

Advanced **Plant-Wide** Control and Monitoring for **Offshore PWT**: Conventional Control or AI- Based Control: What We Learned...

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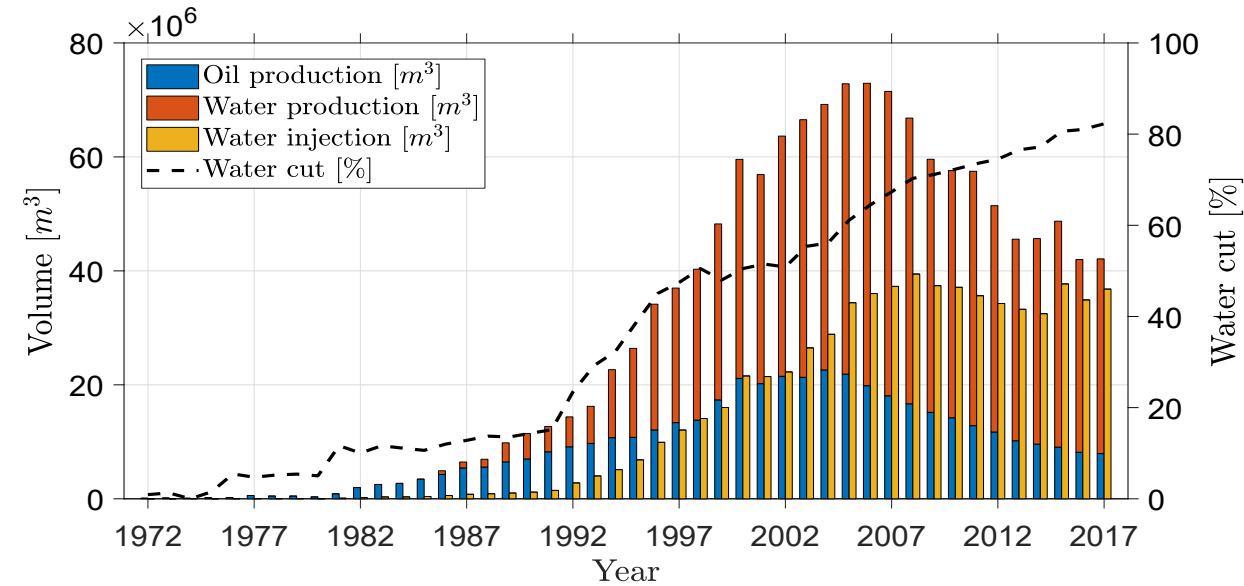
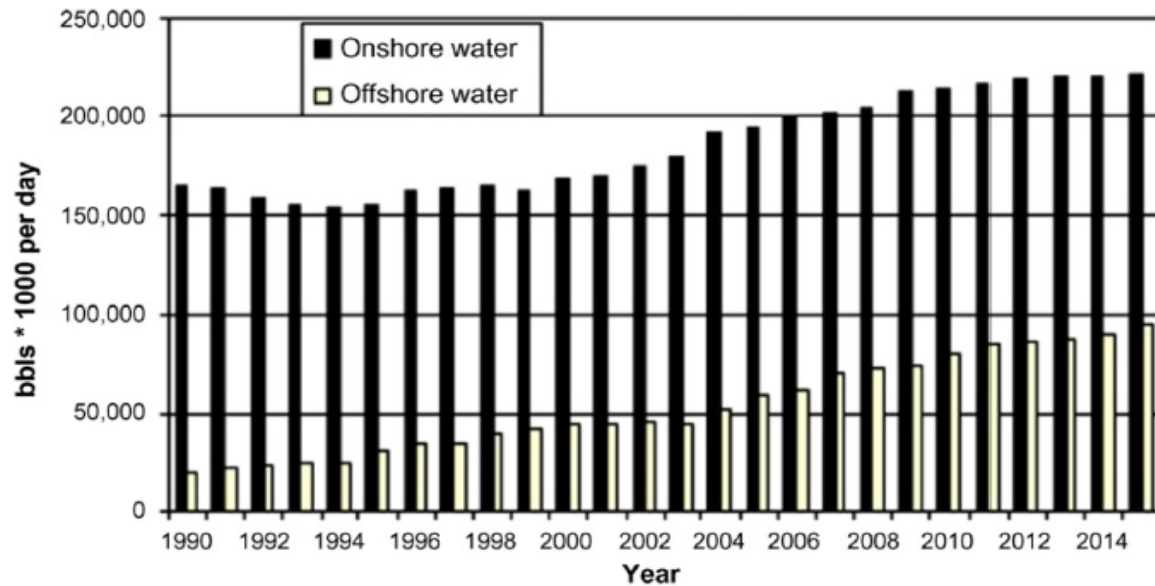


Agenda

1. Produced water challenges
2. Advanced Plant-wide control
3. Online quality monitoring
4. Quality-based Control
5. Reflections & cooperation

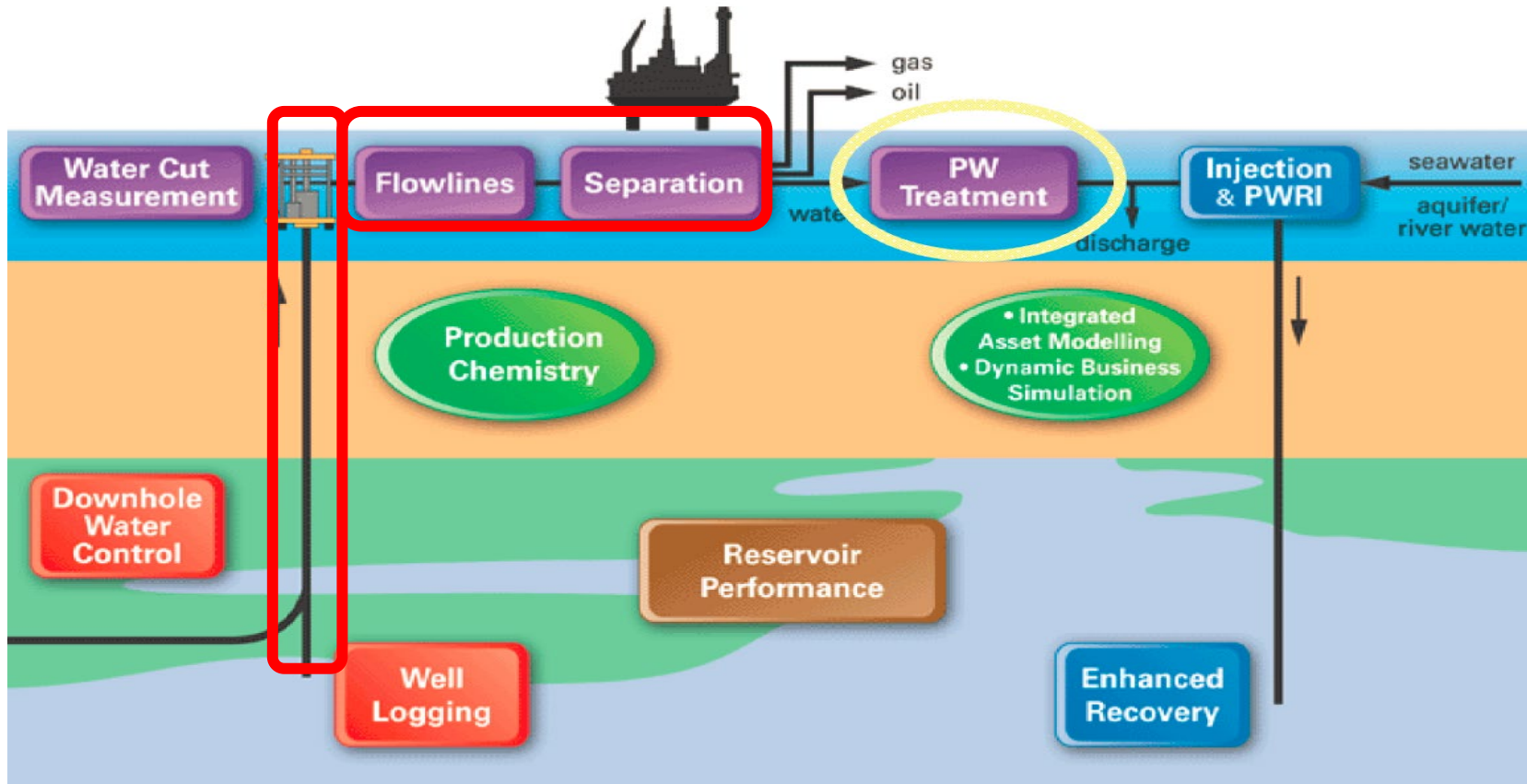


Produced Water (PW)

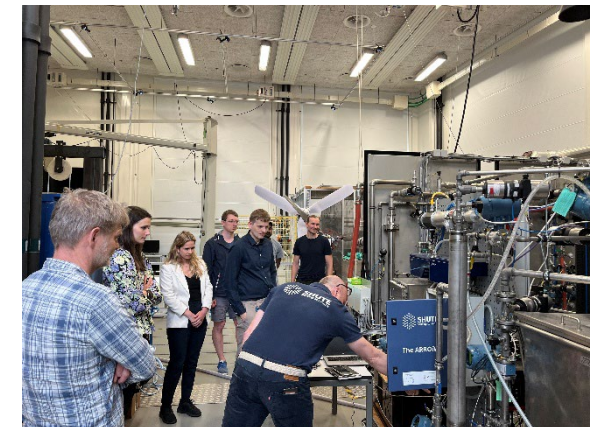
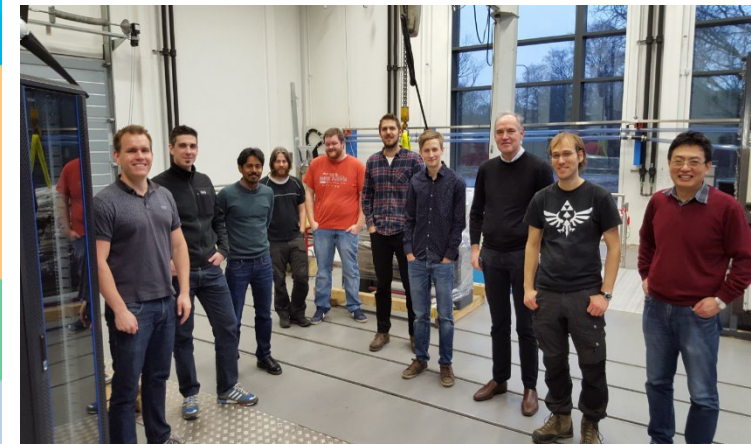


- Globally, the oil & gas industry produces an average of three barrels of water for each barrel of oil
- The produced water consists of different organic and inorganic compounds, it is firmly prohibited to be directly discharged into environment

Plant-wide PWT Control

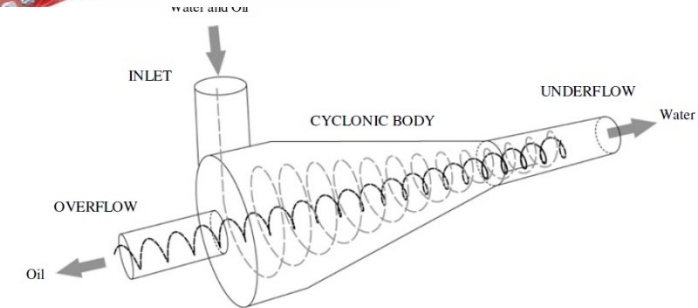
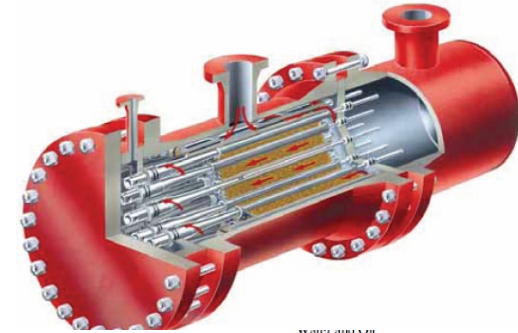
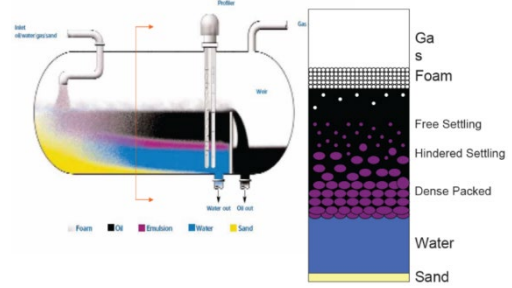


Maximally utilize the **degrees of freedom hidden among interactive subsystems**



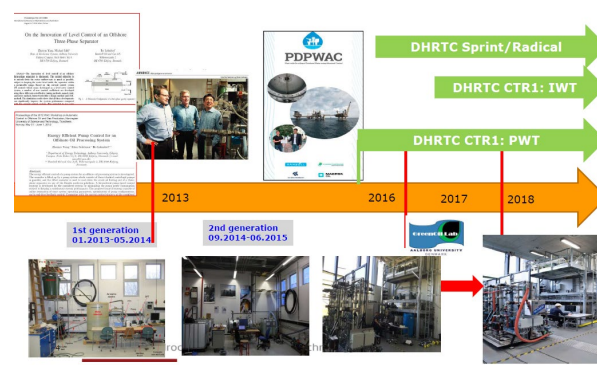
Plant-wide Control Solutions...

- **Software retrofit solutions** – control algorithms
 - Anti-slugging control
 - Coordinated PID control
 - H_∞ robust control (Advanced)
 - Nonlinear MPC (Advanced)
 - Model reference adaptive control (Advanced)
 - Reinforcement learning control (AI-based)
 -
- **Combined soft- & hard-ware retrofit solutions**
 - Online OiW measurement
 - **OiW sensor-fusion & control**
- **Breakthrough technology solution**
 - zero-discharge ceramic membrane filtration: real-time monitoring & control

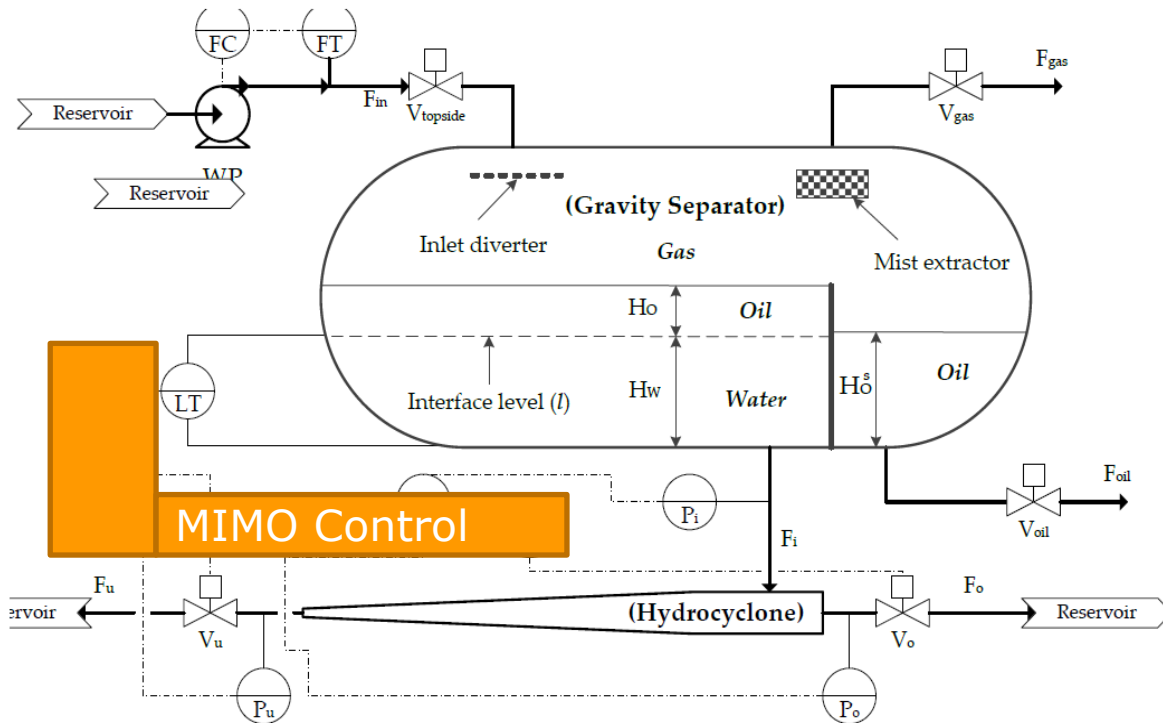
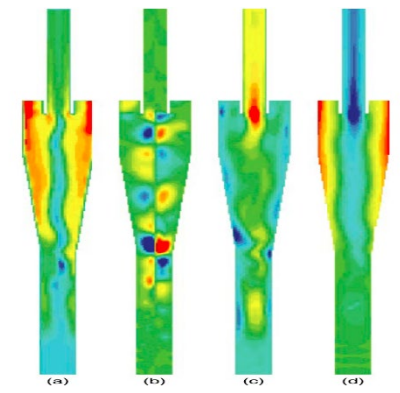


PWT Pilot-plant

- **Three-phase separation facility**
- **De-oiling hydrocyclone facility**
- Riser and transport pipeline system
- Gas injection system
- Ceramic membrane filtration facility
- Flow measurement equipment
- **ABB HMI 800 6.0 system**
- **ABB VIS Multi-phase flow meter**
- Tomography (ERT & ECT) sensors
- **Turner TD-4100XD(fluorescence)**
- **Jorin ViPA analyser (microscopy)**
- Canty Inflow Analyzer (**microscopy**)



MIMO Control for PWT



Design issues:

- Model issues (white, grey, black-box)
- Control objectives
- Design methods

Our solutions:

- Robust H_∞ Control (**black-model-based**)
- Nonlinear MPC (**block-model-based**)
- MRAC
- Grey-box modeling of hydrocyclone
- H_∞ Control via RL (**model-free**)

ADVANCED PROCESS CONTROL USING
AI-ENHANCED MODELING AND ITS
APPLICATION IN OFFSHORE PRODUCED
WATER TREATMENT

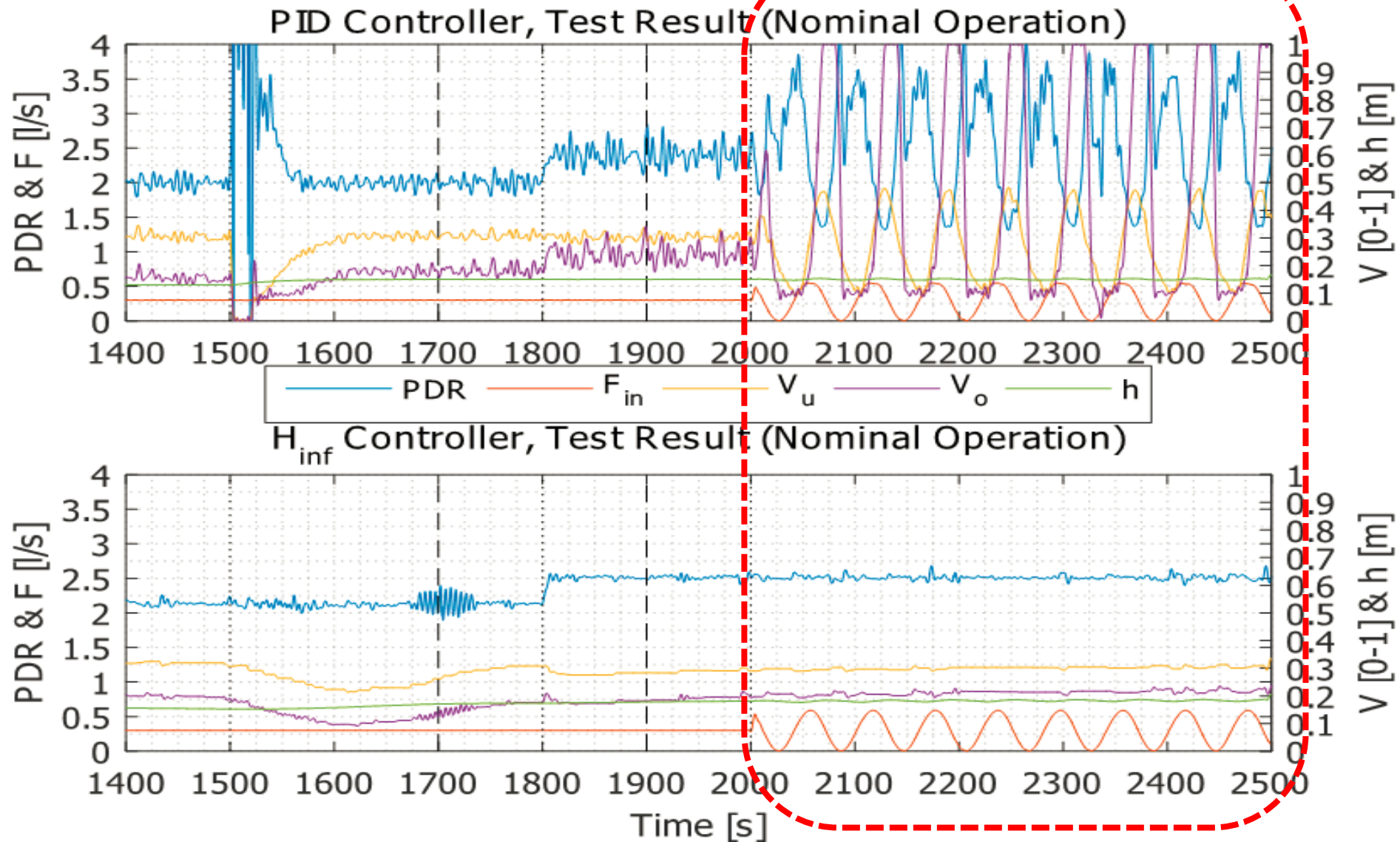
BY

REAL-TIME MONITORING AND
ROBUST CONTROL OF OFFSHORE
DE-OILING PROCESSES

BY
PETAR DURDEVIC LÖHNDOFF

DISSERTATION SUBMITTED 2017

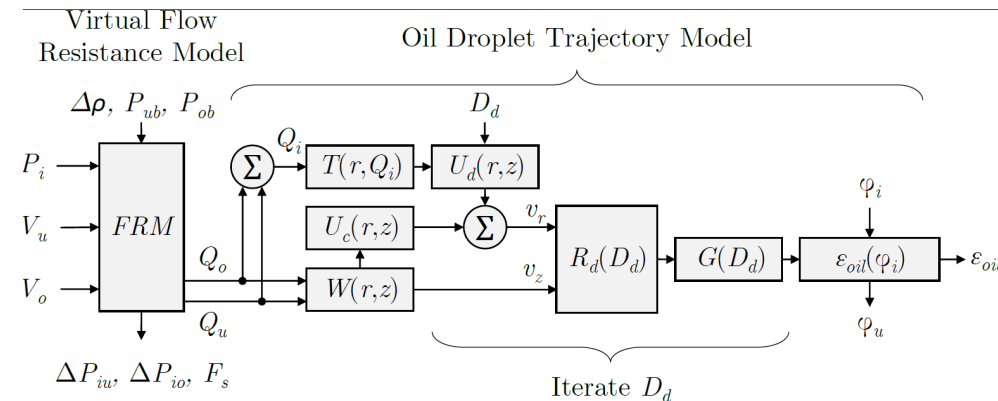
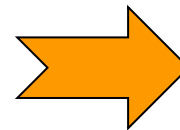
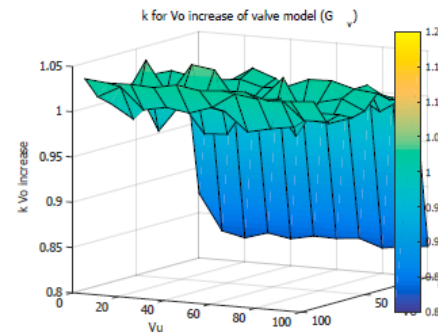
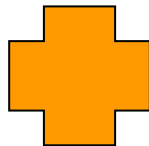
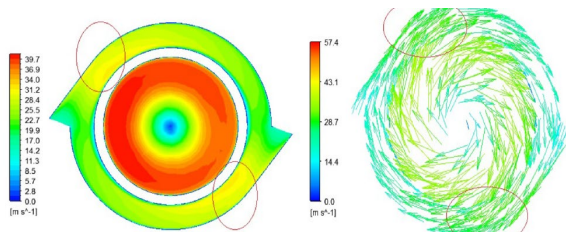
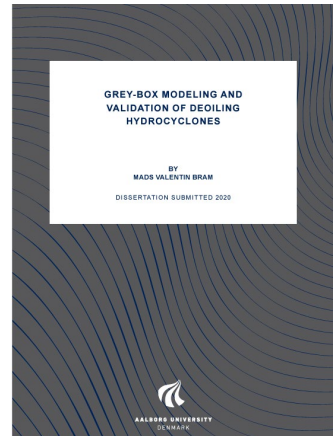
H_∞ Control vs. PID



Grey-box Modeling of Hydrocyclone

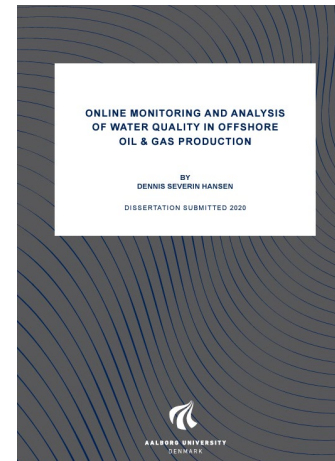
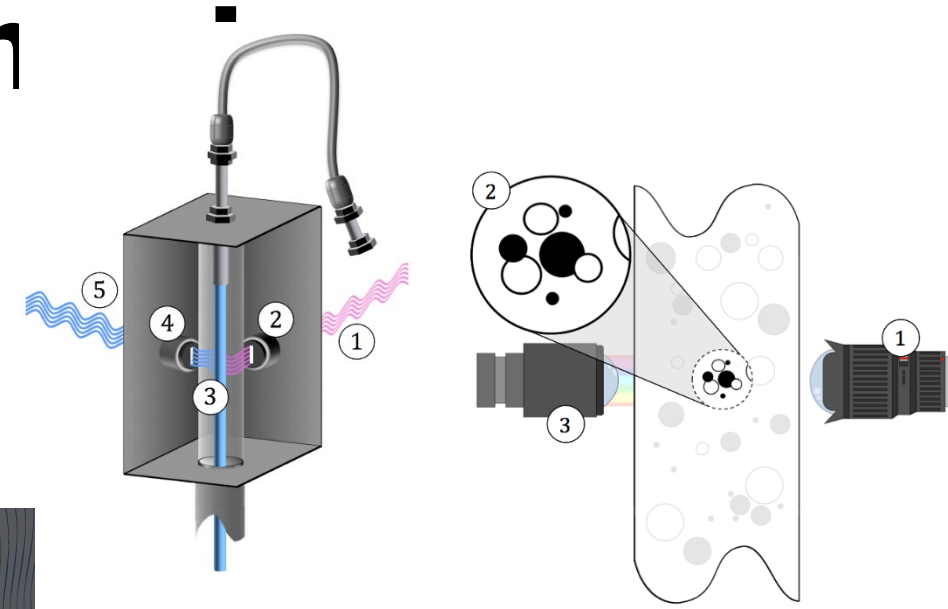
Mathematical model **oriented for control design**

- **"White-box"** modeling – CFD models
- **"Black-box"** modeling – data-driven model
- **"Grey-box"** modeling – combined physical and data-driven modeling



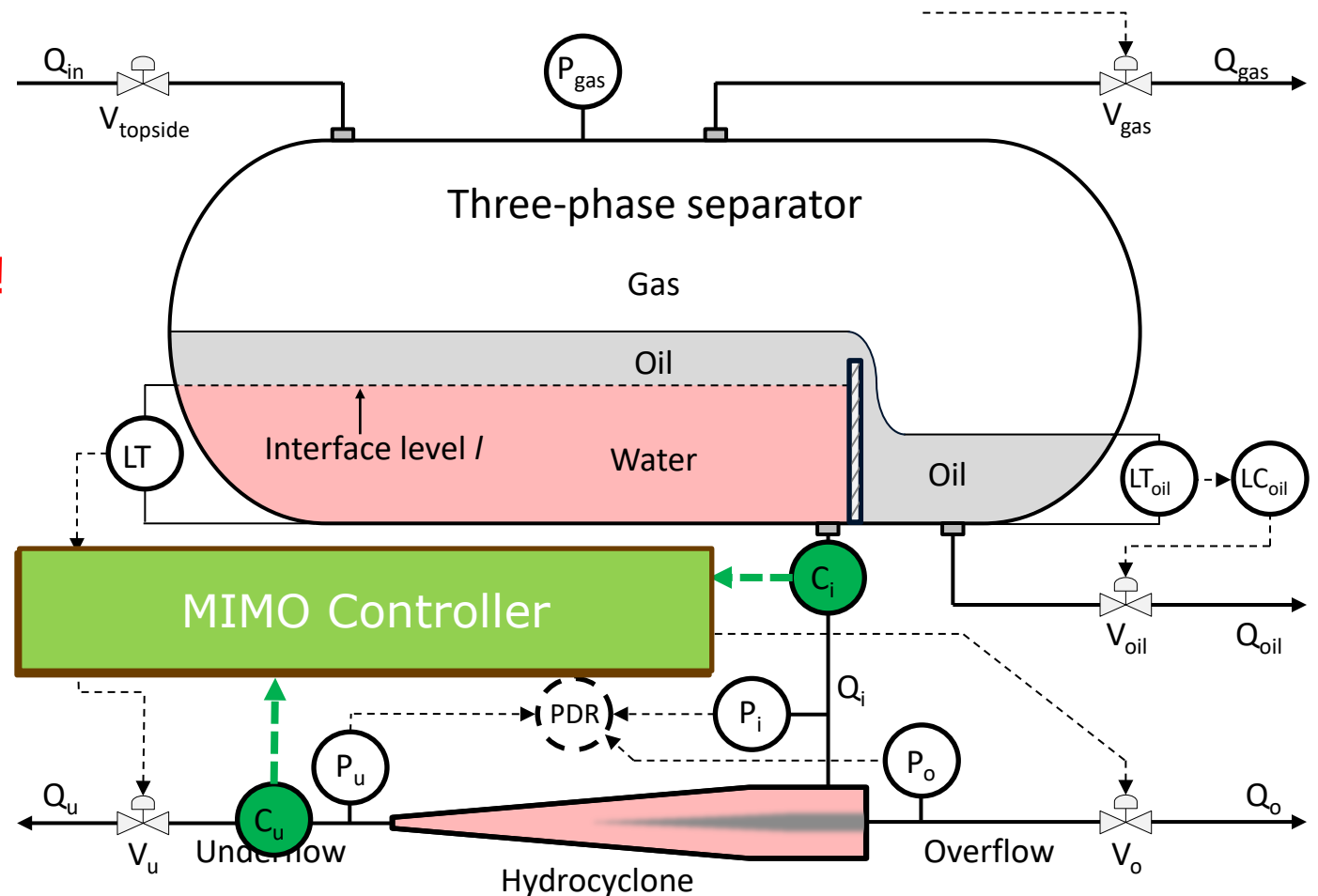
Online OiW measurem

- The **reliable** accuracy, resolution, and capability of dynamic tracking of any currently available OiW monitors/sensors are affected by
 - dedicated sensing technology,
 - instrument construction,
 - process installation,
 - sampling mechanism, and
 - Diverse operational conditions.
- **Shute Arrow sensor (EUDP)**
- Reliable calibration procedures
- Regular maintenance and re-calibration
- **Robust control (uncertainties)**



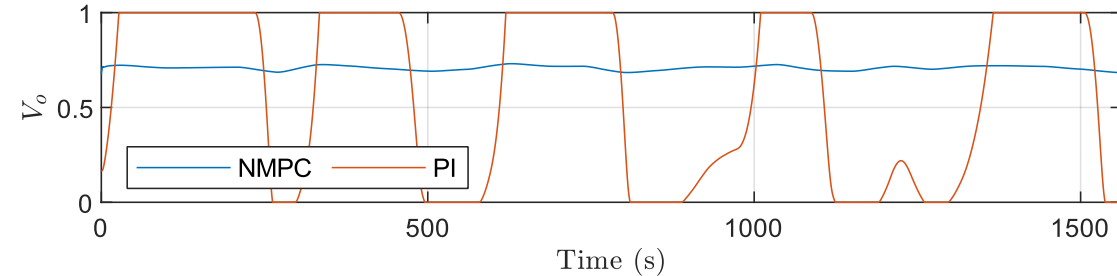
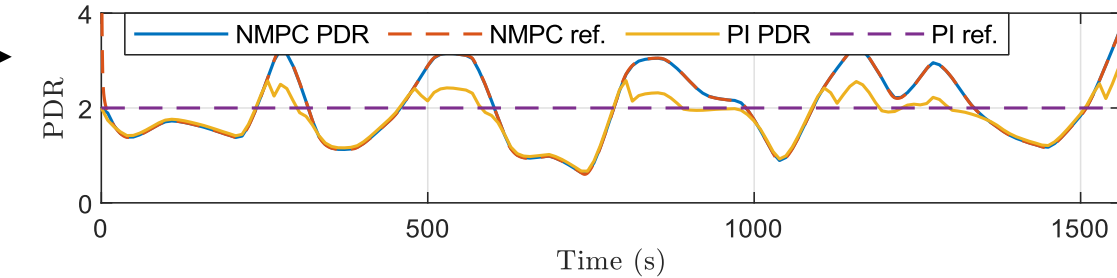
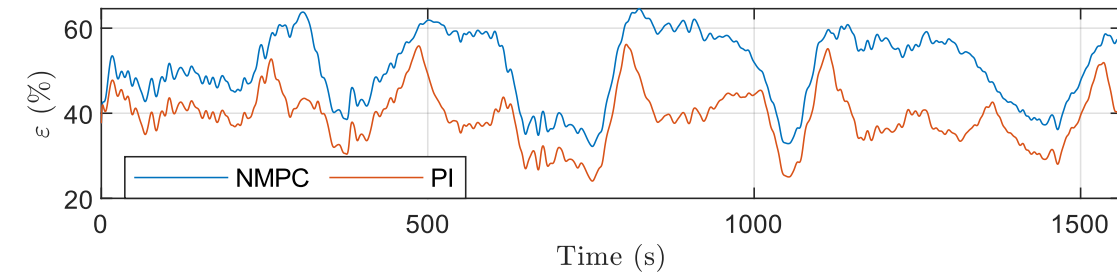
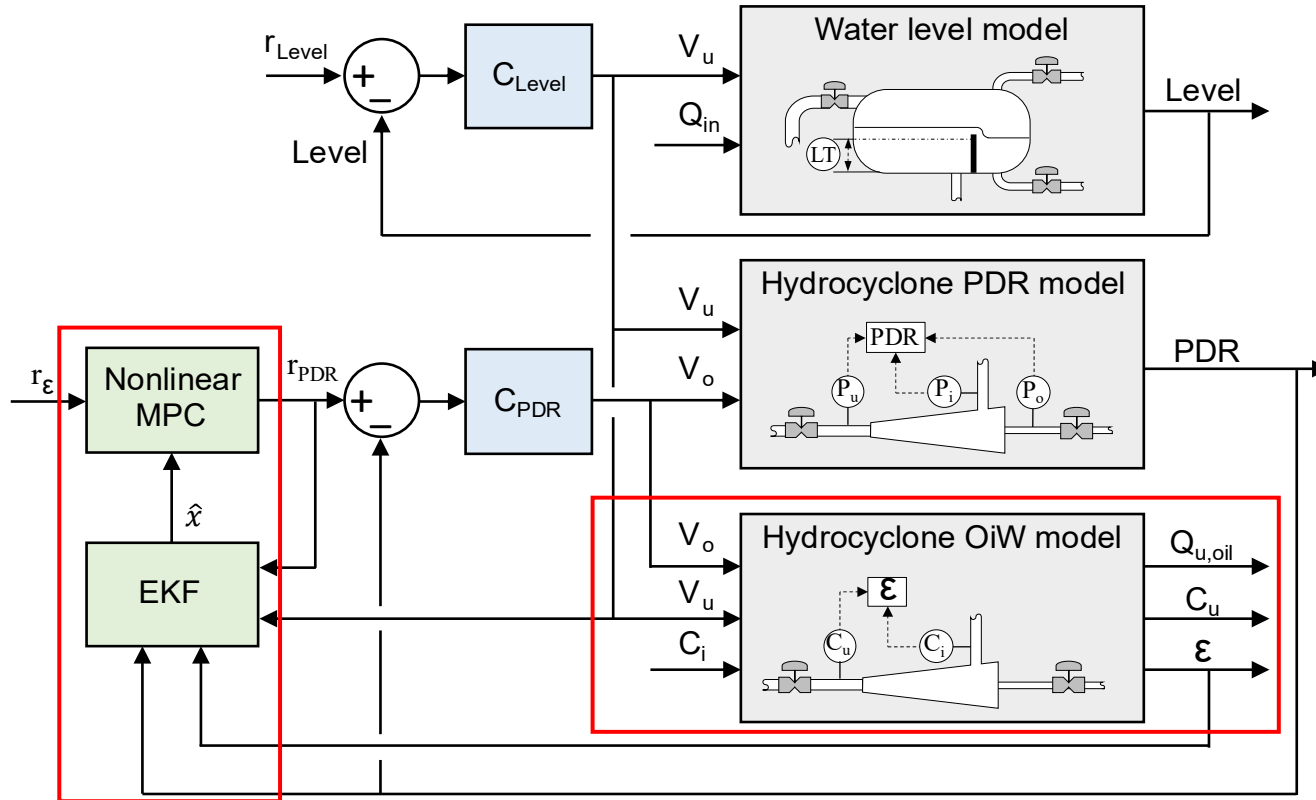
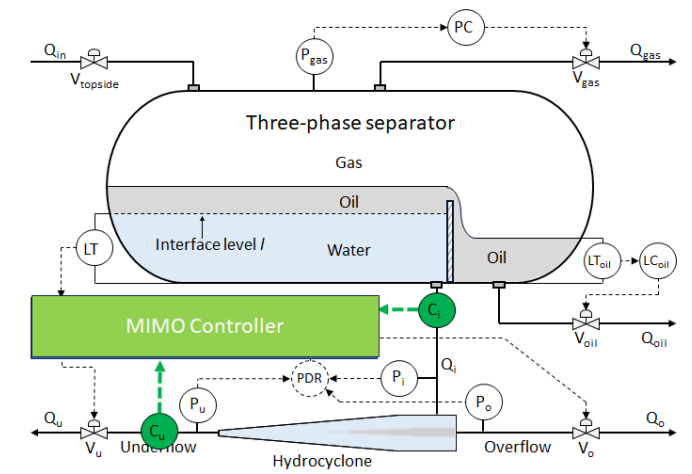
Directly quality-based Control

- Reliable online OiW sensors?
- OiW-based control algorithms?
- **Brand-new PWT control solution!**
- Pilot-plant demonstration (EUDP: 3D OiW Control 2021-2025)
- **On-site testing & demonstration (EUDP – ARROiW 2026-2028)**

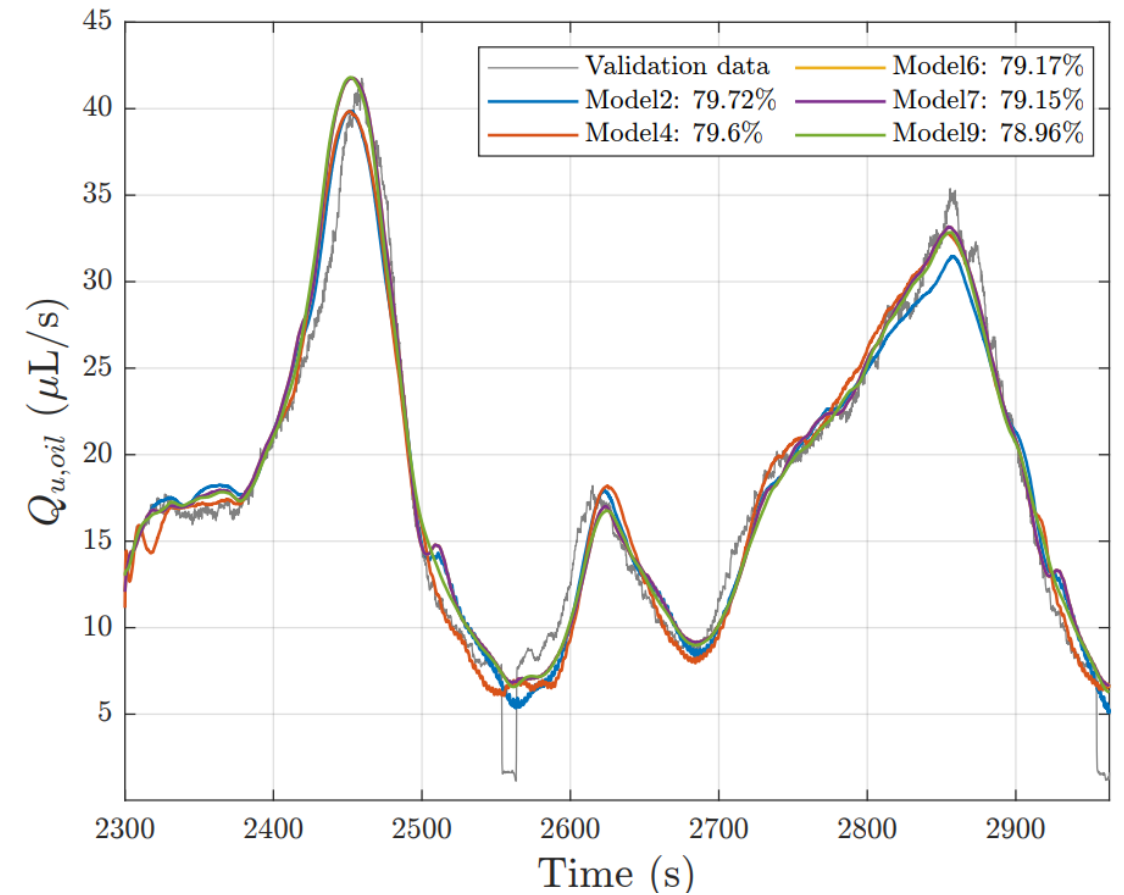
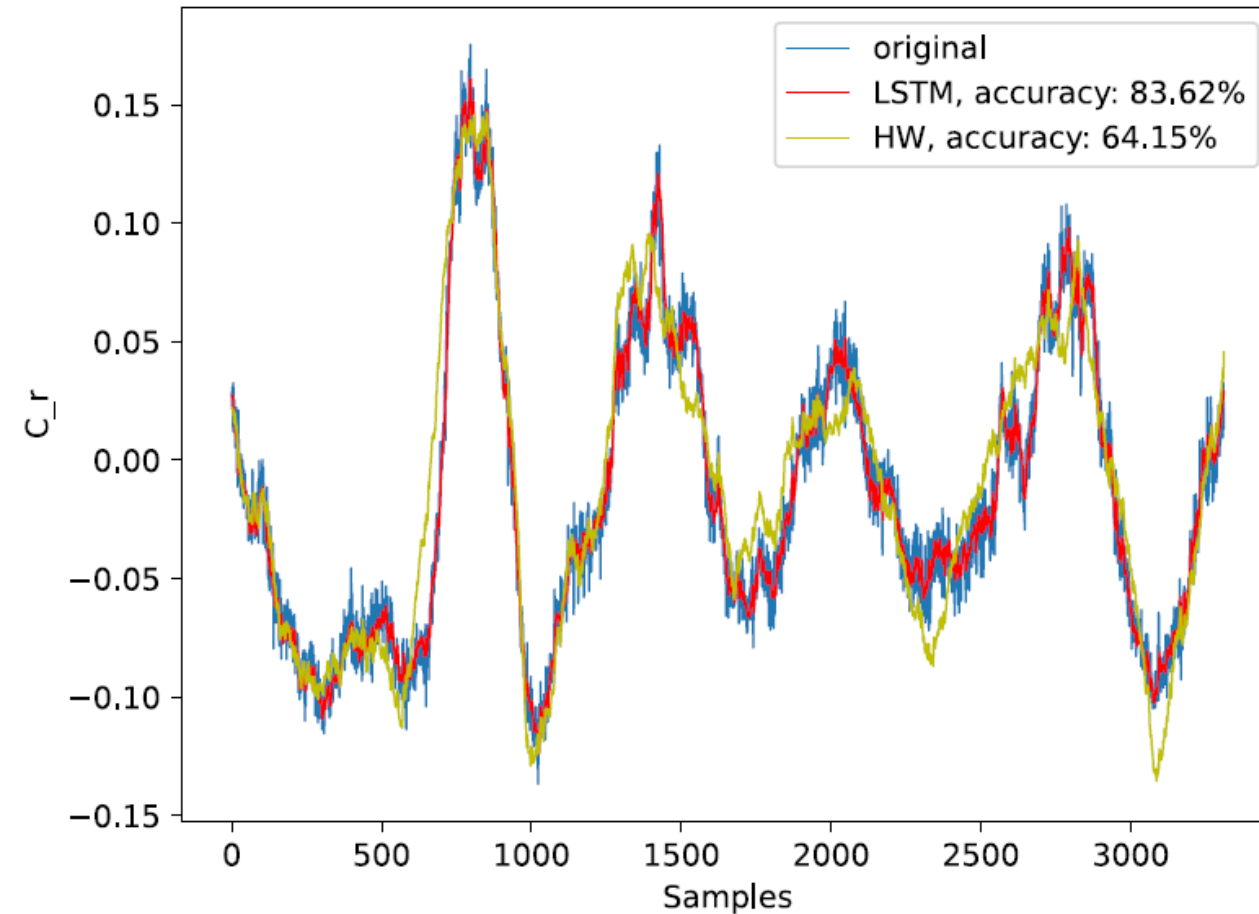


OiW-Based Control

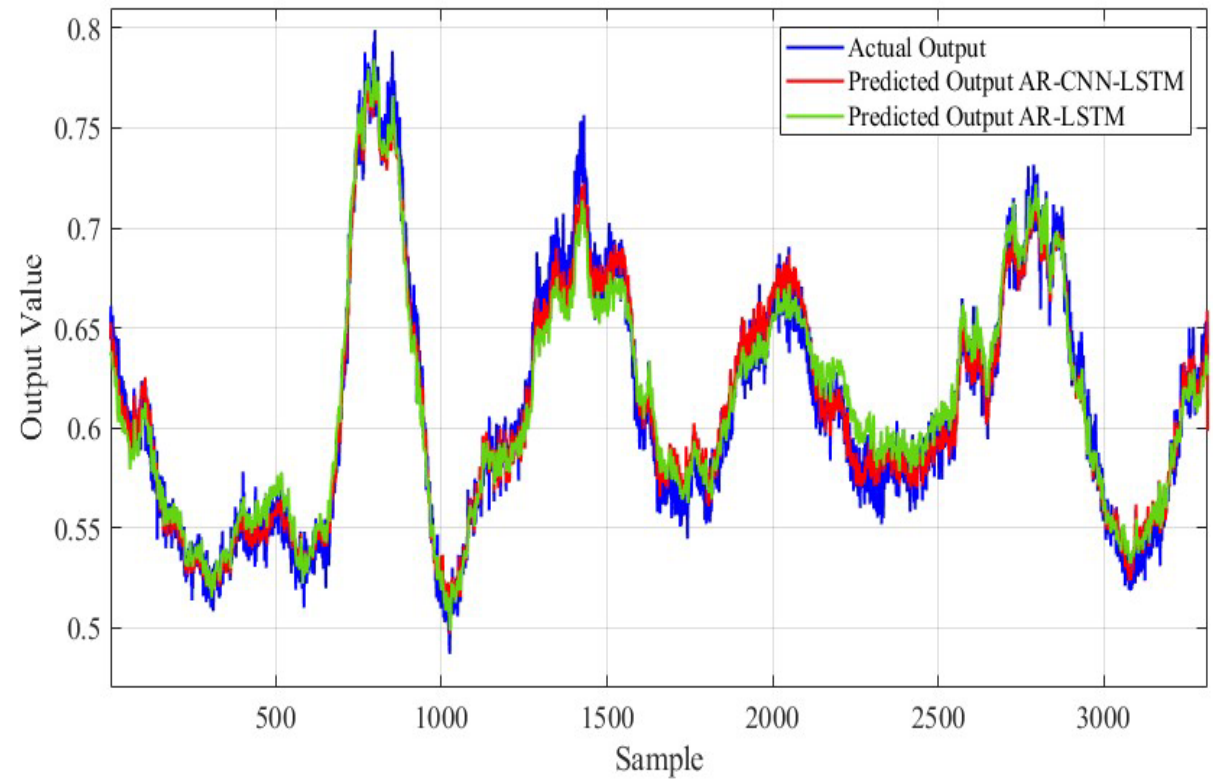
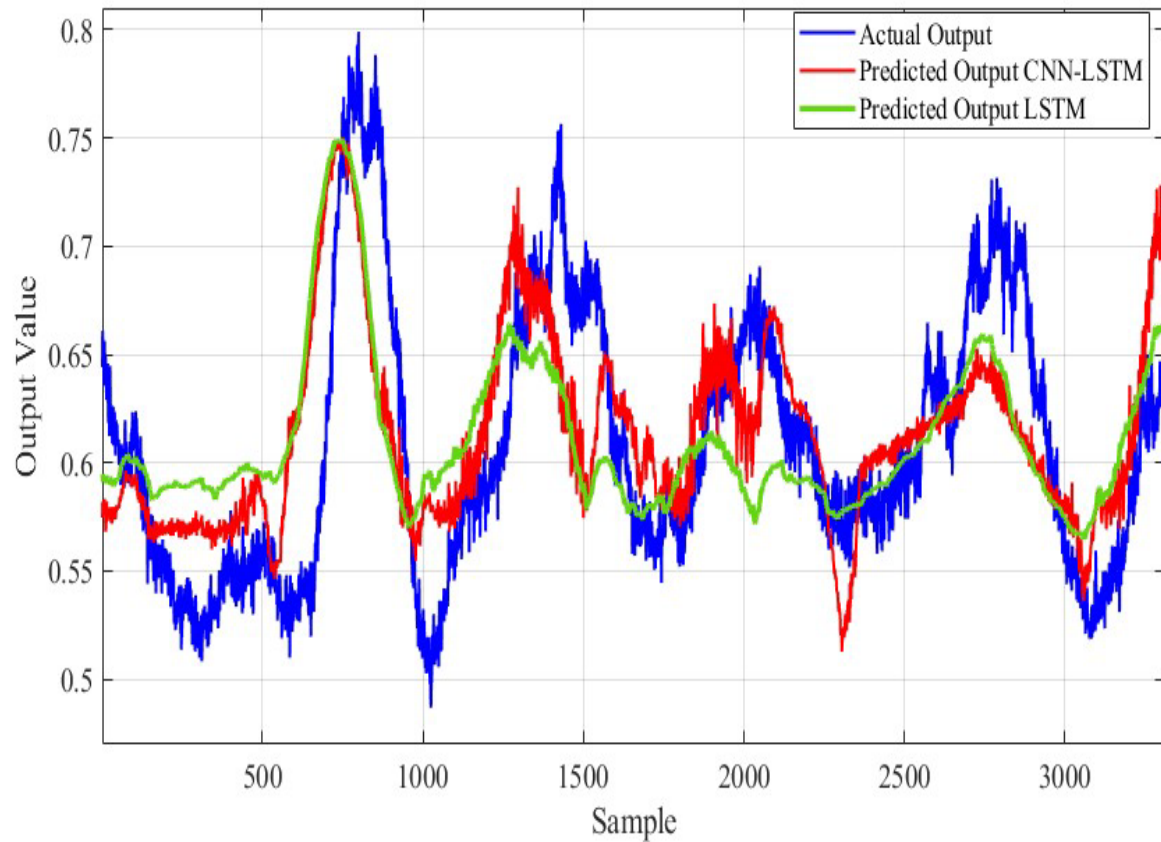
- OiW-based feedback Nonlinear MPC loop for PDR reference generation



3. LSTM-based Models



Results - Prediction accuracy



Reflections

- The superior performances of these AI models in terms of accurate dynamic prediction of complicated engineering systems
 - Data quality? overfitting problem?
- Configuration selection and hyper-parameter tuning& assessment criteria... (PSO algorithm: R^2 improved from 0.295 to 0.940)
 - Occam's razor?
- The standard LSTM (combined CNN-LSTM) can be significantly improved by adding the **output feedback** (Observer/KF)
- Reinforcement Learning design of OiW-based control system using the developed AI model



Model-free H_∞ tracking control for de-oiling hydrocyclone systems via off-policy reinforcement learning[☆]

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IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS: SYSTEMS

Fault-Tolerant H_∞ Control for Topside Separation Systems via Output-Feedback Reinforcement Learning

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Abstract

The automation of science is a long-standing ambition in artificial intelligence (AI) research^{1,2}. Although the community has made substantial progress in automating individual components of the scientific process, a system that autonomously navigates the