SUOMEN SOODAKATTILAYHDISTYS
FINNISH RECOVERY BOILER COMMITTEE

Åbo Akademi University

From Research to Improved Recovery Boiler Technology

Mikko Hupa and Markus Engblom
Åbo Akademi

International Chemical Recovery Conference
International Recovery Boiler Conference – 50 Years of Cooperation In Finland
Tampere Hall, Tampere, June 11, 2014

RECOVERY BOILER RESEARCH HIGHLIGHTS – 10 STEPS FORWARD

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RECOVERY BOILER RESEARCH HIGHLIGHTS – 10 STEPS FORWARD

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Finding the Top-10 Research Efforts

- On *liquor combustion and the furnace process*
- Influencing recovery boiler design or operation

- Evaluators: two from North-America, two from Europe
- 100+ years experience

Top-10 Recovery Boiler Research Efforts by 2014

1. Lower Furnace Wall Corrosion

1. Dust Chemistry and Melting

3. Single Droplet Combustion Characterization

4. CFD Based Furnace Modeling

5. High Solids Firing

Top-10 Recovery Boiler Research Efforts by 2014

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6. NO_x Formation
7. Alkali Chloride Induced Corrosion
8. Acid Sulfates
9. Liquor Spray Droplet Measurements
10. Partial Autocaustization Using Boron

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Continuous Development of Recovery Boiler Technology – 50 Years of Co-operation in Finland" by Suomen Soodakattilayhdistys – Finnish Recovery Boiler Technology Committee, Helsinki 2015.

What has happened since 2014?

- Recent research supporting further development of RB technology or operation
- Industry expert panel comments and ranking
  - significance as research (5 p)
  - potential practical applicability (5 p)

Recent Research Efforts

(Random order)

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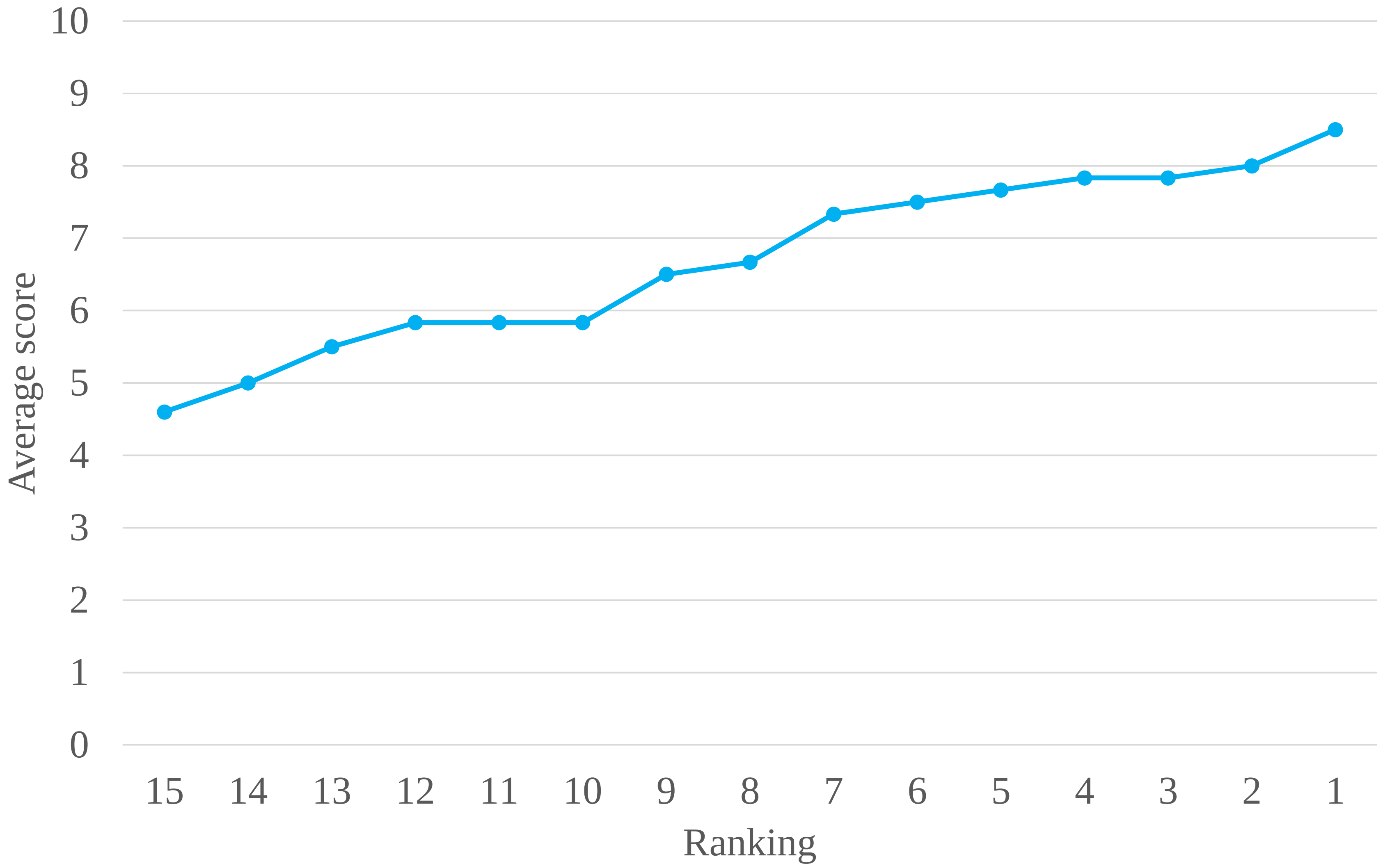
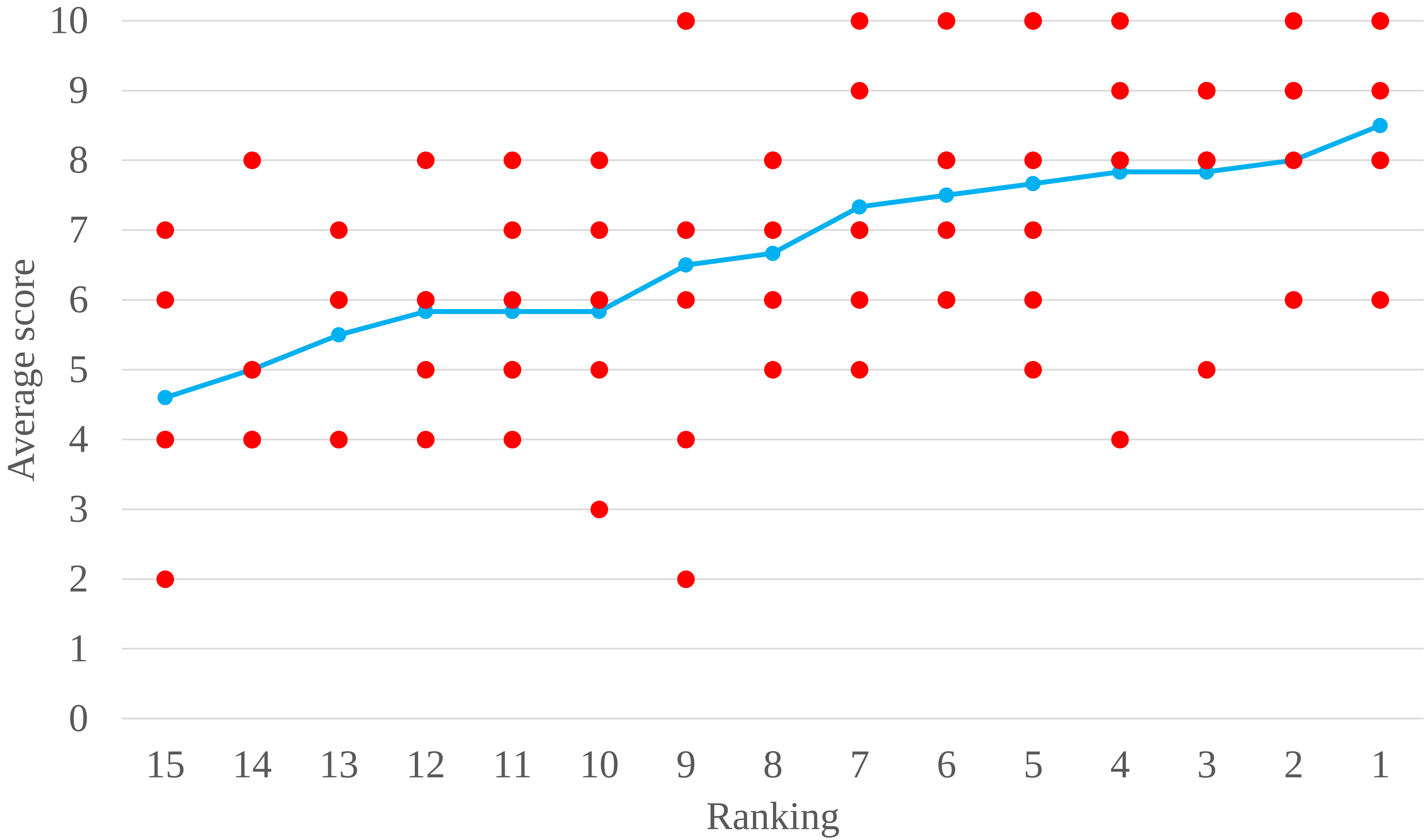
Panel Scores - Average



Panel Scores - Individual



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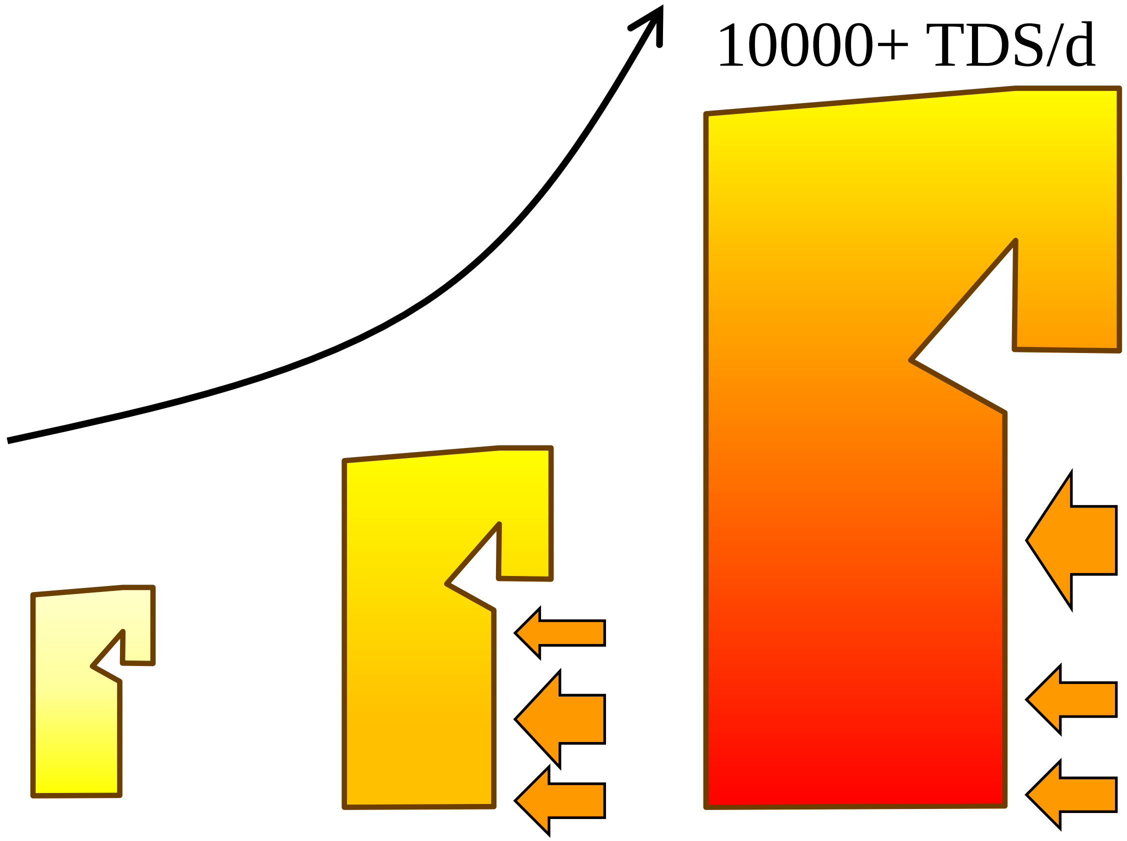
5. Furnace/flue gas chemistry in extra-large furnaces

Changes in the chemistry of NOx, SOx and fly ash in XXL boilers due to changes in the furnace gas temperature and retention time distribution



- Na, S release
- NOx (fuel-NO, thermal-NO) ?

Air distribution

1300 -1500 °C

MW/m^2

5. Furnace/flue gas chemistry in extra-large furnaces

Changes in the chemistry of NOx, SOx and fly ash in XXL boilers due to changes in the furnace gas temperature and retention time distribution

Good topic. How hot furnace is affecting emissions and reactions in lower part of furnace. How much is fume/dust flow increased?

Air distribution is different compared to small furnaces, partly due to NOx and partly due to higher bottom load (kW/m2)

Intellectually interesting work, just not clear that these XXL boilers have any significant issues due to these chemistry changes

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Role of hydroxide vapors NaOH, KOH

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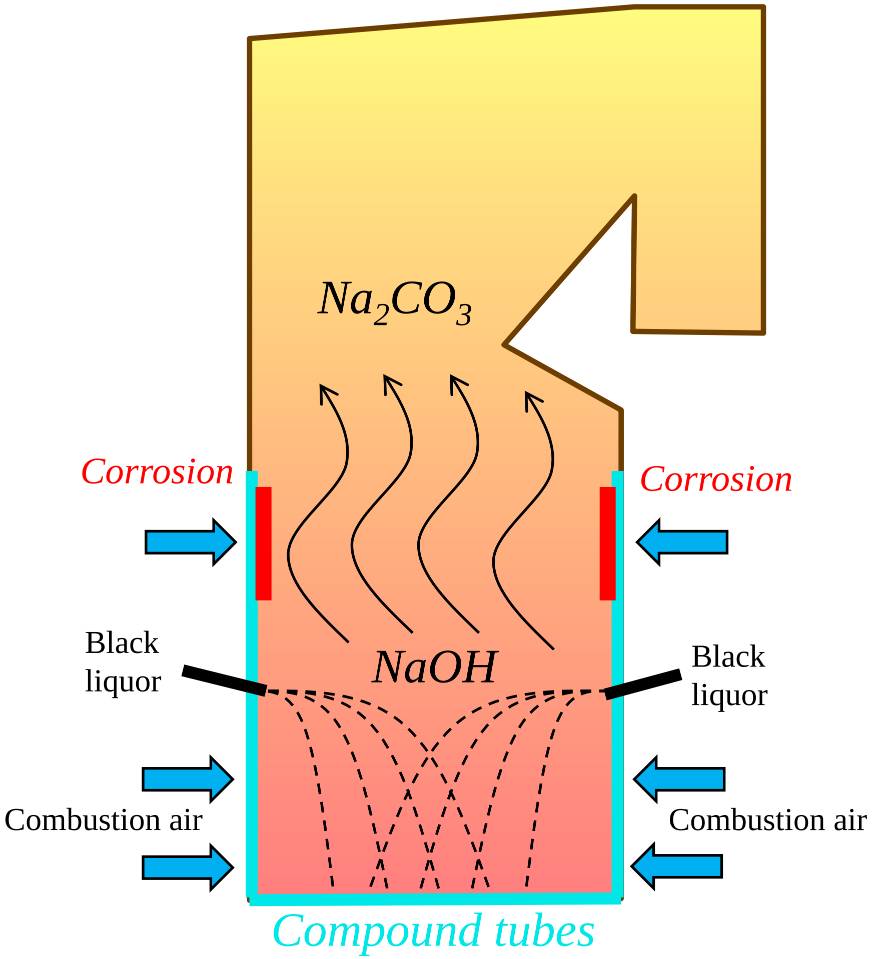
Role of hydroxide vapors NaOH, KOH



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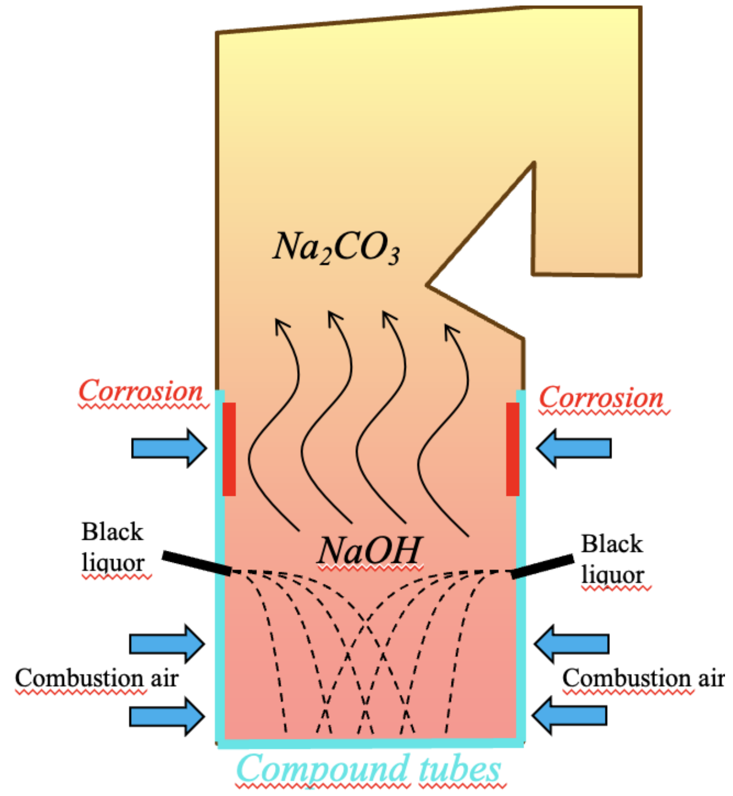
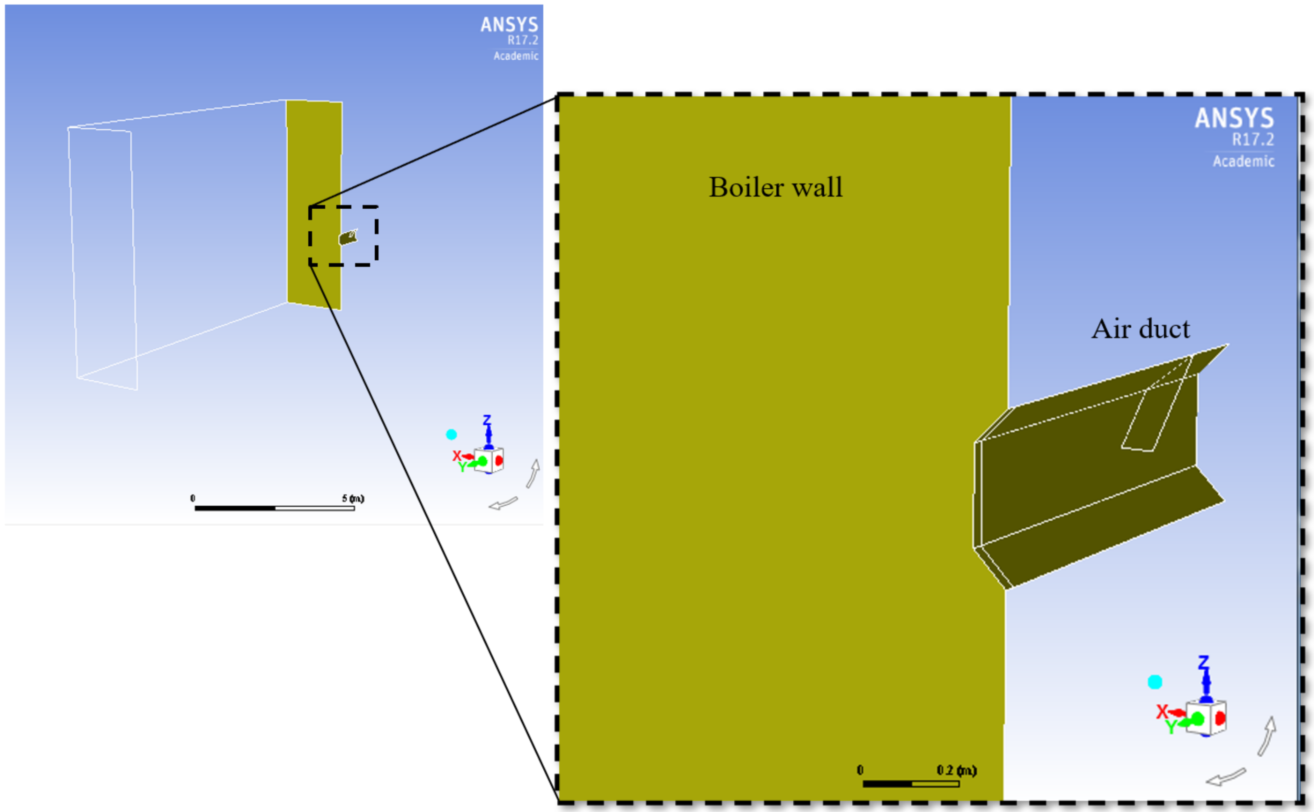
Role of hydroxide vapors NaOH, KOH

Corrosion around high tertiary and quaternary air ports

Hydroxide vapors suspected

CFD modeling to investigate





4. Understanding compound tube cracking around tertiary and quaternary air ports

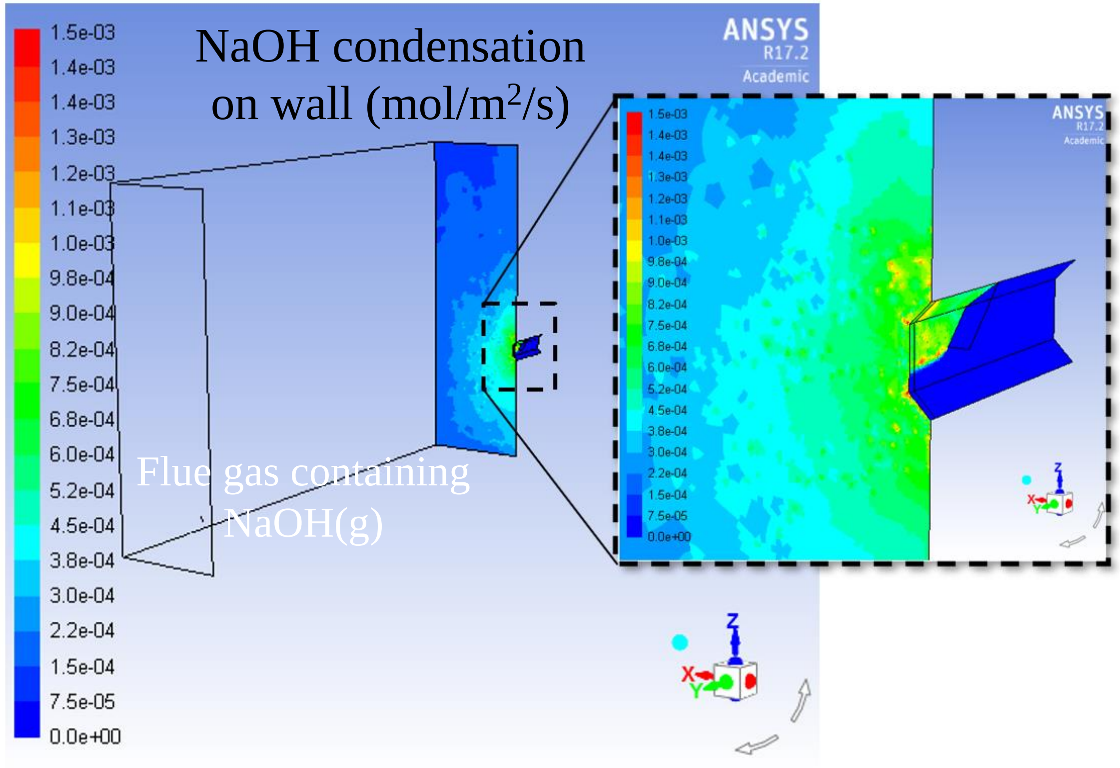
Role of hydroxide vapors NaOH, KOH

Gas recirculation around air port

Causes NaOH(g) to condense around air port

NaOH melts at 300 C

Extremely corrosive on SS



Engblom et al, unpublished 2023

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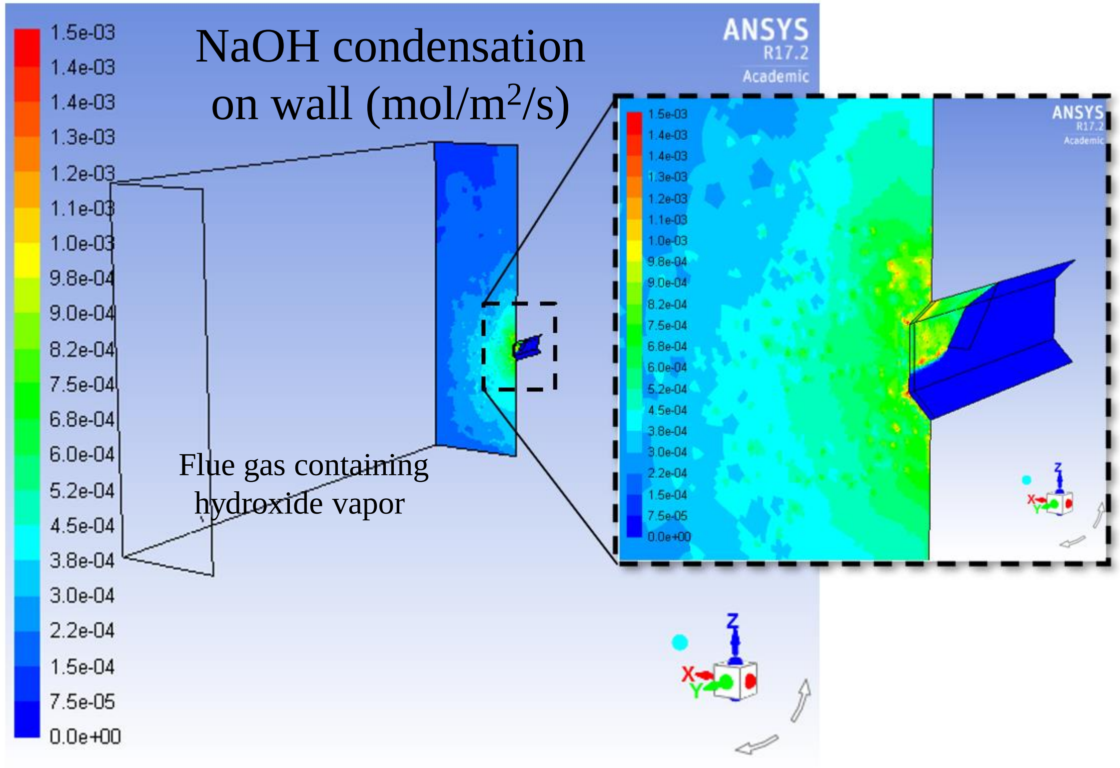

Bruno, F., "Primary Air Register Corrosion in Kraft Recovery Boiler", 4th International Symposium on Corrosionin of the Pulp & Paper Industry, Stockholm, p.68 (1984)

Odelstam,T., Tran, H., Barham,D., Reeve, D., Hupa, M. and Backman, R. "Primary Air Port Corrosion of Composite Tubes in Kraft Rccovery Boilers", Tappi Engineering Conference, September, 1987.

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Role of hydroxide vapors NaOH, KOH

In our company corrosion is nowadays more challenging than cracking in those openings.

Scored high because of the safety implications and cost associated with mitigating cracking.

Not yet a significant problem at mills, but good topic to be understood

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3. Improved soot-blower efficiency

Research leading to development of high efficiency soot-blower nozzles

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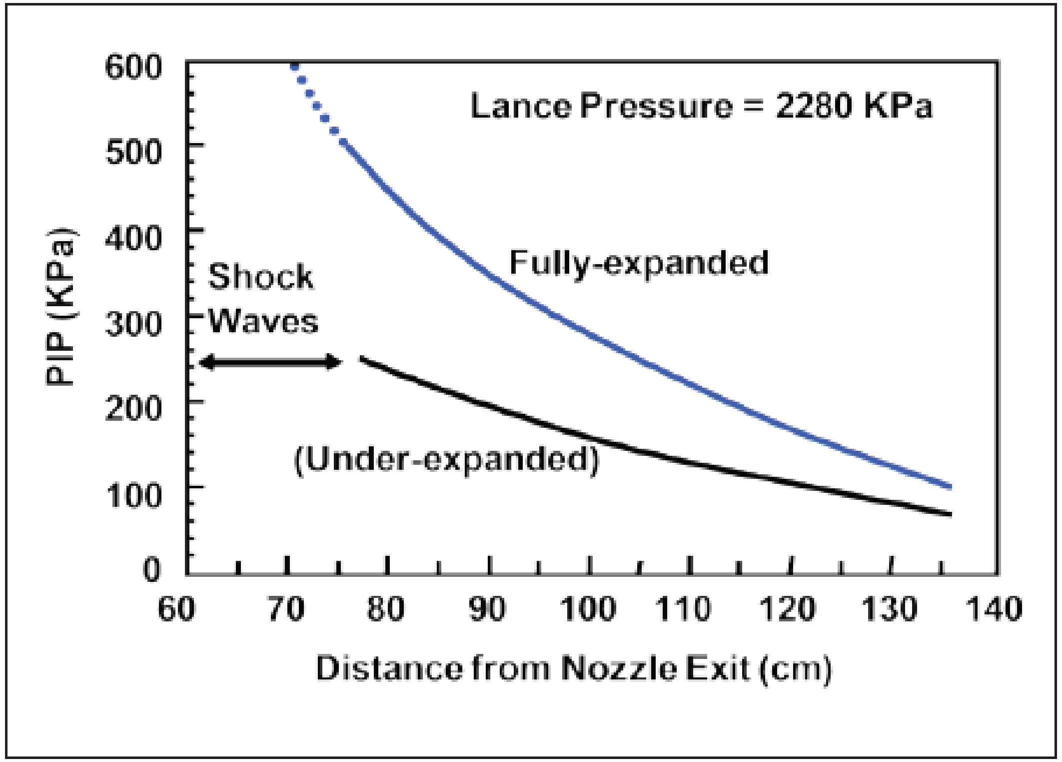
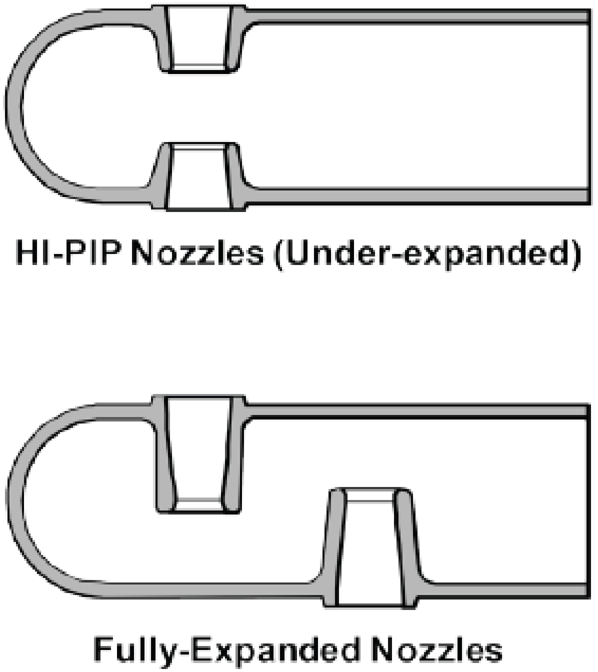
Fully-expanded nozzles avoid supersonic shock waves, resulting in higher Peak-Impact Pressure (PIP)



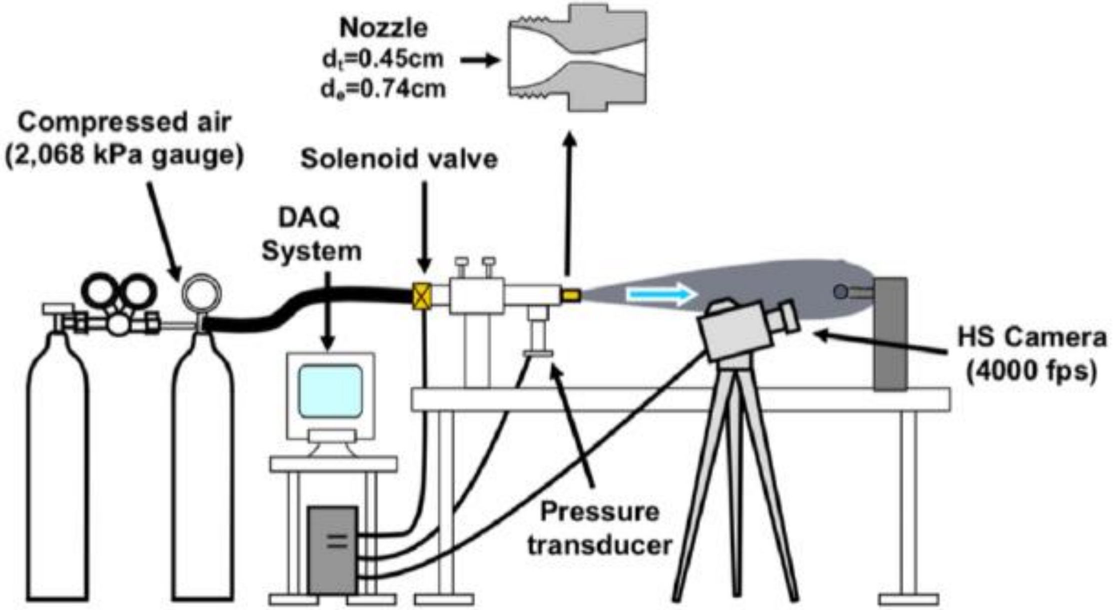


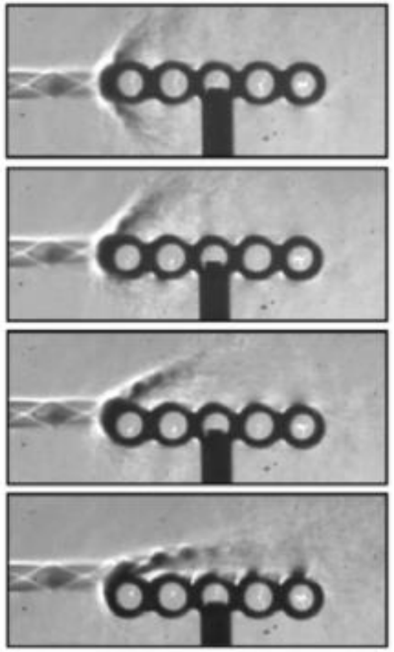
Tran & Tandra, *"Recovery boiler sootblowers: History and technological advances"*, Tappi Journal, 2015

3. Improved soot-blower efficiency

Research leading to development of high efficiency soot-blower nozzles

High-speed camera for studies of jet-deposit interaction and jet visualization





A. Pophali, M. Bussmann, and H. Tran "Supersonic jet impingement on a cylinder and characterization of the resulting deflected jets", Journal of Fluids Engineering, 2014.

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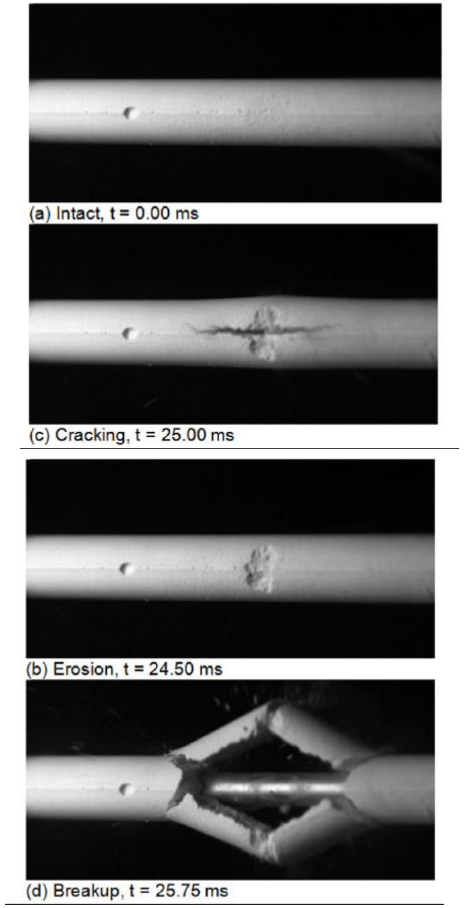
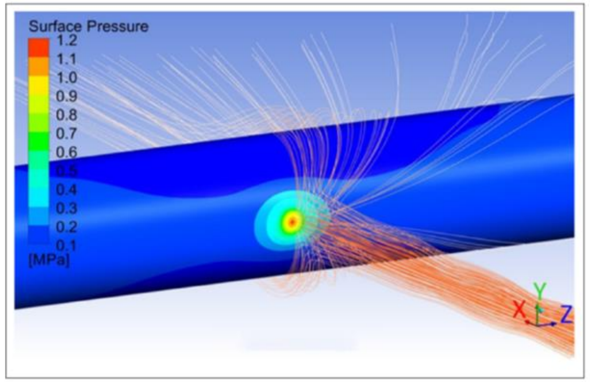
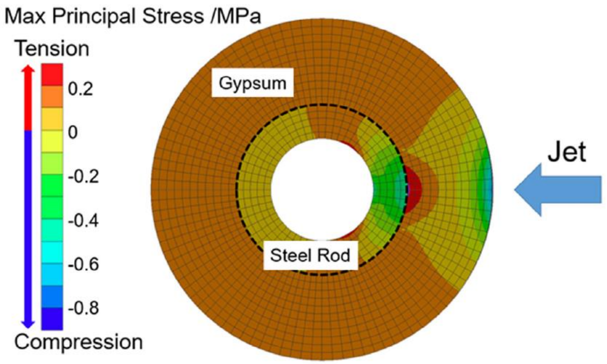
Deposit breakup
high-speed camera

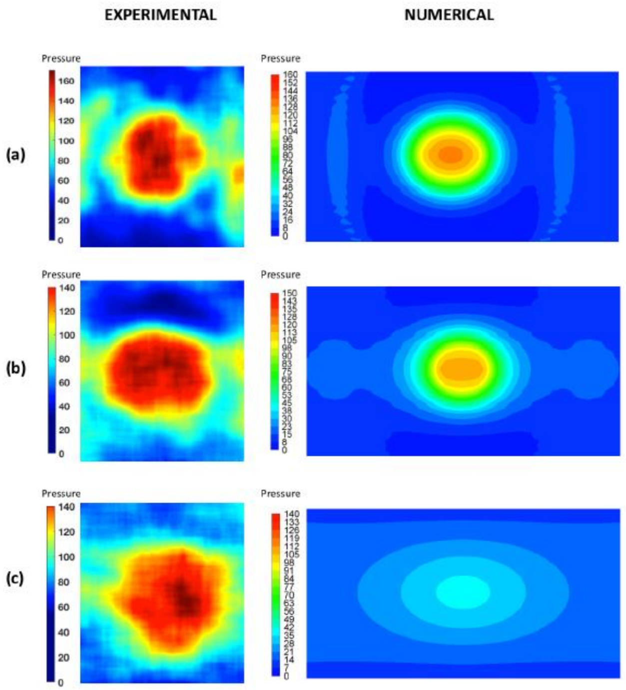


Deposit breakup – Mathematical modeling





Pressure on deposit surface



You, Bussmann, Tran & Tandra *”Modelling deposit breakup under sootblower impingement”*, Tappi Journal, 2017

Fady Mettias *”Measuring sootblower jet forces exerted on deposits”*, MSc thesis, 2019

3. Improved soot-blower efficiency

Research leading to development of high efficiency soot-blower nozzles

… important topic although Cl and K are quite well under control in many mills.

…one of the highest ongoing expenses on a recovery boiler, easily $5MM per year.

Turbine extraction at 25~30 bar pressure has decreased the feasibility of such technology. It could be valuable if a solution for 10 bar pressure could be found.

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2. Machine learning to improve recovery boiler operation

Opportunities to use advanced machine learning tools to explain and predict key operating targets such as reduction efficiency, fouling rates and flue gas emissions

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Opportunities to use advanced machine learning tools to explain and predict key operating targets such as reduction efficiency, fouling rates and flue gas emissions

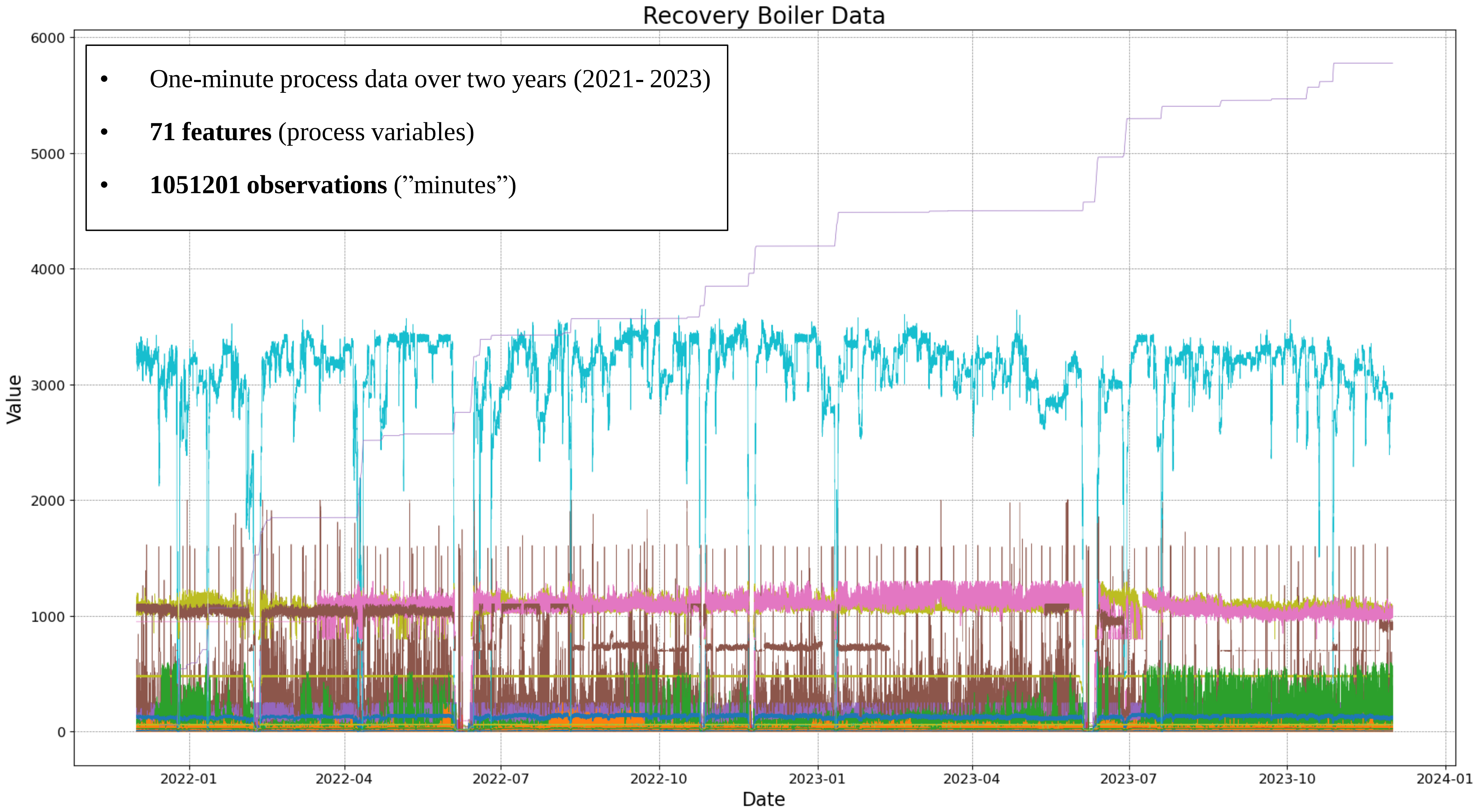
- Large amounts of process data available on boiler operation
- Great potential to machine learning for analysis, prediction and control
  - Reduction
  - Fouling
  - Emissions
  - etc

2. Machine learning to improve recovery boiler operation

1 Volumetric flow rate of lower secondary air, right
2 Volumetric flow rate of lower secondary air, left
3 Pressure of lower secondary air, right
4 Pressure of lower secondary air, left
5 Sulfidity of white liquor after causticizing
6 Pressure drop over economizer 1, right
7 Pressure drop over economizer 1, left
8 Pressure drop over economizer 2, right
9 Pressure drop over economizer 2, left
10 Pressure drop over economizer 3, right
11 Pressure drop over economizer 3, left
12 Mass flow rate of black liquor (dry matter)
13 Green liquor Sulfur reduction degree
14 Pressure of NCG
15 Temperature of smelt spout cooling water 1
16 Temperature of smelt spout cooling water 2
17 Temperature of smelt spout cooling water 3
18 Temperature of smelt spout cooling water 4
19 Temperature of smelt spout cooling water 5
20 Temperature of smelt spout cooling water 6
21 Volumetric flow rate of NCG
22 BCTMP liquor, mixed into heavy liquor
23 ESP ash pH
24 Concentration, O2 in dry flue gases, smoke stack
25 Concentration, O2, superheater area, right
26 Concentration, O2, superheater area, left
27 Start-up / support oil burners; cumulative oil consumption
28 Pressure, black liquor, front wall
29 Pressure, black liquor, right wall
30 Pressure, black liquor, back wall
31 Pressure, black liquor, left wall
32 Volumetric flow rate, black liquor, front wall
33 Liquor dry solids, measurement 1
34 Volumetric flow rate, black liquor, right wall
35 Volumetric flow rate, black liquor, back wall
36 Volumetric flow rate, black liquor, left wall
37 Liquor firing temperature
38 Liquor dry solids, measurement 2
39 Total volumetric flow rate of black liquor
40 Temperature of primary air
41 Volumetric flow rate of primary air
42 Pressure of primary air, right
43 Pressure of primary air, left
44 Raw measurement
45 Mass flow rate of water injector to secondary superheater, stage 1
46 Mass flow rate of water injection into superheater, stage 1
47 Mass flow rate of water injection into superheater, stage 3
48 Concentration, CO, smokestack
49 Concentration, NOx, smokestack
50 Concentration, SO2, smokestack
51 Concentration, TRS
52 Concentration, Dust, smokestack
53 Concentration, O2, in wet flue gases, smoke stack
54 Temperature of secondary air
55 Volumetric flow rate of upper secondary air
56 Feedwater to steamdrum
57 Pressure of tertiary air after fan
58 Volumetric flow rate of tertiary air
59 Time
60 Temperature in furnace, lower secondary air area, right
61 Temperature in furnace, lower secondary air area, left
62 Temperature in furnace, primary air area, back
63 Temperature in furnace, upper secondary air area, front
64 Pressure drop over superheaters, right
65 Pressure drop over superheaters, left
66 Temperature of superheated steam
67 Pressure of superheated steam
68 Pressure of upper secondary air, front
69 Pressure of upper secondary air, back
70 Pressure of upper tertiary air, front
71 Pressure of upper tertiary air, back

M. Oliviera et al., unpublished 2024, ÅA

2. Machine learning to improve recovery boiler operation



- One-minute process data over two years (2021- 2023)
- **71 features** (process variables)
- **1051201 observations** ("minutes")

2. Machine learning to improve recovery boiler operation

Recovery Boiler Emissions - NOx

Predicted based on 71 process parameters (“features”)

Three different ML techniques

Model	MAE	MAPE (%)
MLP	30.9	21.9
CNN	21.3	15.2
LSTM	9.2	6.2

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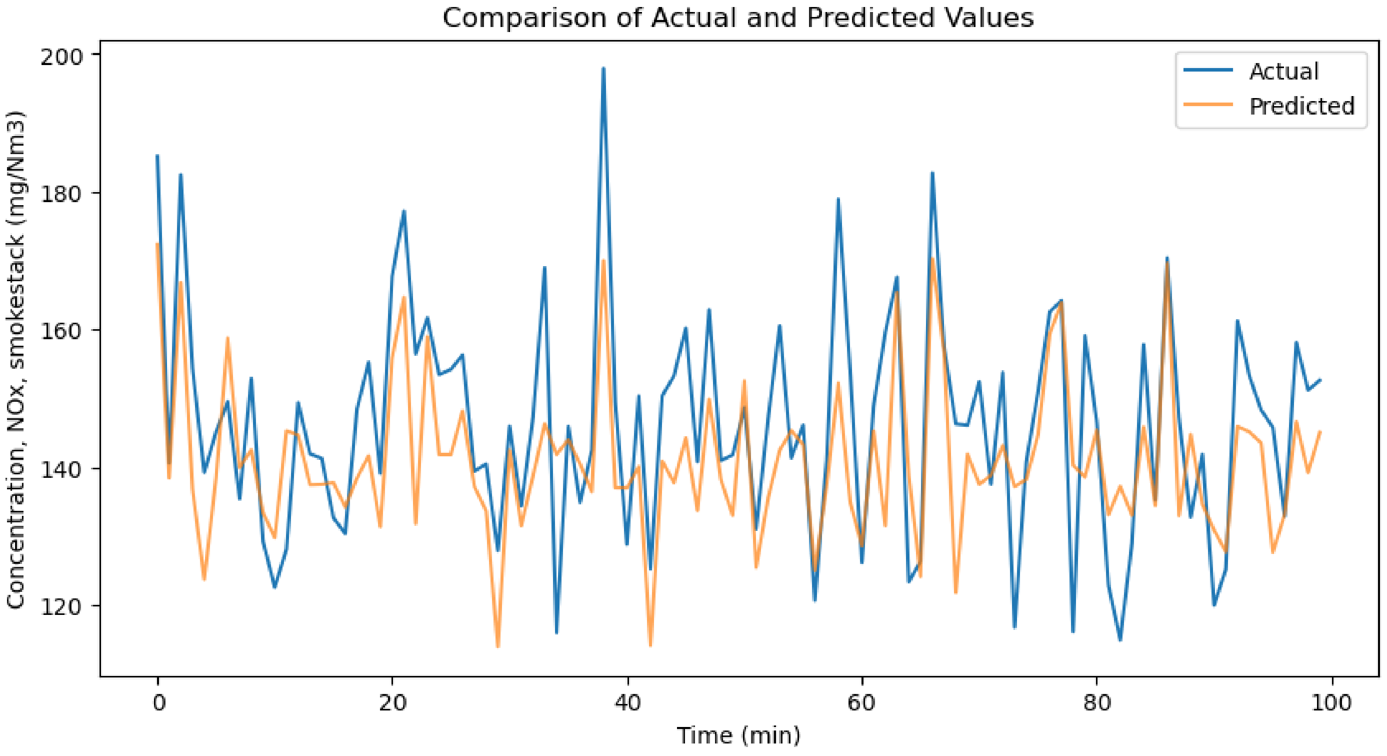
NOx Prediction - LSTM - All features



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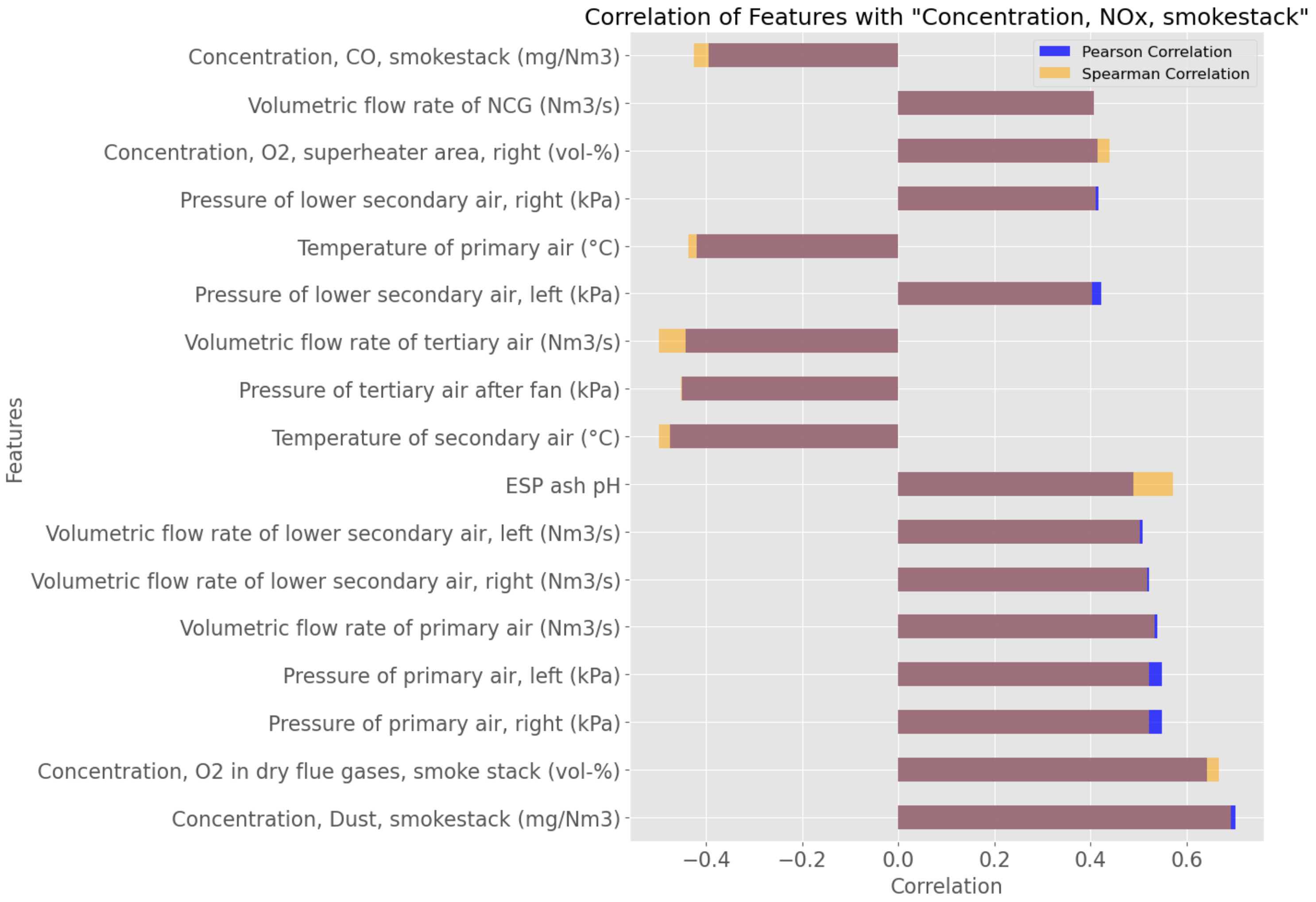

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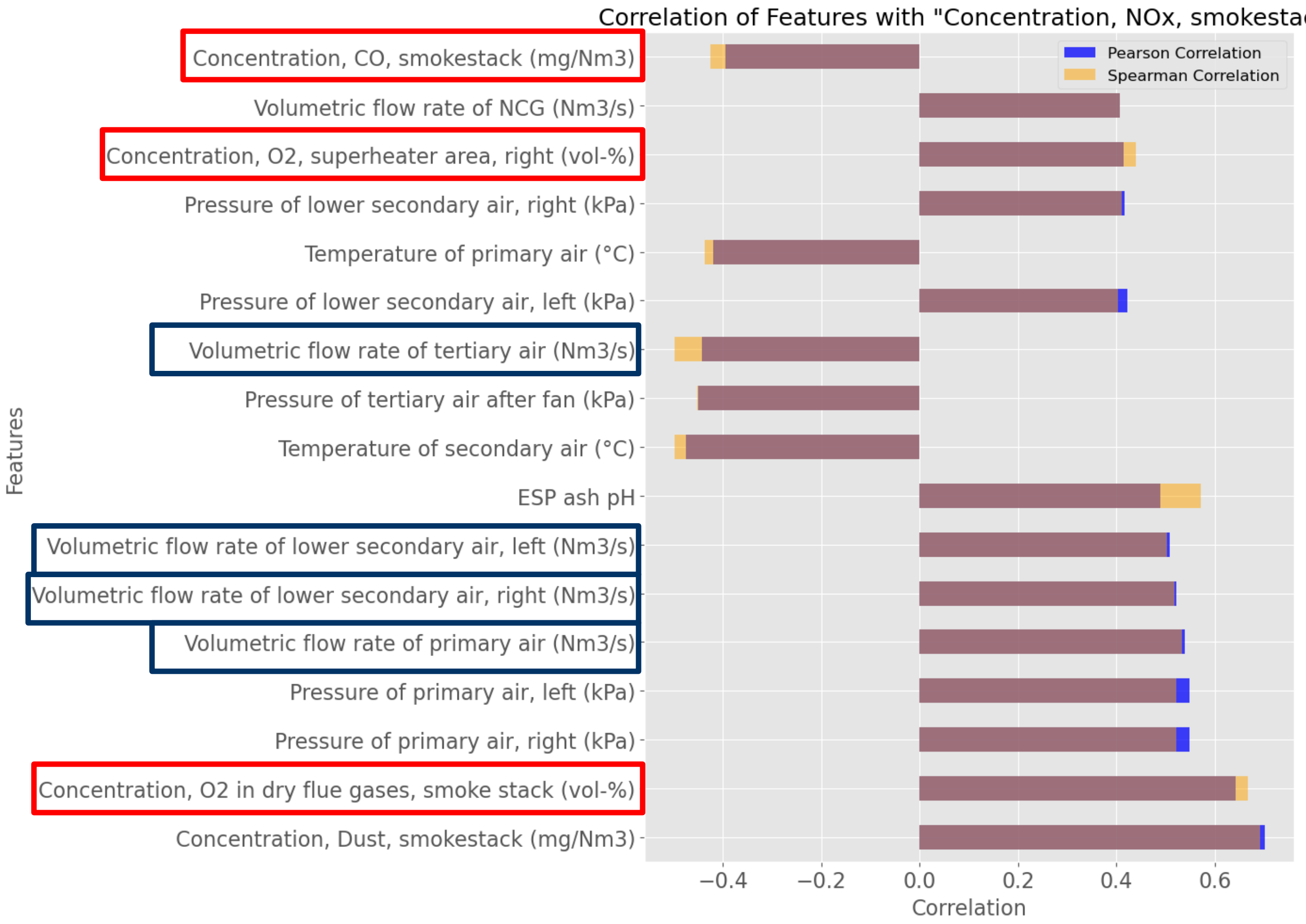

NOx correlated with CO and O_2

NOx correlated with air distribution

M. Oliviera et al., unpublished 2024, ÅA

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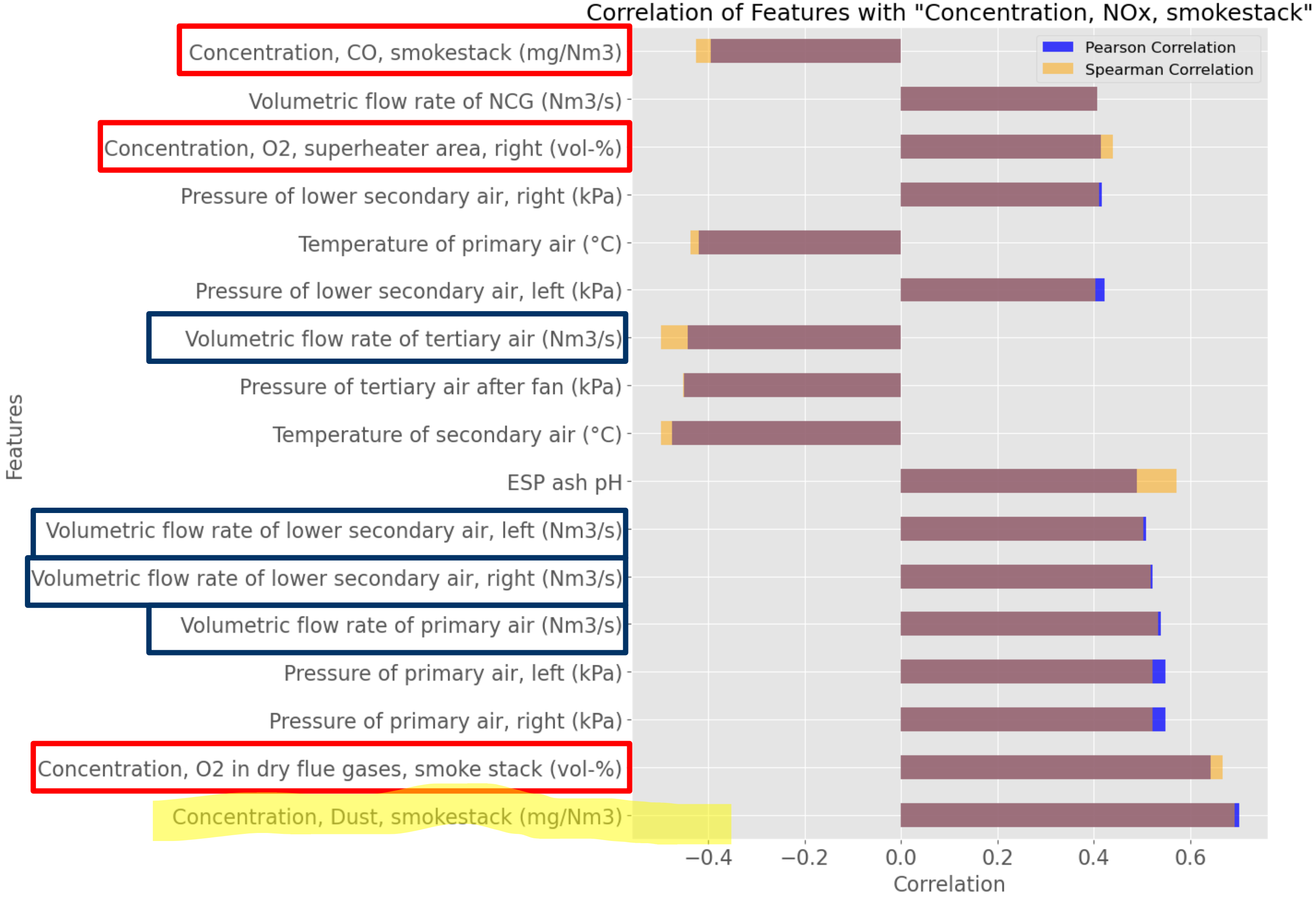

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2. Machine learning to improve recovery boiler operation

Opportunities to use advanced machine learning tools to explain and predict key operating targets such as reduction efficiency, fouling rates and flue gas emissions

Evaluation already started in several companies

Developing widely applicable accurate techniques and identifying pitfalls are the main research activities. - Doing this in a way that creates useful knowledge for industrial application requires great care (currently struggling with this!)

It is quite hard … as machine-learning *is very much dependent on the specific use case (every model is different),*

Not involved in this kind of study so much but maybe good for future

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Laboratory work to better understand the influence on corrosion by the amount of molten phase in contact with the tube surface

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Ebba Malm, *''Alkali chloride induced superheater corrosion – Impact of percentage of molten phase''*, MSc thesis, ÅA 2021

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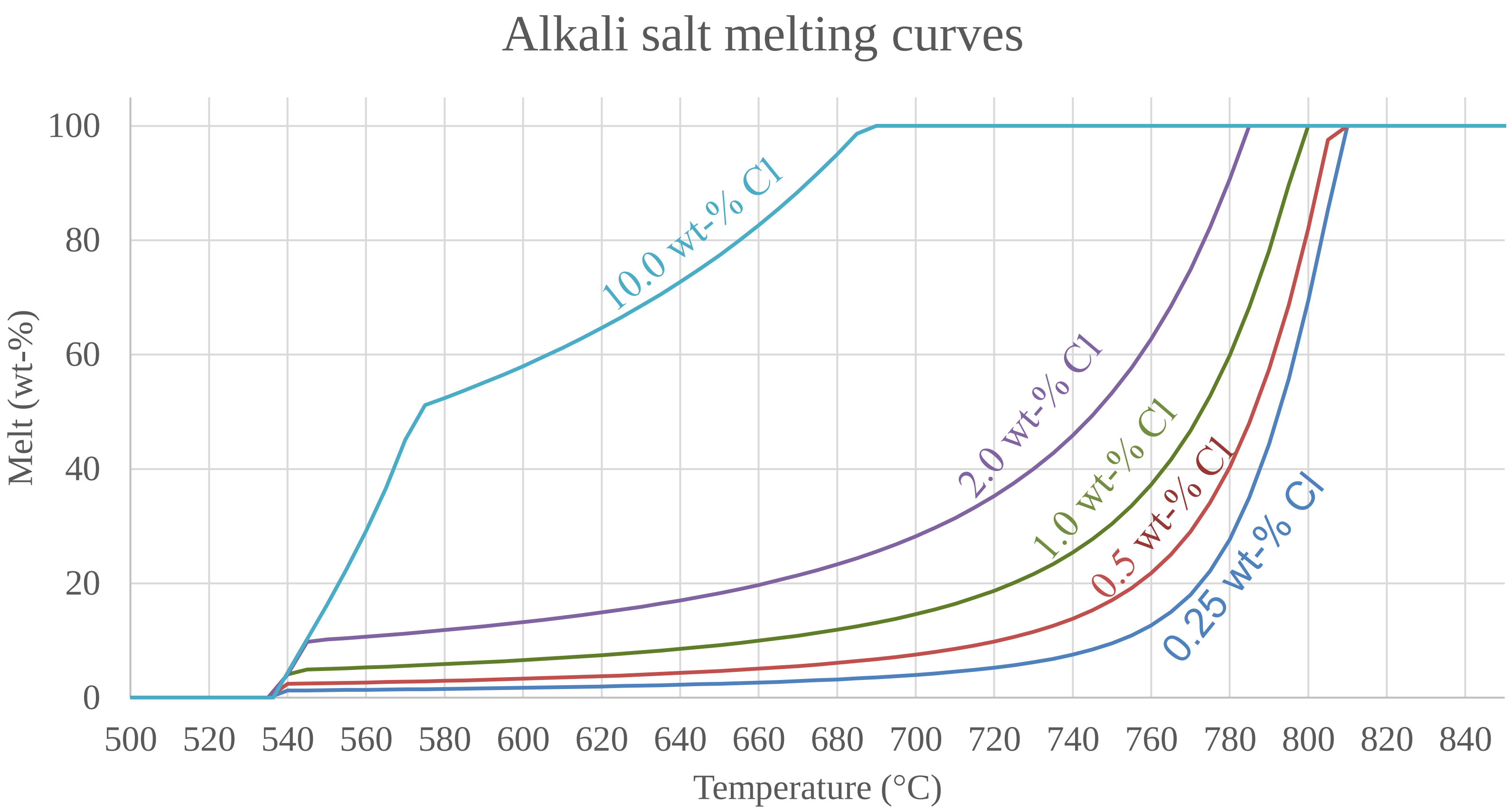

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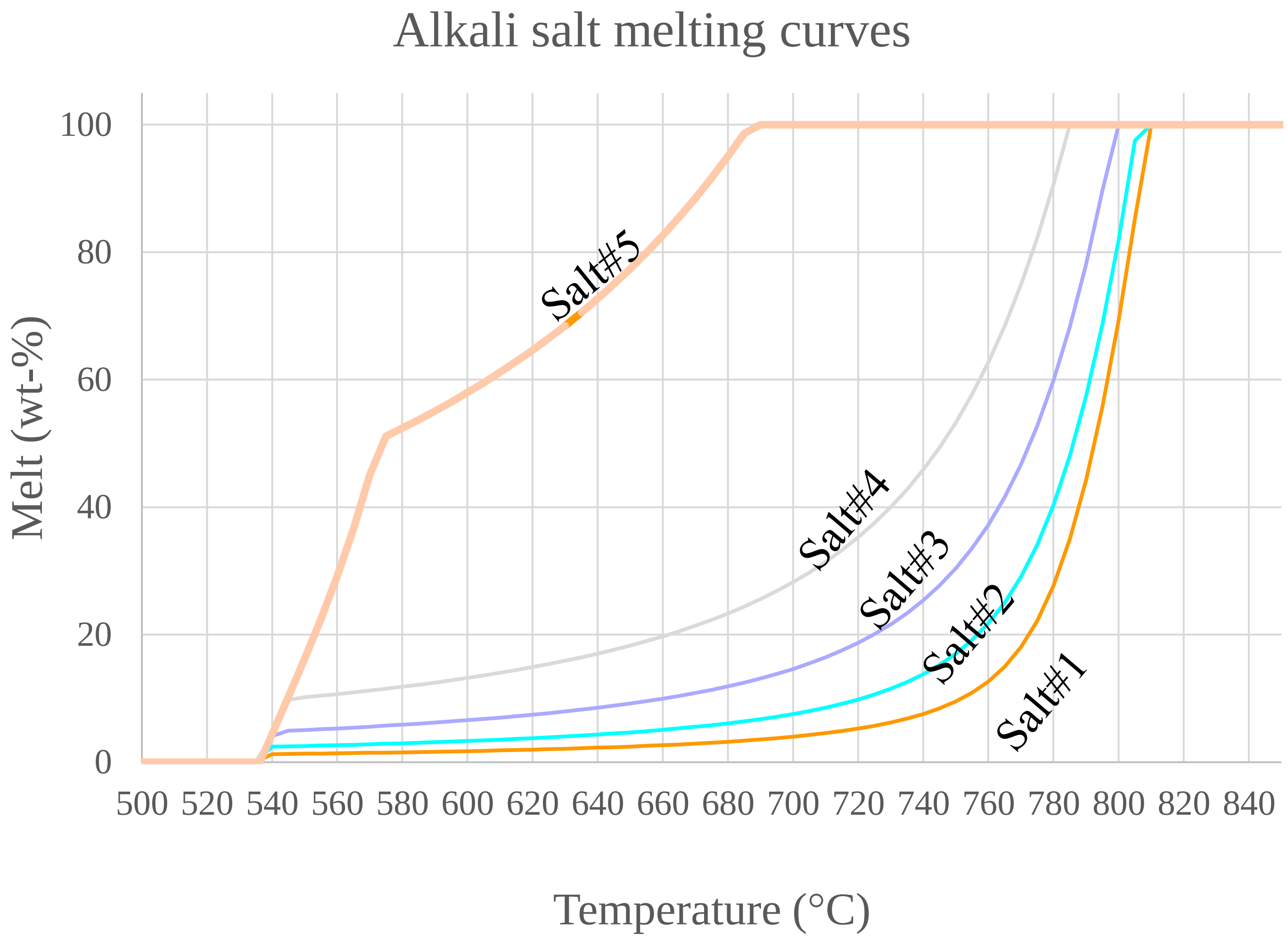
- Five alkali salts with same T_0= 538 °C
- But different percentages of melt at > T_0



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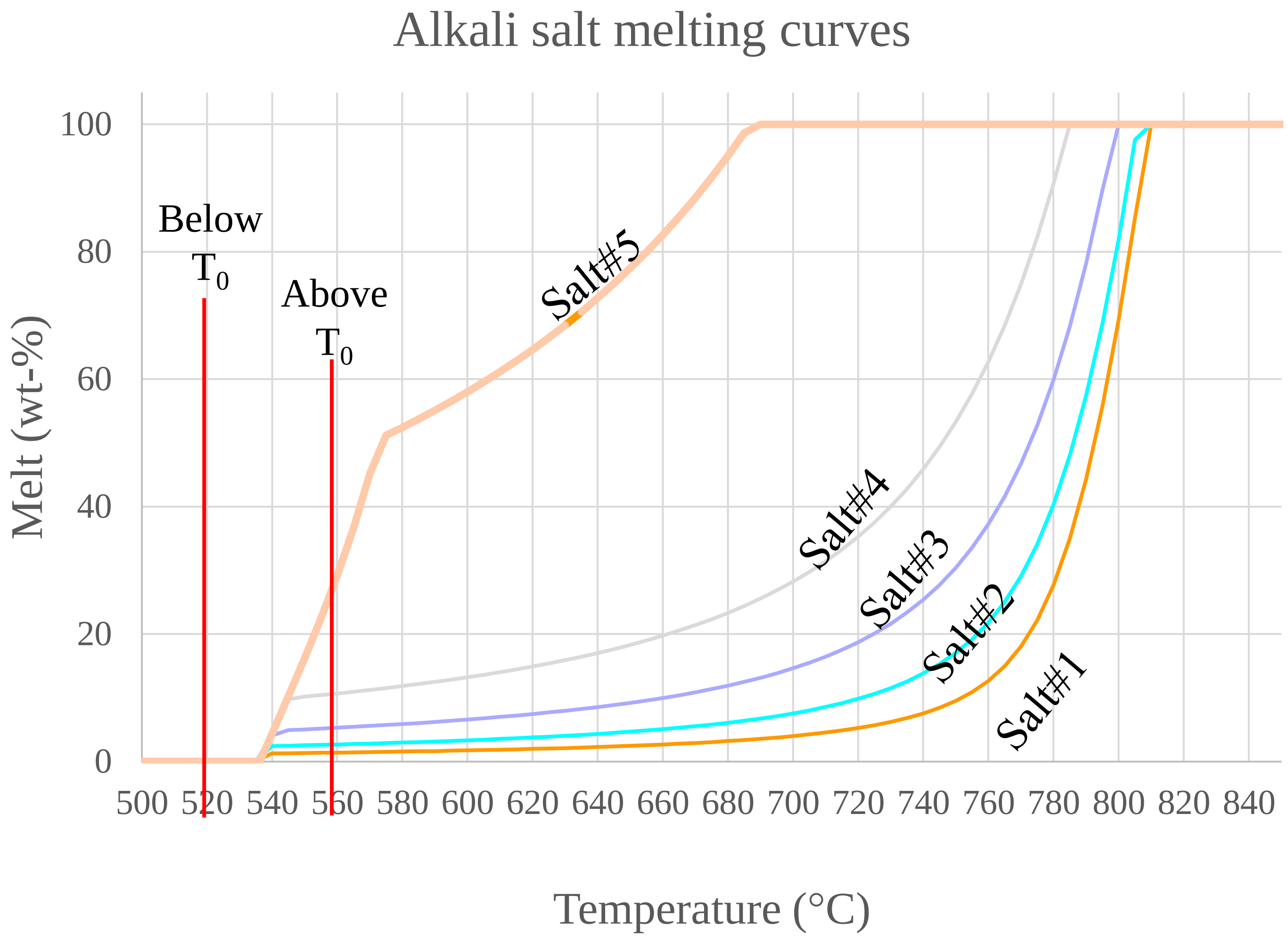
- Five alkali salts with same T_0= 538 °C
- But different percentages of melt at > T_0
- Corrosion at below and above T_0
- Materials tested
  - 10CrMo
  - Sanicro 28
  - Alloy 625



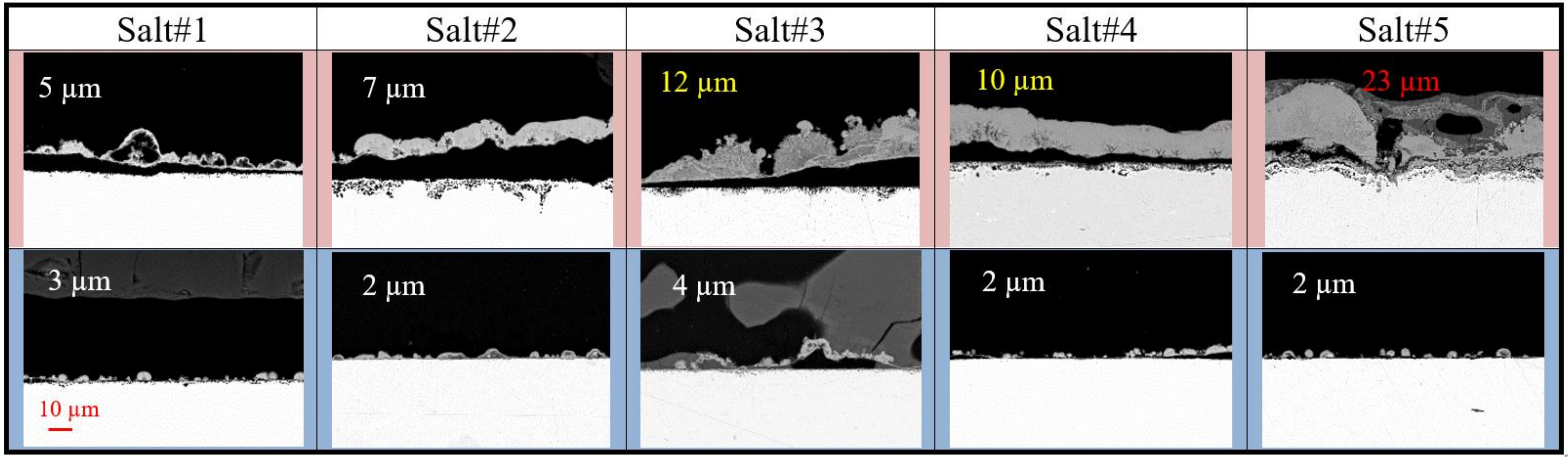
1. The role of the deposit first melting point T_0 in high-temperature corrosion

Laboratory work to better understand the influence on corrosion by the amount of molten phase in contact with the tube surface

Melt amount | 2 wt-% | 4 wt-% | 6 wt-% | 10 wt-% | 20 wt-%

Above T_0 — 560°C

Below T_0 — 520°C



Sanicro 28

Ebba Malm, *”Alkali chloride induced superheater corrosion – Impact of percentage of molten phase”*, MSc thesis, ÅA 2021

1. The role of the deposit first melting point T_0 in high-temperature corrosion

Laboratory work to better understand the influence on corrosion by the amount of molten phase in contact with the tube surface

Most important corrosion criteria at least for me. What is margin with different materials between tube surface temperature and T0 when corrosion starts?

What is important is that how different SH materials will be dissolved into the melts and try to find more molten corrosion resistant materials

This is a critical need to continue to improve the selection of superheater materials and to explain the influence of black liquor chemistry on corrosion rates.

Recent Research Efforts

(Random order)

- Capture efficiency of ESP dust
- Jelly-roll phenomenon
- The role of the deposit first melting point T_0 in high-temperature corrosion 1.
- Deposit aging
- Effects of boiler operation on green liquor dregs settling and filterability properties
- Colorization of deposits
- Understanding compound tube cracking around tertiary and quaternary air ports 4.
- Influence of lignin removal on recovery boiler process
- Accurate detection of SO_3 in recovery boiler flue gases
- Advancement of CFD tools for detailed chemical processes in the furnace
- Improved soot-blower efficiency 3.
- Furnace/flue gas chemistry in extra-large furnaces 5.
- Understanding smelt dissolution mechanisms for safer dissolving tank operation
- Machine learning to improve recovery boiler operation 2.
- Oxy-combustion in the recovery boiler

Conclusions

- Impressive technology development boilers today clean, reliable – and big
- Supported by successful fundamental research efforts
- Key to success:
  - Clear practical need
  - Good communication between companies and researchers (FRBC!)
  - Joint contribution by many people and groups
  - Long-term competence (10 + years before “success”)