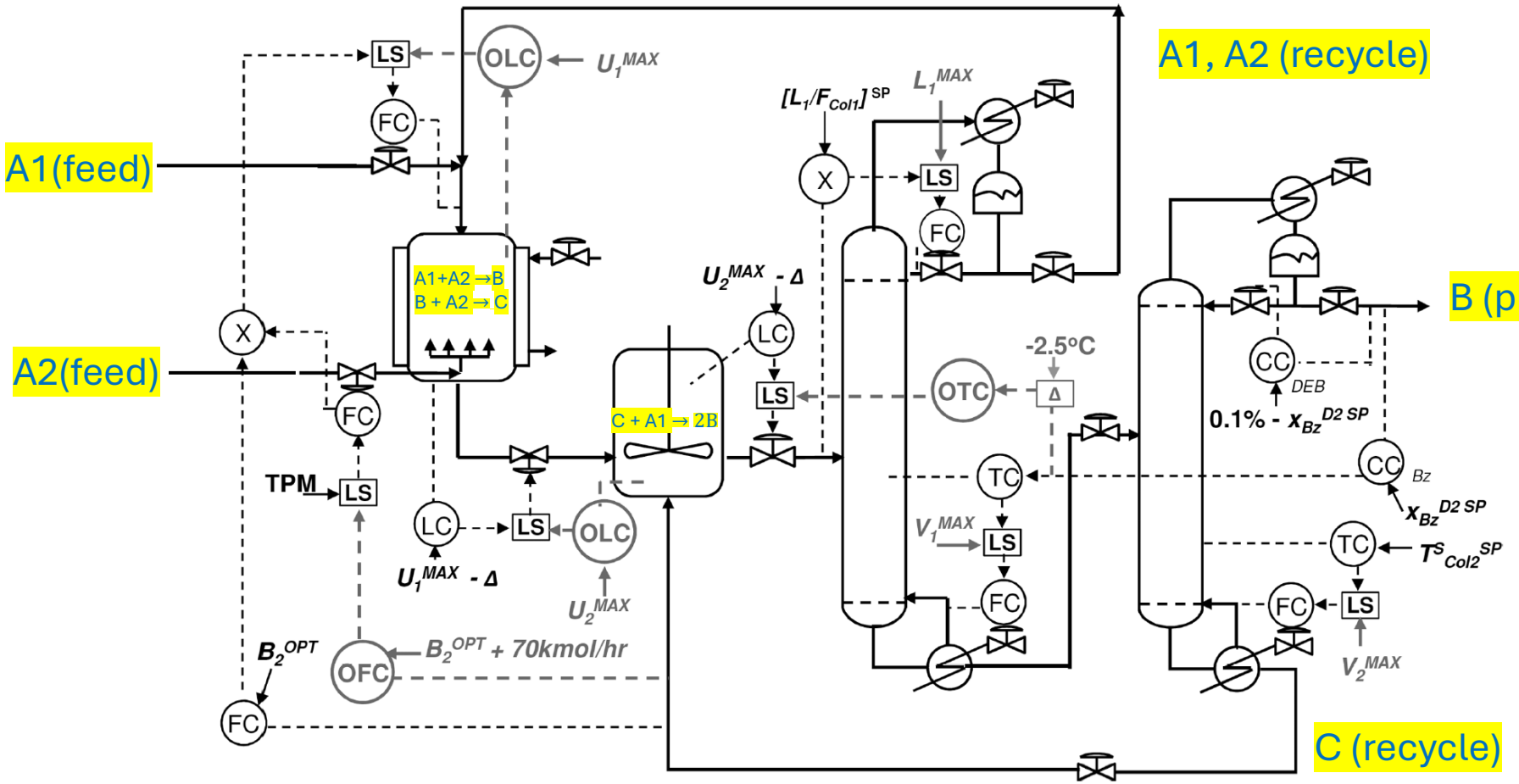


Figure 7. CS2 with overrides for handling equipment capacity constraints.

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**.

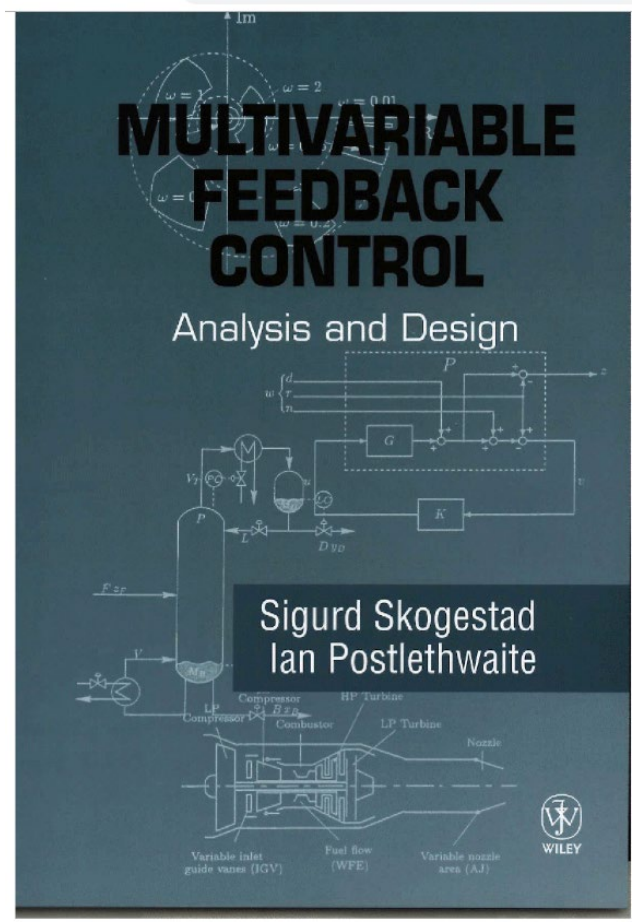
Which variables should be measured, which inputs should be manipulated and which links should be made between the two sets?

*Current terminology: Control system architecture

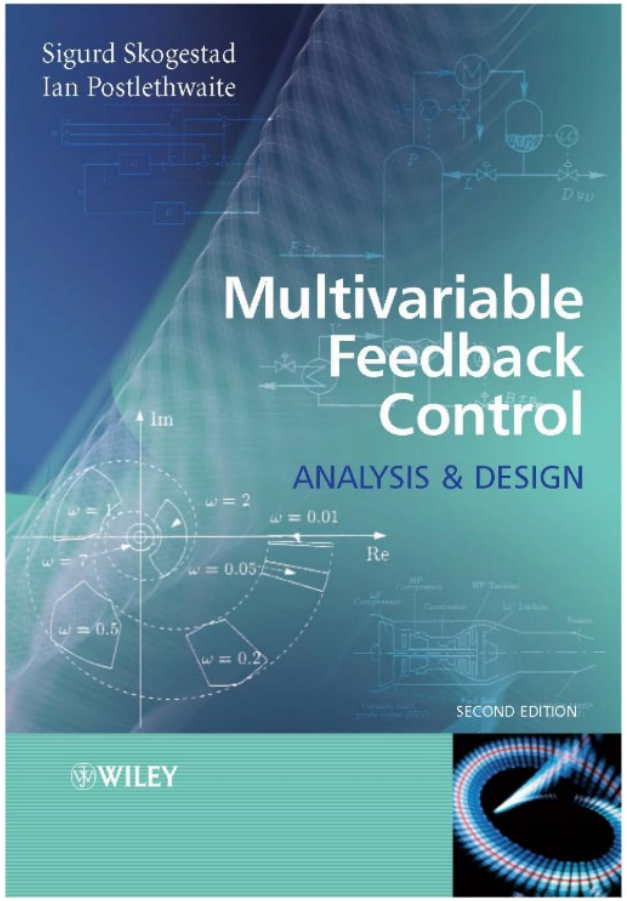
Since 1987: Professor at NTNU

Robust control

Berkeley, Dec. 1994

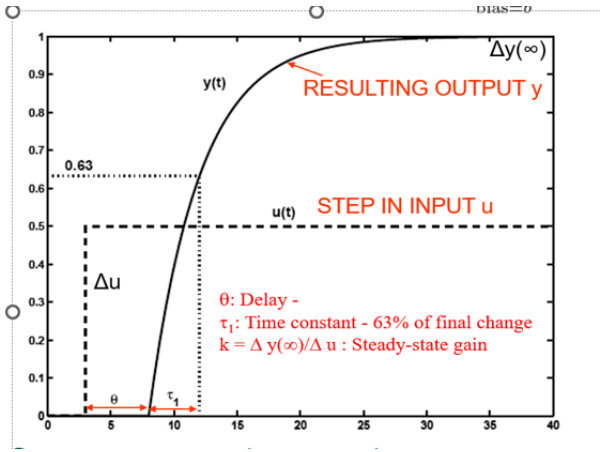


1996



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

ELSEVIER

Journal of Process Control 13 (2003) 291–309

JOURNAL OF PROCESS CONTROL

www.elsevier.com/locate/jprocont

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

Received 18 December 2001; received in revised form 25 June 2002; accepted 11 July 2002

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)

Chemical Engineering Research and Design

Trans IChemE,
Part A, January 2007

THE DOS AND DON'TS OF DISTILLATION COLUMN CONTROL

S. Skogestad*

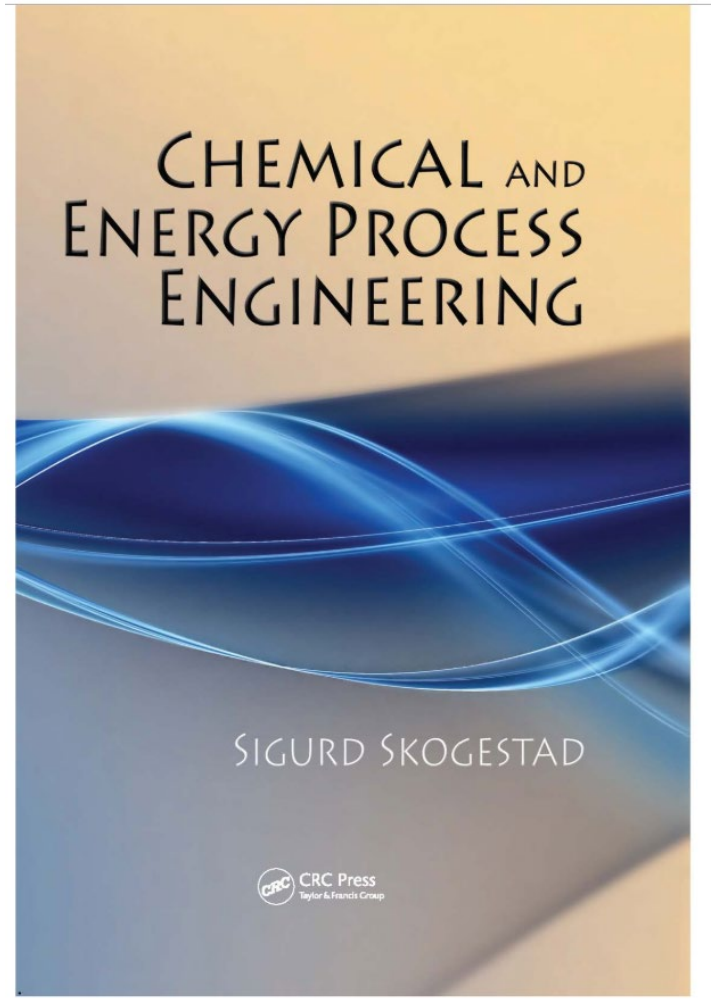
Department of Chemical Engineering, Norwegian University of Science and Technology, Trondheim, Norway.

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

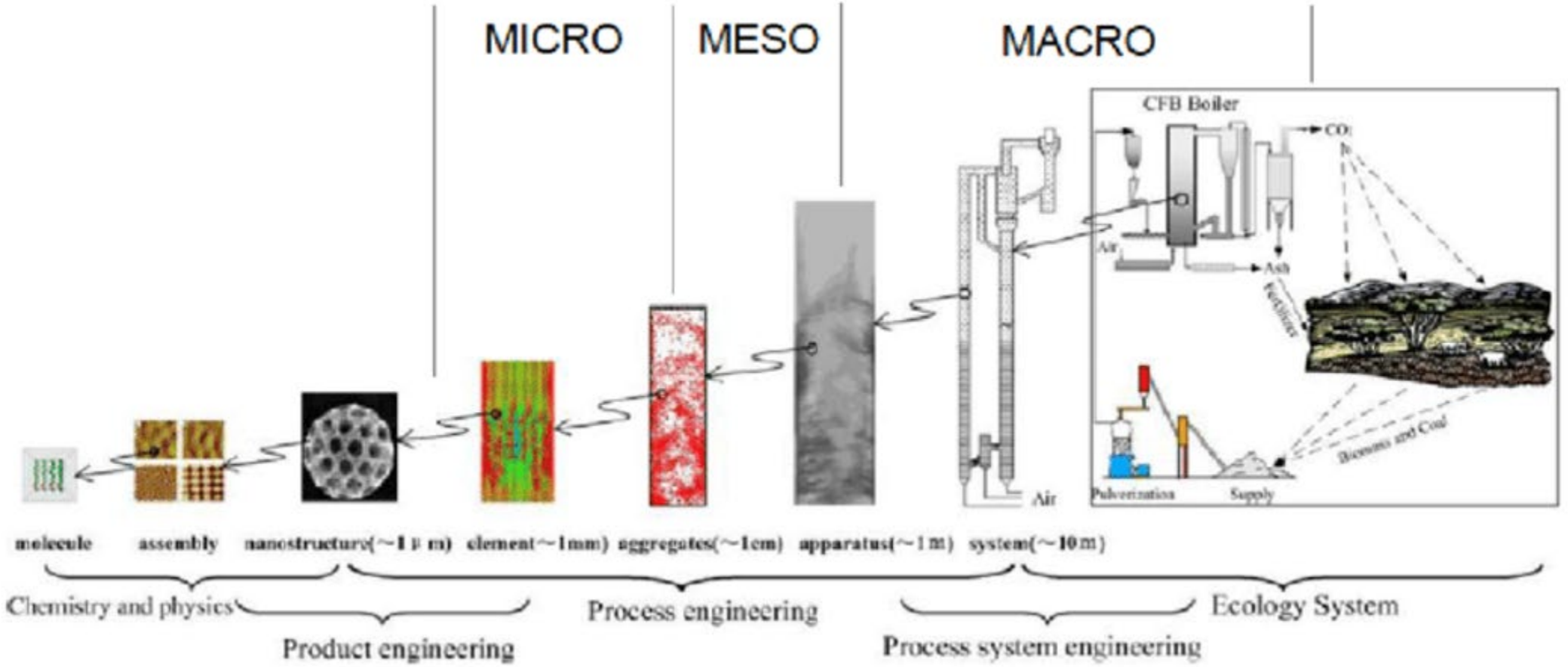
Academic process control community fish pond

Optimal centralized Solution (**EMPC**)

Simple solutions that work (PID++)

PSE Group at NTNU

Chemical Engineering and Process Systems Engineering

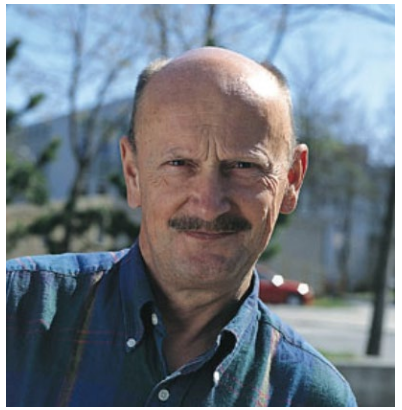


Main areas PSE:

- 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

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	

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
  - Archana 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

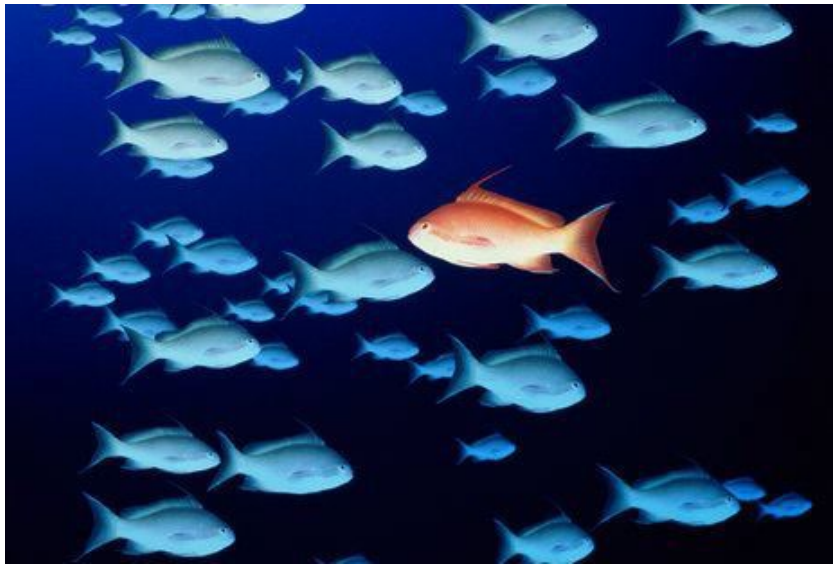
- **Krister Forsman, Professor 2**
- **Ivar Halvorsen, Professor 2**

- **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

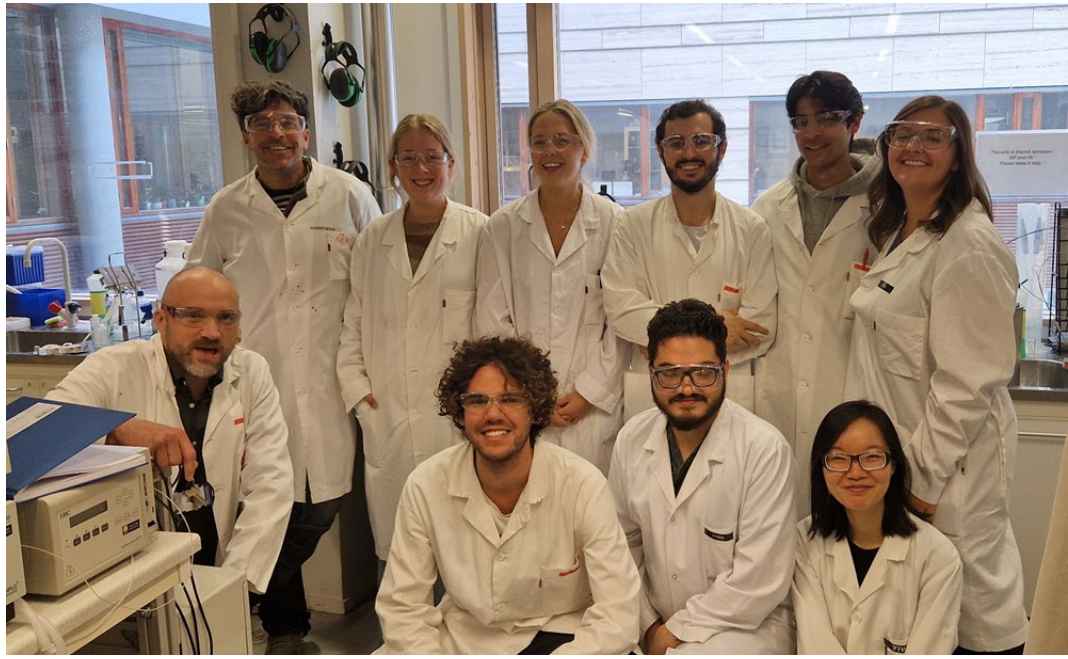
Projects:

- 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!