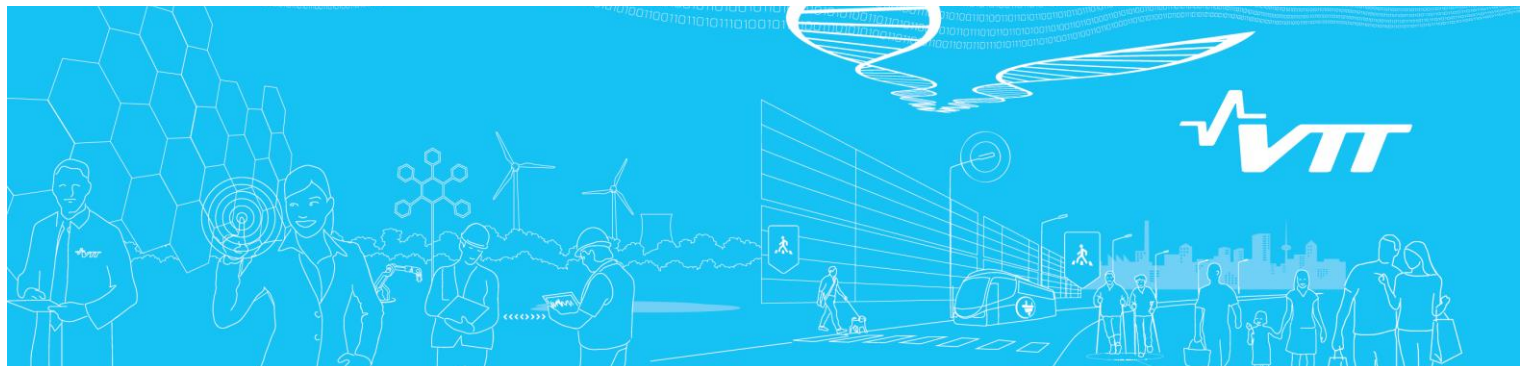


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Nitrogen in wood and its fate in kraft pulping – a review

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1. Introduction

During the past 20-30 years, the knowledge on the fate of wood-derived nitrogen at kraft pulp mills and on the factors affecting (and reducing) nitrogen oxide emissions has significantly increased. It still looks, however, that there is not yet sound reliable information available on all the correlations between the nitrogen contents in wood and black liquor, and the nitrogen oxide emissions. The creation of these correlations has apparently been hampered by varying data available (from literature and different laboratories) on the nitrogen contents, both in wood raw material and black liquors.

Therefore, the current review work was planned to cover the available literature and other potential information sources on the following questions: nitrogen contents in stemwood or pulp mill chips of the key Nordic wood raw materials (pine, spruce and birch), the chemical nature of the wood nitrogen, and the behaviour of nitrogen at the kraft pulp mills (covering both fibre lines and recovery lines).

The material for the current review was based on two different sets: 1) comprehensive collection of literature on wood nitrogen, collected at KCL during 2000–2002 as part of the Rempulp EU project, and 2) further literature searches that especially focused on the new material published during the past 15 years. For the searches, different databases and information sources available at VTT were used, strengthened by comprehensive searches with the help of Scopus and Google Scholar websites.

It can be mentioned here that the elemental composition of wood began to attract chemists during the second half of the 19th century. One of the first investigators was König, who in 1861 found that wood losses some of its nitrogen by copper sulphate treatment (but no exact figures were given). More precise data was later reported by Schroeder (1874), Gottlieb (1883), and Hartig (1888). According to Schroeder (1874), spruce and other woods always contain less than 0.3% of nitrogen. Slightly lower nitrogen figures were reported by Gottlieb (1883), whose numbers are in good agreement with the best current data. Today, there is a lot of wood nitrogen related information available, created for largely varying purposes. These have varied from industrial wood uses to environmental questions and numerous other needs. As a result, the data is also often heterogeneous and challenging to review and analyse; also different analytical methods easily make sound conclusions challenges.

2. NITROGEN IN WOOD – CONTENTS AND DISTRIBUTION

2.1 Nitrogen in softwood

During the comprehensive literature searches it became evident that there is a huge amount of information available on nitrogen contents in dozens of different softwood species covering numerous industrially important genera, including pines, spruces, firs, larches, hemlocks, cypresses and many others. It also became clear that the studies cover all different tree parts, including twigs and branches, bark, roots, and needles. Furthermore, it is evident that practically taken all the main softwood species contain equally low amounts of nitrogen in mature stemwood, as the figures above >0.2–0.3% have only seldom been reported. As will be shown later by selected examples, the highest nitrogen contents are typically found only in the outer layers of sapwood.

Due to the availability of the vast amount of published data, the present Section will mainly focus on the main Nordic softwood species, Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*). For comparison, however, selected data on other pine and spruce species will also be provided, strengthened by examples on other types of softwood species. The currently available information on wood nitrogen does not focus only on the total nitrogen contents. In addition, there is detailed information available on the distribution of nitrogen in different parts of stemwood. This type of variation will also be demonstrated below, with the help of selected examples.

For the nitrogen contents of Scots pine (Table 1) and Norway spruce (Table 2), most of the figures reported during the past 100 years have remained below 0.15%. In only a few cases any figures on the levels of >0.15% have been published. The highest figures for both pine (0.24%) and spruce (0.25%) are derived from the Swedish Ecocyclic pulp mill project (Anon. 1999) and may be explained by systematically different analytical approach.

Table 1. Nitrogen contents (%) of Scots pine, according to different sources.

Nordic studies		Other European studies	
Contents (%)	Reference	Contents (%)	Reference
0,07-0,13	Magnusson et al. 1979	0,13	Schwalbe & Becker 1919
0,04	Paavilainen 1980	0,05-0,09	Nickel 1960
c. 0,05-0,1	Siltala 1988, Helmisaari 1989	0,08-0,11	Becker 1962
0,06-0,07	Finér 1989	0,03-0,08	Popović 1966
0,05-0,08	Häsänen & Huttunen 1989	0,06	Keller & Nussbaumer 1993
0,04-0,08	Boutelje et al. 1990	0,07	Marutsky & Roffael 1977
0,09-0,11	Terziev et al. 1997	0,05-0,08	Adelsberger & Petrowitz 1976
0,06	Terziev 1995	0,13	Allsop & Misra 1940
0,04-0,06	Varhimo 1988	0,07	Ovington 1957
0,05	Telkkinen 1996, 1999	0,08-0,1	Wright and Will 1958
0,05-0,08	Hedenberg 1996	0,06-0,09	Laidlaw & Smith 1965
0,12-0,24	Anon. 1999	c. 0,04-0,1	King et al. 1974
0,07	Nurmi 1997		
0,04	Niemelä & Ulmgren 2002		
c. 0,05	Palvianen et al. 2010		

Table 2. Nitrogen contents (%) of Norway spruce, according to different sources.

Nordic studies		Other European studies	
Contents (%)	Reference	Contents (%)	Reference
0,07-0,17	Magnusson 1979	0,07	Marutsky & Roffael 1977
0,06	Finér 1989	0,04	Gottlieb 1883
0,05	Boutelje et al. 1990	0,11	Schwalbe & Becker 1919
0,03	Westernark et al. 1986	0,18	König & Becker 1919
0,04-0,05	Varhimo 1988	0,04-0,08	Becker 1962
0,05	Telkkinen 1996, 1999	0,07	Keller & Nussbaumer 1993
0,04-0,05	Hedenberg 1996	0,07-0,10	Ovington 1957
0,12-0,25	Anon. 1999	0,17	Ovington 1957
0,04	Nurmi 1997	0,07	Merrill and Cowling 1966a
0,09-0,13	Ingerslev 1999	c. 0,04-0,08	King et al. 1974
0,06-0,11	Anttonen et al. 2002		
0,08-0,15	Kaakinen et al. 2007		
0,14-0,16	Kaakinen et al. 2009		
c. 0,07	Palviainen et al. 2010		

There is an interesting difference between the above data reported for pine and spruce. Namely, nearly all the figures for pine are below 0.1%, whereas for spruce two different data sets can be recognised: those around from c. 0,04 to 0,08%, and those going clearly above 0.1% (up to 0.16-0.18%). No unambiguous explanation for that can now be given, and for example, no apparent differences could be recognised in the applied analytical methods to readily explain the differences.

For many of the above nitrogen contents figures there are ranges given, for a number of reasons. For example, Magnusson (1979), Varhimo (1988), Häsänen & Huttunen (1989) and Hedenberg (1996) have studied wood samples from several geographical areas. On the other hand, Nickel (1960), Siltala (1988), Boutelje et al. (1990) and many others have provided figures from different parts of the logs. There is also variation in the nitrogen contents caused by the use of different levels of fertilisation, e.g. those by Ingerslev (1999), Anttonen et al. (2002) and Kaakinen et al. (2007, 2009). Selected examples are given below to further demonstrate the extent of this type of variations.

Nickel (1960) investigated nitrogen and protein contents in a 100-year-old Scots pine wood and found a steep decrease from the utmost sapwood towards the heartwood, followed by a small rise in the inner heartwood zone towards the centre (Fig. 2). Orman and Will (1960) found a similar distribution pattern in a 26-year-old radiata pine. Becker (1962) investigated in detail nitrogen contents (expressed as proteins by multiplying with 6.25) in Scots pine and other softwoods (Fig. 2). His results support (and widen) those from the earlier investigations.

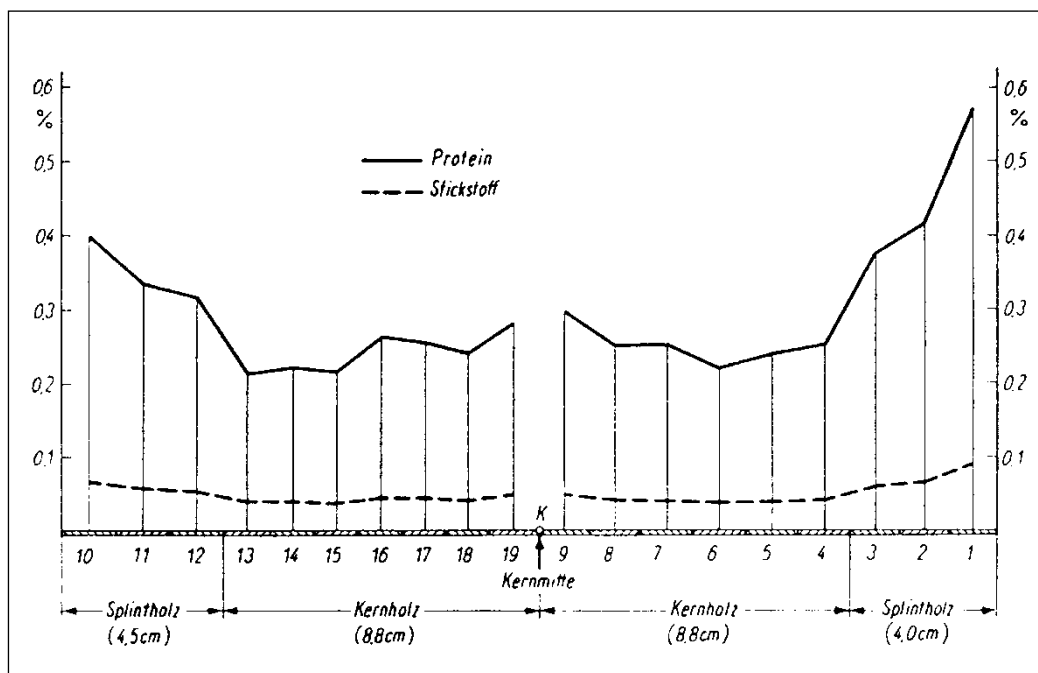


Fig. 1. Nitrogen and protein concentrations in a 100-year-old Scots pine (Nickel 1960).

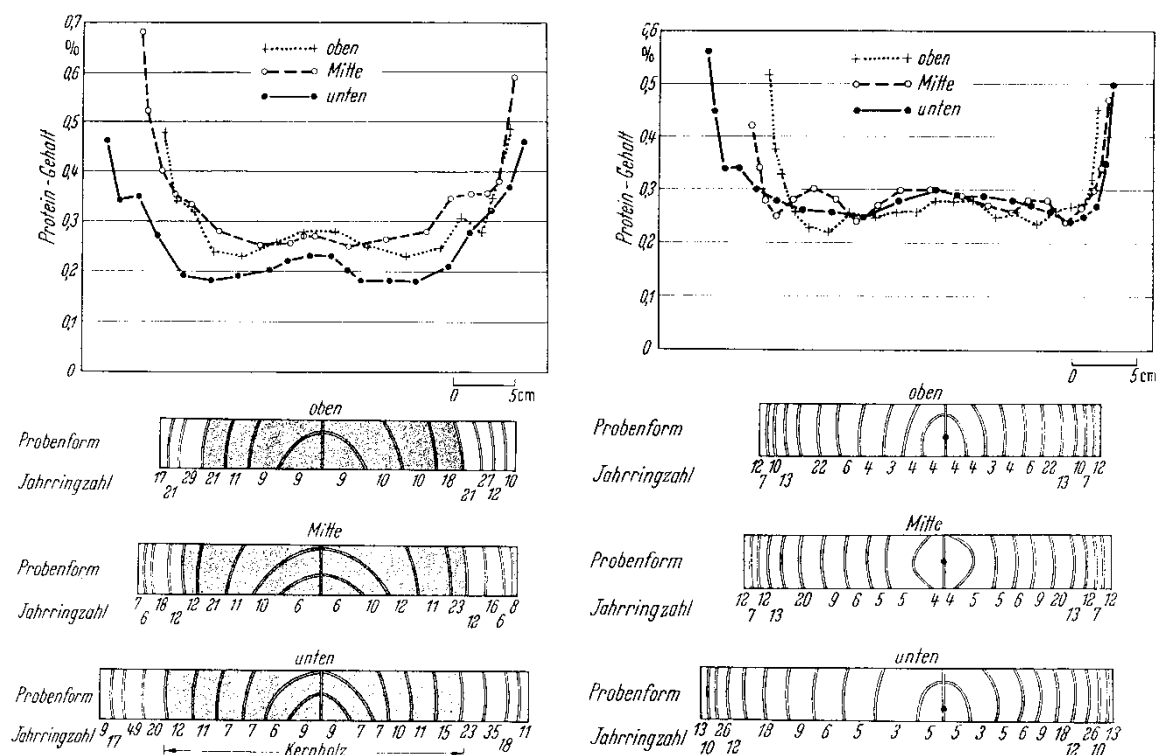


Fig. 2. Protein concentrations over cross sections in Scots pine (left) and Italian spruce (*Picea excelsa*, right) at three different heights (oben, Mitte, unten) corresponding to 2.5, 5, and 7.5 metres (Becker 1962). Similar distribution was also found (figure not reproduced) for a noble fir (*Abies pectinata*).

Apparently one of the most comprehensive of the above-mentioned distribution-related studies is that by Siltala (1988). In his M.Sc. Thesis, he investigated distribution of nitrogen in pine seedlings, young trees, and mature trees, paying attention to xylem, inner bark, outer bark, seasonal changes, and soil fertilisation (Figs. 3–8). The major results from the Siltala's Thesis are also published in a scientific paper by Helmisaari and Siltala (1989).

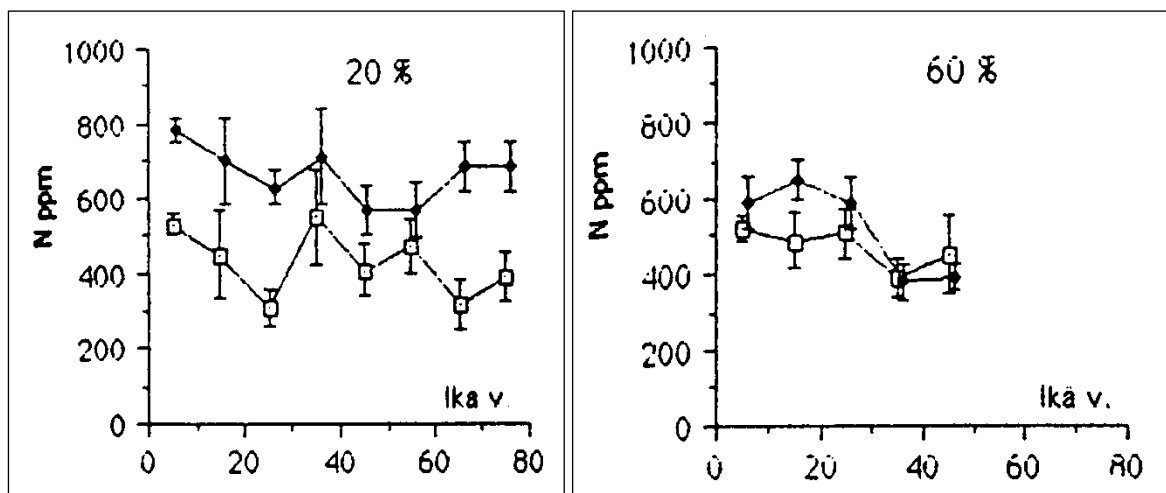


Fig. 3. Horizontal distribution of nitrogen in pine wood (xylem) at relative heights of 20% and 60%, according to Siltala (1988). *lkä* refers to number of growth rings; • indicates pine grown in a fertilised area; and □ refers to pine grown in a non-fertilised area.

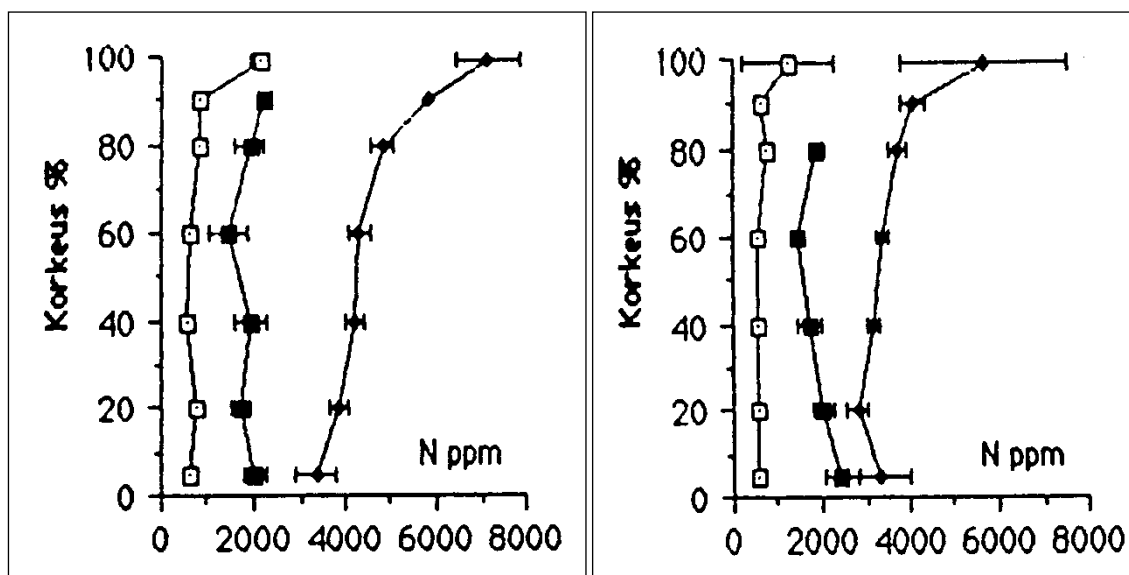


Fig. 4. Vertical distribution of nitrogen in pine wood grown in a fertilised (left) and non-fertilised (right) area, according to Siltala (1988). *Korkeus* refers to relative tree height; □ indicates xylem; ■ indicates inner bark, and • indicates outer bark.

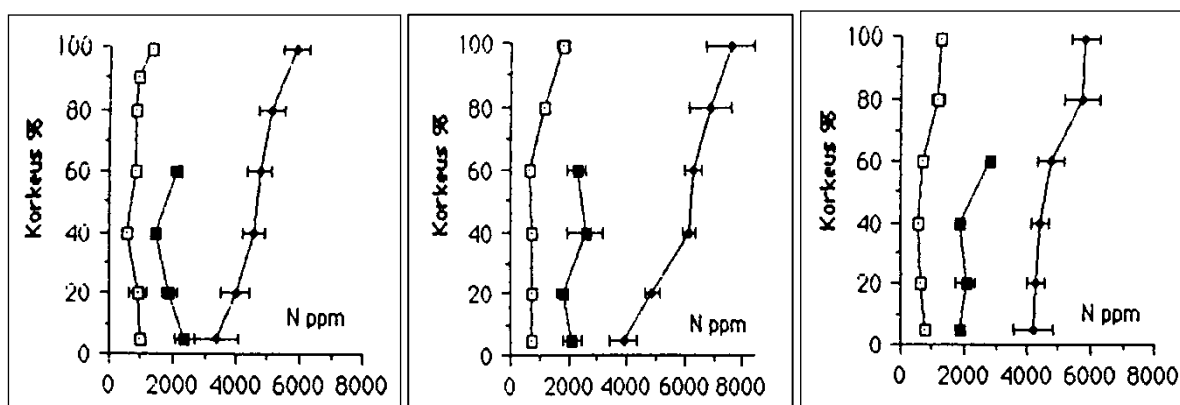


Fig. 5. Vertical distribution of nitrogen in pine wood grown in different localities, according to Siltala (1988). Symbols as in Fig. 3.

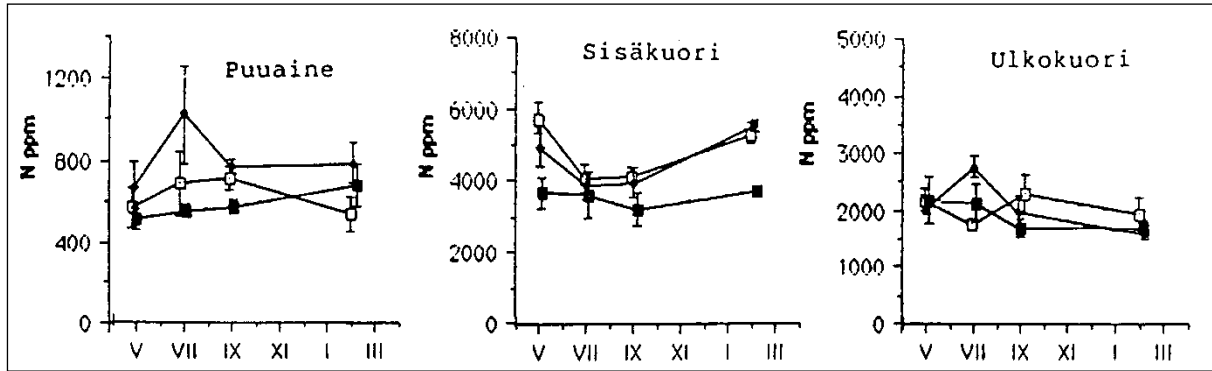


Fig. 6. Seasonal variation of nitrogen content in pine wood xylem (left), inner bark (middle), and outer bark (right), according to Siltala (1988). $\square$ indicates seedlings; $\blacksquare$ indicates young forest, and $\bullet$ indicates mature trees.

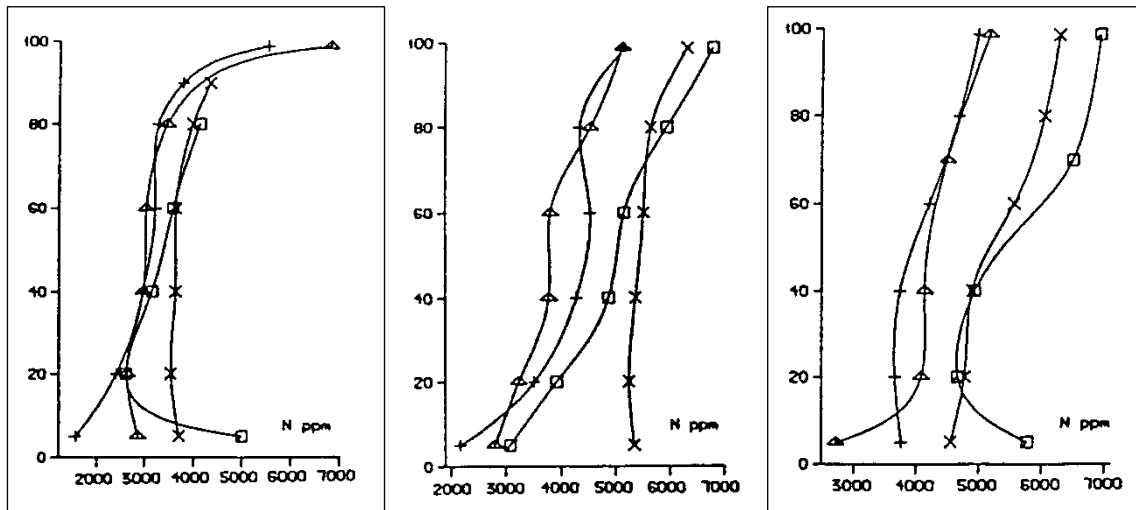


Fig. 7. Seasonal variation in vertical nitrogen content in inner bark of pine: mature trees (left), young trees (middle), and seedlings (right), according to Siltala (1988). Sampling in February ($\square$), May ($\square$), July ($\otimes$), and September (+).

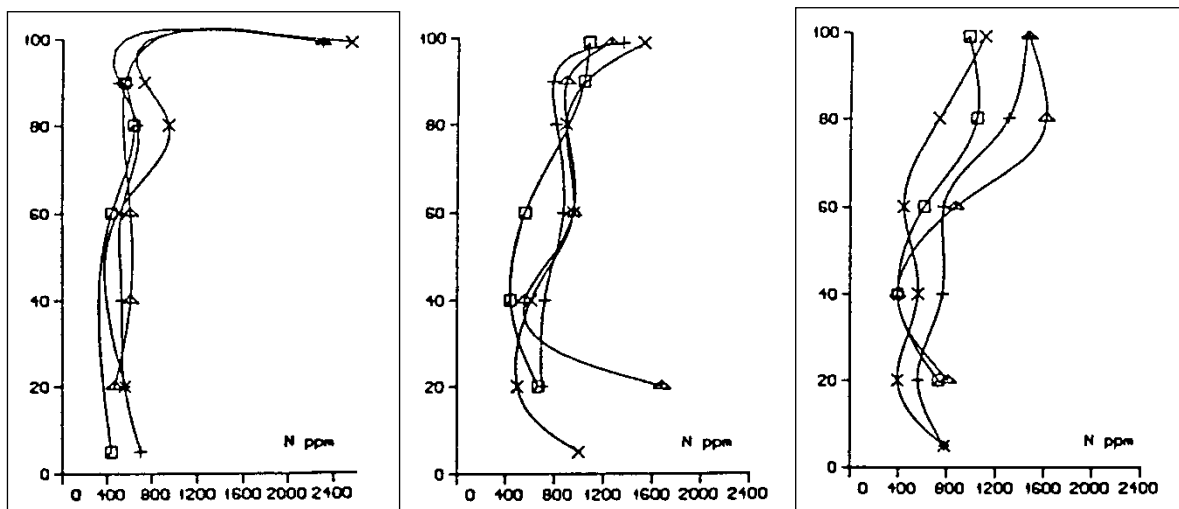


Fig. 8. Seasonal variation in vertical nitrogen content in outer sapwood of pine: mature trees (left), young trees (middle), and seedlings (right), according to Siltala (1988). Sampling in February ($\square$), May ($\square$), July ($\otimes$), and September (+).

The above Siltala's (1988) figures for Scots pine clearly confirm earlier findings on higher nitrogen content in wood bark, and also reveal some seasonal variation. This type of variation is, however, much more typical for hardwood (Section 2.2).

Results from a highly interesting study were published by Kaakinen et al (2007) some years ago, including measurements on the effects of nitrogen-fertilisation on the nitrogen contents of Norway spruce on two locations in Finland. They studied "the effect of long-term nitrogen fertilisation on wood chemistry at two boreal sites in Finland: the northern site (Kemijärvi) and the southern site (Heinola). N-fertilisation was repeated in five-year intervals from the 1960s. The trees that had been planted in 1938 and 1954, in the northern and the southern site, respectively, were harvested in October 2002. Altogether 20 trees, in five different size classes, either unfertilised or fertilised, were felled. Wood sections at breast height, consisting of five consecutive annual rings, from six (Kemijärvi) or five (Heinola) points with different distances from the pith were examined. Differences in growth between the northern and southern sites were marked in favour of the southern site. In the northern site fertilisation had clearly increased the diameter growth, while in the southern site fertilisation had no effect. Nitrogen fertilisation resulted in slight changes in wood chemistry that included increased nitrogen concentrations in the northern site and extractives in the southern site (Table 3). Stem wood had higher concentrations of extractives, starch, and uronic acids, and lower concentration of cellulose, in the northern than in the southern site".

Table 3. Wood component concentrations (% DM) and ratios from the pith to the bark in the northern site (Kemijärvi) and in the southern site (Heinola) in Finland (Kaakinen et al. 2007). U, unfertilised; F, nitrogen-fertilised.

Annual ring sections	Carbon		Nitrogen		Carbon/nitrogen		Total lignin/nitrogen	
	U	F	U	F	U	F	U	F
The northern site								
1958–1962	49.92 ± 0.05	50.00 ± 0.24	0.112 ± 0.008	0.098 ± 0.013	455 ± 33	542 ± 73	277 ± 17	316 ± 44
1965–1969	49.66 ± 0.09	49.93 ± 0.07	0.110 ± 0.004	0.108 ± 0.009	455 ± 19	481 ± 42	263 ± 10	281 ± 24
1975–1979	49.76 ± 0.05	49.95 ± 0.10	0.120 ± 0.004	0.112 ± 0.007	417 ± 16	452 ± 25	242 ± 11	259 ± 13
1985–1989	49.52 ± 0.17	49.63 ± 0.20	0.102 ± 0.016	0.136 ± 0.007	553 ± 113	365 ± 17	317 ± 62	213 ± 8
1993–1997	49.66 ± 0.04	49.65 ± 0.13	0.130 ± 0.000	0.143 ± 0.008	382 ± 0	351 ± 18	222 ± 4	204 ± 13
1998–2002	49.83 ± 0.17	49.35 ± 0.22	0.133 ± 0.009	0.148 ± 0.003	381 ± 26	335 ± 7	221 ± 18	190 ± 7
The southern site								
1963–1967	50.70 ± 0.24	50.64 ± 0.08	0.088 ± 0.008	0.094 ± 0.005	596 ± 54	544 ± 29	345 ± 32	317 ± 17
1973–1977	50.76 ± 0.15	50.78 ± 0.10	0.076 ± 0.007	0.100 ± 0.007	693 ± 65	518 ± 38	403 ± 40	299 ± 20
1983–1987	50.60 ± 0.09	50.76 ± 0.06	0.106 ± 0.011	0.102 ± 0.008	503 ± 62	510 ± 41	291 ± 38	288 ± 26
1993–1997	50.42 ± 0.10	50.56 ± 0.08	0.108 ± 0.004	0.118 ± 0.012	469 ± 17	457 ± 67	265 ± 7	258 ± 39
1998–2002	50.28 ± 0.07	50.24 ± 0.08	0.150 ± 0.012	0.140 ± 0.004	343 ± 26	360 ± 12	193 ± 14	201 ± 6

Kaakinen et al. (2009) also compared the properties and composition of control and nutrient optimised Norway spruce stems, grown in Sweden. The reported nitrogen contents were 0.14 and 0.16% for the control and nutrient optimised samples, respectively. Anttonen et al. (2002) also studied in Sweden the impacts of optimal fertilization of chemistry of spruce and found the wood nitrogen increase from 0.06 to 1.1%

Other type of data on concentrations and distribution of nitrogen in pines comes from several studies on the effect of drying on nitrogen compounds. For example, Boutelje (1990) analysed a large number of pine plank samples (at different locations) with both Antek and Dumas methods (Table 4). The latter method always gave somewhat higher nitrogen figures. The results are also discussed by Theander et al. (1993).

Table 4. Nitrogen content in 32 samples taken from two Scots pine planks (A and B), according to Boutelje et al. (1990). IS, inner sapwood; H, heartwood. See the original work for the sampling details and for the effects of drying on the nitrogen content. The original work also gives some nitrogen concentrations for Norway spruce.

Sample No	Origin and location	N, % of dry weight	
		Dumas	Antek
1	A; IS; 0–2 mm fr. original end surface	0.083	0.057
2	A; IS; 2–4 mm fr. original end surface	0.075	0.057
3	B; IS; 0–2 mm fr. original end surface	0.092	0.057
4	B; IS; 2–4 mm fr. original end surface	0.097	0.063
5	A; H; 0–2 mm fr. original end surface	0.073	0.055
6	A; H; 2–4 mm fr. original end surface	0.070	0.048
7	B; H; 0–2 mm fr. original end surface	0.060	0.053
8	B; H; 2–4 mm fr. original end surface	0.068	0.049
9	A; IS; 750–760 mm fr. original end surface	0.057	0.047
10	A; – ;	0.057	0.046
11	A; – ;	0.058	0.045
12	B; IS; 750–760 mm fr. original end surface	0.061	0.044
13	B; – ;	–	0.046
14	B; – ;	0.073	0.047
15	A; H; 750–760 mm fr. original end surface	0.036	0.036
16	A; – ;	0.044	0.039
17	A; – ;	0.045	0.039
18	B; H; 750–760 mm fr. original end surface	0.042	0.046
19	B; – ;	0.039	0.039
20	B; – ;	0.041	0.034
21	A; IS; 0– 1 mm fr. radial surface	0.061	0.053
22	A; IS; 1– 2 mm fr. radial surface	0.062	0.048
23	A; IS; 2– 3 mm fr. radial surface	0.053	0.044
24	A; IS; 15–16 mm fr. radial surface	0.057	–
25	B; IS; 0– 1 mm fr. radial surface	0.087	0.069
26	B; IS; 1– 2 mm fr. radial surface	0.079	0.079
27	B; IS; 2– 3 mm fr. radial surface	0.063	0.058
28	B; IS; 15–16 mm fr. radial surface	0.058	0.049
29	B; IS; 0– 1 mm fr. tangential surface	0.061	0.059
30	B; IS; 1– 2 mm fr. tangential surface	0.087	0.075
31	B; IS; 2– 3 mm fr. tangential surface	0.064	0.060
32	B; IS; 15–16 mm fr. tangential surface	0.061	0.042

The above studies, substantiated by that of King et al. (1974), also reveal some re-distribution of nitrogen during drying. This was studied in more detail by Terziev (1995) and Kreber et al. (1998). Selected examples shown in Figs. 9–10 show the tendencies of (soluble) nitrogen to migrate from deeper layers towards the surface, particularly during kiln drying. There is also some stain formation, believed to be caused by Maillard-type reactions between amino acids and carbohydrates. This has also been evidenced in a more detailed study of the nitrogen compounds (Donald et al. 2000).

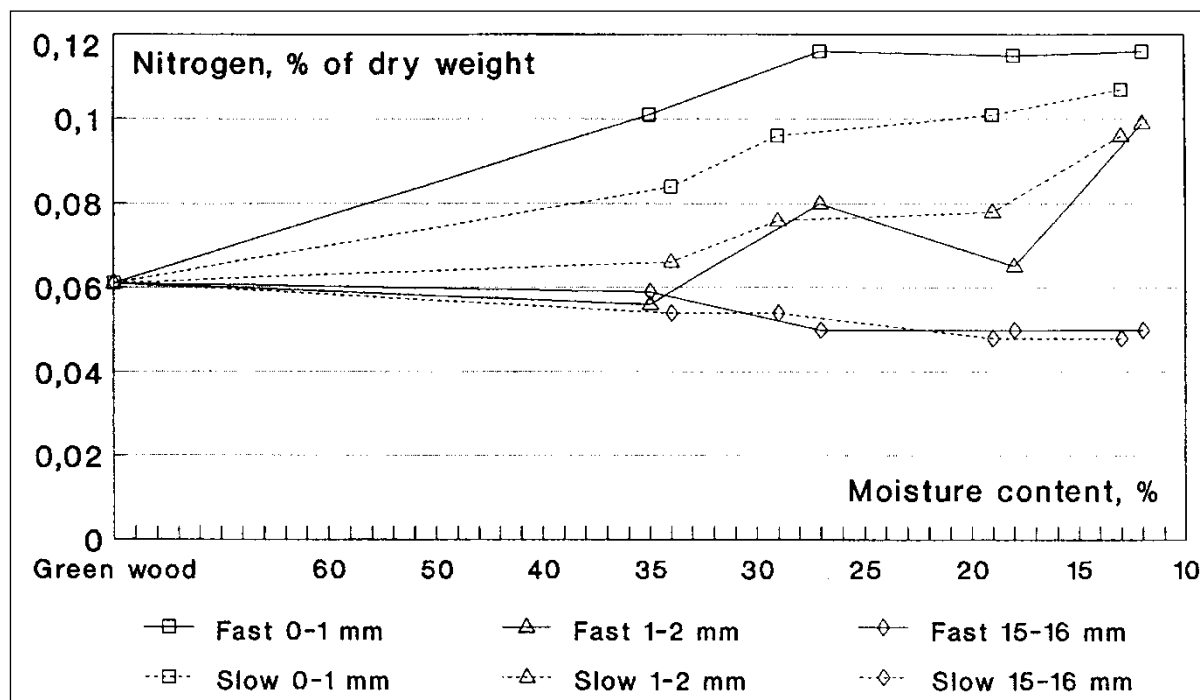


Fig. 9. Concentration of nitrogen in unedged planks of Scots pine during kiln drying at 80 C, as a function of moisture content. (Terziev 1995). Note the increase of nitrogen content in the surface layers, as a result of nitrogen migration from deeper layers. Similar tend was not found during air drying (see the original publication for that).

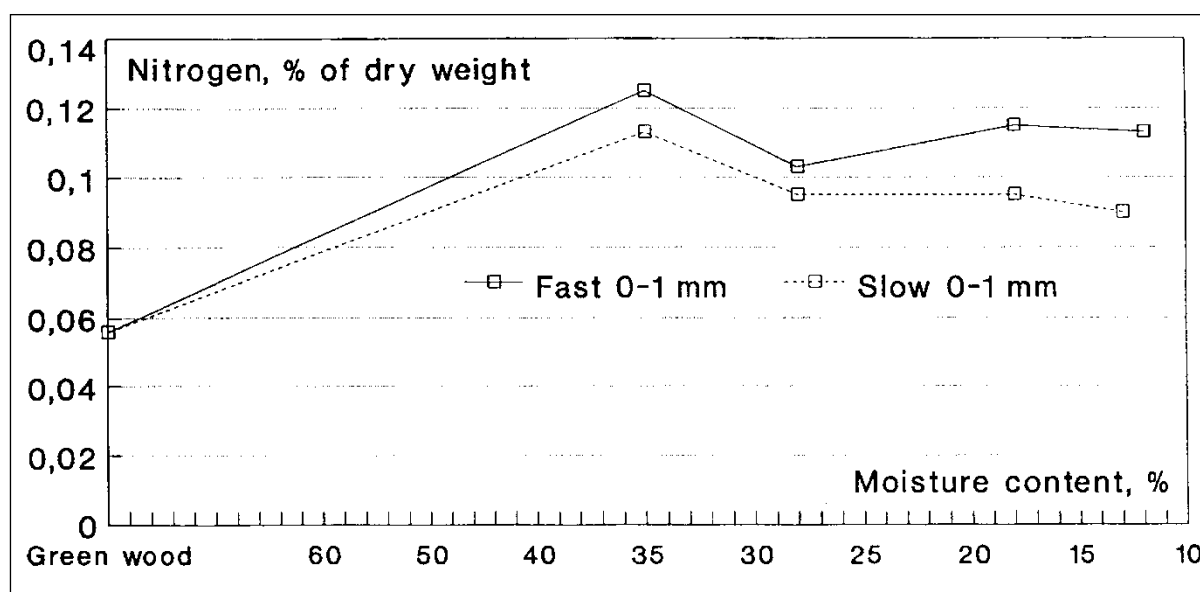


Fig. 10. Concentration of nitrogen in edged planks of Scots pine during kiln drying (Terziev 1995).

As already pointed out in the beginning of this Section, other pine and spruce species (as well as softwoods from other genera) all seem to have very similar or even equal nitrogen contents. In this context it is not justified to provide detailed summaries on such investigations. For the potential need of further information on this question, the following references can be recommended as representative examples:

- Meerts (2002) has summarised contents of nitrogen and other nutrients for nearly 100 different wood species, including >20 softwoods. For comparison, the summary tables from this study are provided in Appendix 1.
- A large number of papers report the nitrogen contents of c. 0.04-0.12% for several foreign pine species, such as contorta, echinata, elliotii, nigra, lambertiana, monticola, palustris, ponderosa, taeda, radiata and strobus (e.g. Allison et al. 1963, Ovington 1957, Wright and Will 1958, Orman and Will 1960, Young and Guinn 1964, Merrill and Cowling 1966a, Ziegler 1968, Haas and Kremer 1964, Young 1971, Birk and Vitousek 1986, Wong and Wilkes 1988, Martin et al. 2015).
- Similar (usually c. 0.05–0.15%) nitrogen contents have been reported for numerous foreign spruce, fir, larch and hemlock species (for example by Allison et al. 1963, Ovington 1957, Young and Guinn 1964, Ziegler 1968, Haas and Kremer 1964, Young 1971, and Martin et al. 2015).

2.2 Nitrogen in hardwood

For the contents of nitrogen in the Nordic birch wood, there is clearly less information available than for softwood (Table 5). The scattered data reveals the concentration ranges very similar than those in softwood, covering a few examples showing values below 0.1%, and several examples with somewhat higher figures. The highest reported figures seem to be just under 0.2%. The figure of 0.18% by Palviainen et al. refers to birch stumpwood.

Data collected by Meerts (2002) for dozens of different hardwood species includes only a few examples of any species with the nitrogen contents of c. 0.2-0.25%, more typical ranges being around 0.05–0.17%. It thus looks that the Nordic birch species represent typical nitrogen contents among many other hardwood genera. In the total dataset by Meerts, the average values for nitrogen were 0.08% and 0.11% in all softwood and hardwood (heartwood) materials, respectively. It may be added here that the typical Eucalyptus wood nitrogen contents were around 0.1–0.15%.

Table 5. Nitrogen contents (%) in birch (*Betula pendula/verrucosa*), according to the selected Nordic and European studies.

Nordic studies		Other European studies	
Contents (%)	Reference	Contents (%)	Reference
0,06-0,15	Magnusson et al. 1979	0,1	Gottlieb 1883
0,11-0,19	Mälkönen & Saarsalmi 1982	0,12	Schwalbe & Becker 1919
0,08-0,11	Varhimo 1988	0,19	König & Becker 1919
0,08-0,1	Telkkinen 1996, 1999	0,14	Marutzky & Raffael 1977
0,07-0,08	Hedenberg 1996	0,14-0,15	Ovington 1957
0,04-0,07	Nurmi 1997		
0,06	Niemelä and Ulmgren 2002		
0,13	Niemelä et al. 2003		
c. 0,18	Palviainen et al. 2010		

2.3 Nitrogen in wood bark

It has already been mentioned that sapwood and especially bark contains more nitrogen than heartwood. As a good representative example on the nitrogen contents in the main Nordic (Finnish) bark, a summary table from Nurmi (1997) is reproduced (Table 6).

Table 6 Content of carbon, hydrogen and nitrogen in different parts of the main Finnish softwood and hardwood species (Nurmi 1997).

Element/ Species	Wood				Inner bark		Outer bark		All bark		Foliage
	Stem	Branches	Stump	Roots	Stem	Branches > 5mm	Stem	Branches > 5mm	Branches < 5mm	Roots	
Carbon, % of dry weight											
<i>P. sylvestris</i>	52.70	55.59	58.49	54.08	51.86	52.32	54.88	54.72	55.07	55.59	50.49
<i>P. abies</i>	51.48	52.84	52.69	54.08	52.04	48.84	55.54	55.90	54.95	52.32	51.50
<i>B. pubescens</i>	51.68	52.68	51.52	52.67	51.08	51.68	72.77	70.62	54.88	53.28	51.50
<i>B. pendula</i>	51.92	52.37	51.2	51.52	52.44	52.46	72.24	70.24	53.02	54.94	51.00
<i>A. incana</i>	52.72	51.61	51.78	52.24	54.61	54.14	65.07	60.71	55.31	55.11	52.60
<i>A. glutinosa</i>	51.78	51.54	49.02	50.94	53.08	53.33	59.07	60.71	56.34	53.96	50.69
<i>P. tremula</i>	51.86	51.50	51.44	50.70	51.86	50.99	55.70	52.85	52.43	54.19	51.40
Hydrogen, % of dry weight											
<i>P. sylvestris</i>	6.46	6.39	7.07	6.38	5.81	5.60	5.52	5.66	5.77	4.89	6.37
<i>P. abies</i>	6.32	6.52	6.25	6.36	5.79	5.39	5.66	5.46	5.64	5.32	5.78
<i>B. pubescens</i>	6.28	6.38	6.32	6.22	5.63	5.77	9.21	8.93	6.24	5.19	5.84
<i>B. pendula</i>	6.21	6.45	6.15	6.31	5.81	5.79	9.24	9.00	5.87	5.28	6.13
<i>A. incana</i>	6.34	6.33	6.16	6.26	6.07	5.88	7.49	7.08	6.13	5.73	5.89
<i>A. glutinosa</i>	6.23	6.35	6.07	6.15	5.72	5.77	6.03	7.13	6.34	5.52	5.94
<i>P. tremula</i>	6.32	6.28	6.18	6.17	5.88	5.80	6.44	6.33	5.80	5.41	5.90
Nitrogen, % of dry weight											
<i>P. sylvestris</i>	0.07	0.08	0.05	0.08	0.54	0.53	0.25	0.25	0.73	0.37	1.07
<i>P. abies</i>	0.04	0.09	0.08	0.12	0.61	0.39	0.39	0.4	0.53	0.41	0.89
<i>B. pubescens</i>	0.07	0.17	0.08	0.24	0.38	0.39	0.32	0.32	0.65	0.49	1.99
<i>B. pendula</i>	0.04	0.16	0.07	0.17	0.38	0.51	0.33	0.38	0.82	0.61	1.61
<i>A. incana</i>	0.18	0.21	0.22	0.28	0.75	0.91	0.99	1.22	1.45	1.22	3.21
<i>A. glutinosa</i>	0.2	0.33	0.24	0.53	1.17	1.19	0.98	1.14	1.44	1.3	2.7
<i>P. tremula</i>	0.02	0.14	0.13	0.37	1.13	0.91	0.49	0.46	0.75	1.21	1.95

Similar data for pine, spruce and birch bark nitrogen has also been reported by Hedenberg (1996), using material from several Swedish pulp mills. Otherwise, it is especially noteworthy that the highest nitrogen contents always seem to be present in inner bark, demonstrating the role of good debarking as one of the means to control pulp mill's NO_x emissions.

2.4 Nature of nitrogen compounds in wood

There should be no doubt that majority of wood nitrogen is bound to proteins, although free amino acids are apparently also always present. Lower amounts of miscellaneous organic nitrogen compounds have also been reported, and in addition, some inorganic compounds (ammonia and nitrate) can be found. The existing literature on wood amino acids and proteins is relatively extensive (Lists 1-2), indicating that typical major plant amino acids also play key roles in trees.

List 1. Studies on characterisation conifer proteins and free amino acids.

Holmes and Kurth (1961), Barnes (1963), Fukuda (1963), Laidlaw and Smith (1965), Durzan and Steward (1967), Hodges et al. (1968), Ziegler (1968), Clark and Mills (1970), Adelsberger and Petrowitz (1976), Butcher and Fountain (1987), Fukuda et al. (1988), Wetzal and Greenwood (1989), Harms and Sauter (1991), Roberts et al. (1991), Pietiläinen and Lähdesmäki (1995), Lähdesmäki and Pietiläinen (1996), Donald et al. (2000), Sudachkova et al. (2000), Hafrén (2007).

List 2. Examples of studies on characterisation of hardwood proteins and amino acids.

Mittler (1953), Reuter and Wolfgang (1954), Bollard (1957), Mugg (1959), Lamport and Northcote (1960), Barnes (1963), Dickson (1989), Dietrichs and Funke (1967), Sauter (1981), Titus et al. (1982), Cleve et al. (1988), Putman et al. (1989, 1991), Wetzell and Greenwood (1991a, 1991b), Harms and Sauter (1992), Sauter and van Cleve (1994), Stepien et al. (1992, 1994), Close (1996), Sauter and Wellenkamp (1998), Sauter et al. (1989, 1999).

During the past years and, more and more attention has been paid to the roles and characterisation of different cell wall proteins in wood (List 3), as more advanced isolation and analysis techniques have been developed. For example, Gion et al. (2005) identified 175 proteins in a wood forming tissue of maritima pine and found them play a role in either defence (19.4%), carbohydrates (16.6%) and amino acid (14.9%) metabolisms, genes and proteins expression (13.1%), cytoskeleton (8%), cell wall biosynthesis (5.7%), secondary (5.1%) and primary (4%) metabolisms.

List 3. Studies on protein-lignin complexes, protein-polysaccharide complexes and cell wall proteins in wood.

Heath et al. (1971), Whitmore (1982), Dill et al. (1984), Fukuda et al. (1988), Bao et al. (1992), Karácsonyi et al. (1996, 1998), Gion et al. (2005), Makarova et al. (2015), Costa et al. (2016), Fleming et al. (2016).

Examples of amino acid compositions in Nordic softwood raw materials are given in Tables 7-8. Of these amino acids, hydroxyproline produces a specific compound during kraft pulping that can be found in black liquors, condensates, and rectified methanol. Another example (Table 9) refers to a study by Adelsberger and Petrowitz (1976) who analysed total nitrogen and protein in different parts of pine wood stem, and confirmed the dominating role of proteins compared to total nitrogen.

Tables 7-8. Amino acid composition in Scots pine (left, Bao et al. 1992) and Norway spruce TMP pulp proteins (Hafrén 2007).

Residue	Mol %	Amino acid	Relative amount (%)
Aspartic acid	8.06	Aspartic acid	11
Glutamic acid	3.24	Threonine	6
Hydroxyproline	11.47	Serine	8
Serine	6.34	Glutamic acid	12
Glycine	7.86	Proline	7
Histidine	0.78	Glycine	7
Threonine	4.82	Alanine	6
Arginine	2.19	Valine	7
Alanine	6.44	Methionine	1
Proline	24.04	Isoleucine	6
Tyrosine	4.06	Leucine	8
Valine	5.66	Tyrosine	5
Methionine	0.75	Phenylalanine	5
Cysteine	ND	Histidine	2
Isoleucine	1.34	Lysine	4
Leucine	2.97	Arginine	5
Tryptophan	ND		
Phenylalanine	1.52		
Lysine	8.46	Total	100

Table 3.21. Concentrations of total nitrogen and protein-nitrogen in different annual growth rings of a pine wood stem (Adelsberger and Petrowitz 1976).

Lagerungsdauer [Jahre]	Gesamt-N (Kjeldahl) [µg/g T. G.]	Protein-N (AS-Analyse) [µg/g T. G.]	$\frac{\text{Protein-N}}{\text{Gesamt-N}} \times 100$ [%]	Protein [% T. G.]
0,8*	830	720	87	0,45
1,5*	590	480	82	0,30
18*	660	450	68	0,28
60**	580	340	58	0,21
100**	900	440	49	0,28

3. Fate of wood nitrogen at kraft pulp mills

During the past decades, more and more attention has been paid to the fate of wood nitrogen and its reaction products, both in the fibreline and recovery line processes. Important recent sources of information include extensive studies at Åbo Akademi (Kymäläinen, DeMartini, Vähä-Savo et al.) and EU funded project Rempulp (Reduction of air emissions at kraft pulp mills) (Niemelä et al. 2003). The Rempulp project included the creation of nitrogen balances at three pulp mills, using hardwood (birch and eucalyptus) and softwood as raw materials. In this Chapter, short summary on the key steps is given, supported by selected results mainly from the above studies.

According to the current understanding, nitrogen fate in the pulping stage includes:

- The nitrogen content of the wood raw material is typically 0.05–0.15% (by weight).
- A substantial part of the nitrogen is dissolved from the wood chips into the cooking liquor at early pulping stages; there are no raw material-specific differences. The pulps going to bleaching contain only traces of nitrogen.
- Kjeldahl method was optimised and calibrated for the determination of total nitrogen in black liquors.
- The cooking conditions have only marginal effects on the release of nitrogen from chips.
- Approximately 10–15% of wood nitrogen is converted into ammonia during pulping. Model compound experiments have shown that different amino acids produce ammonia in different yield levels (e.g. 5–20%)
- Most of proteins are apparently linked to kraft lignin that always contains some nitrogen.
- Small amounts of amino acids can also be found in black liquors. Also, there is a number of other (cyclic) compounds formed from different amino acids. Some of the products are specific for certain amino acids, such as the formation of pyrrole from hydroxyproline.

During black liquor evaporation:

- Ammonia and other volatile nitrogen compounds are readily transferred to the condensates at early evaporation stages. There is only some additional ammonia formation during later evaporation stages.
- The extent of nitrogen removal during evaporation can be increased by high-temperature black liquor treatments. The required conditions are, however, probably too drastic for full mill-scale applications. The increased formation of volatile sulphur compounds in such treatments also needs to be taken into account.
- Ammonia and other volatile nitrogen compounds are stripped off from foul condensates, and are thus also found in rectified methanol. Ammonia is always the dominating nitrogen compound in rectified methanol. Some amide-type compounds have not yet been fully identified.
- Ammonia can also be separated as a by-product (from different streams), as happened in Kotka in the 1910s.

In black liquor combustion and white liquor preparation:

- Nitrogen entering the recovery boiler with the black liquor is converted during combustion to gaseous N_2 , NO, and cyanate (OCN^-) in the smelt. The combustion conditions can be controlled to increase nitrogen incorporation into smelt which offers certain opportunities to force more nitrogen as ammonia to different gaseous streams (for separate handling or combustion).
- During combustion, carefully designed air staging conditions and novel vertical air systems have strong potential for minimising the NO_x emissions.

- Cyanate originating from the smelt is slowly converted into ammonia during green liquor handling and white liquor preparation. The kinetics shows significant mill-to-mill differences.
- Some ammonia is removed from the green and white liquors with the vent gases, but most of it returns to cooking with the white liquor. Ammonia emissions from the causticisation lines may correspond to one third of all nitrogen emissions from the recovery cycles.
- Proper handling of all non-condensable gases (NCGs), stripper off-gases or rectified methanol, and causticisation vent gases is of great importance for controlling the millwide NO_x balances. The experience has shown that the recovery boilers offer the best option for the low NO_x combustion of these ammonia-containing streams.
- If necessary, it is also possible to remove ammonia from stripper off-gases, methanol or vent gases before combustion. The removed ammonia could be used, for example, in selective catalytic reduction systems at recovery boilers, or as a nutrient (ammonium sulphate or phosphate) at the activated sludge plants.

The following illustrations from the Rempulp project will be inserted and explained to highlight nitrogen behaviour at selected process steps.

Table 2. Characterisation of pine kraft black liquors derived from laboratory pulping at 170 °C.

Compound (fraction)	Kappa number 134	Kappa number 87.5	Kappa number 20.6
Total nitrogen, mg/l	96	170	180
Ammonium nitrogen, mg/l	7.5	13	16
Lignin, g/l	11.1	40.9	62
Nitrogen in lignin, %	0.26	0.058	0.045
Nitrogen in lignin, mg/l	29	24	28

Table 3.2. The extent of ammonia formation during laboratory-scale cooking of different raw materials.

Raw material	Kappa number	Total N, mg/l	Ammon. N, mg/l	Ammon. N, %
Birch	100	49.6	6.8	13.7
Birch*	15	159.7	21.7	13.6
Eucalyptus	81	66.3	8.1	12.2
Eucalyptus**	13	100.5	12.3	12.2
Pine	134	96	7.5	7.8
Pine	88	170	13	7.6
Pine	18	180	16	8.9

*Another final black liquor contained 162 and 24.1 mg/l of total and ammon. nitrogen, respectively.

**Another final black liquor contained 104 and 11.7 mg/l of total and ammon. nitrogen, respectively.

Table 3.4. The formation of ammonia (% of total nitrogen) after alkali treatment of selected model compounds at 160 or 170 °C for 30 min.

Material	160 °C, NaOH	170 °C, NaOH	170 °C, NaOH/Na ₂ S
4-Hydroxyproline	8.0	n.s.*	n.s.
Glycine	0.6	1.2	0.5
Serine	13.5	22.0	19.5
Valine	1.4	1.6	0.4
Aspartic acid	n.s.	7.4	n.s.
Glutamic acid	n.s.	1.4	n.s.
Proline	n.s.	2.3	n.s.
Phenylalanine	n.s.	3.6	n.s.
Lysine	n.s.	1.5	n.s.

*ns; not studied.

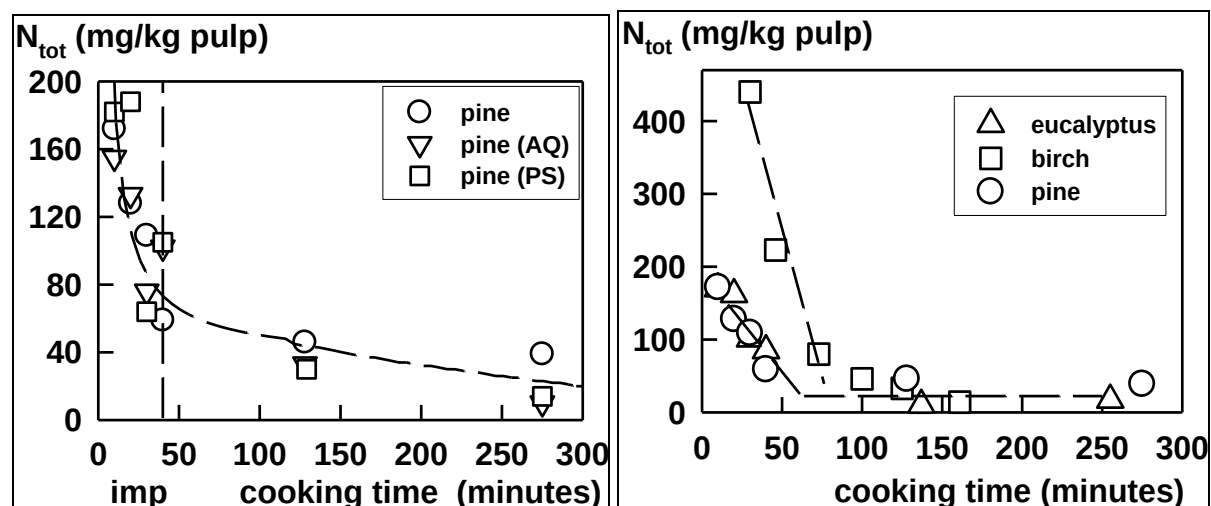


Fig. 3.1 (left). Release of nitrogen from wood chips vs. impregnation (imp) and cooking time for pine cooks with or without addition of anthraquinone (AQ) or polysulphide (PS), at 165 °C.

Fig. 3.2 (right). Release of nitrogen from wood chips versus cooking time. The temperatures for eucalyptus and birch cooks were 147 and 162 °C, respectively.

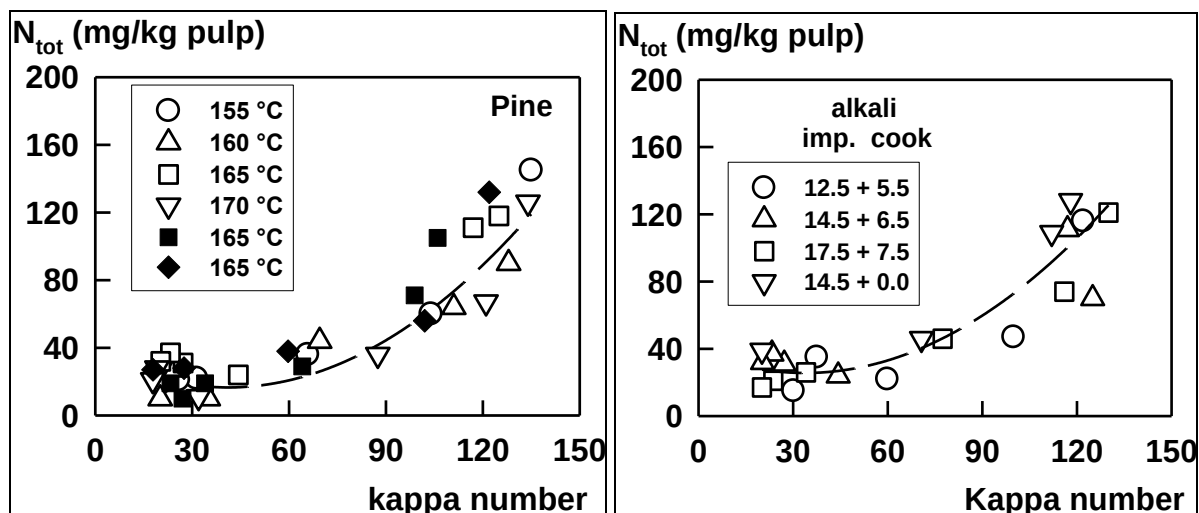


Fig. 3.3 (left). Release of nitrogen from pine wood vs. kappa number during cooking at different temperatures. Unfilled and filled symbols refer to the cooking experiments with synthetic and industrial white liquors, respectively.

Fig. 3.4 (right). Release of nitrogen from pine chips versus kappa number at different distributions of alkali charge (% of wood) between impregnation (first number) and cooking (second number). The cooking temperature was 165 °C.

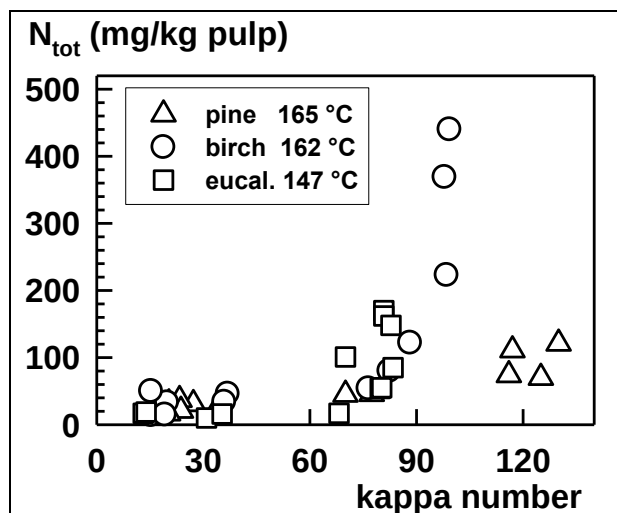
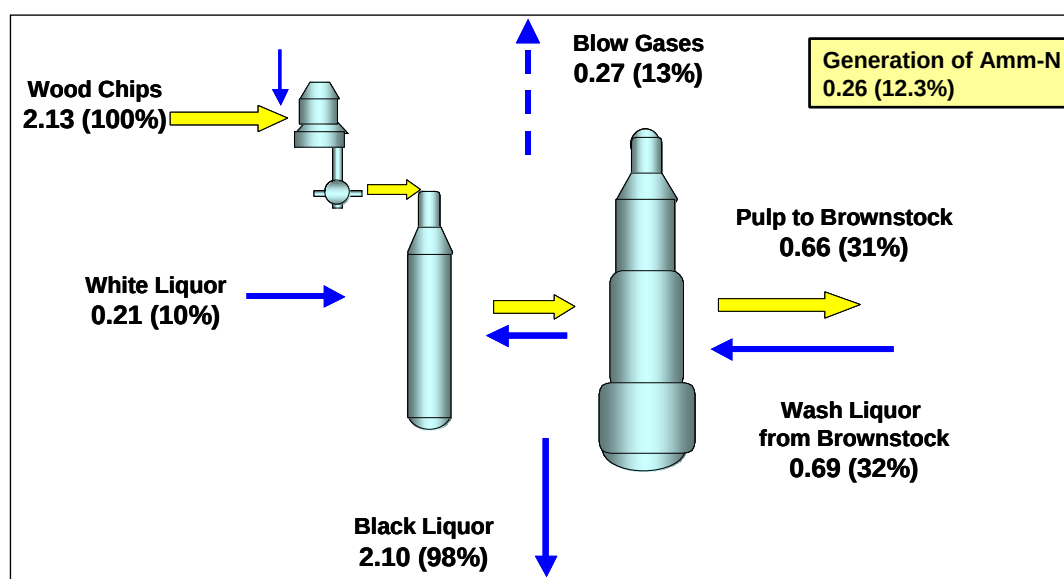


Fig. 3.8. Nitrogen remaining in pulp after cooking of Scandinavian pine and birch, and Portuguese eucalyptus versus kappa numbers. The cooking temperatures are also given.

Table 3.5. Concentrations (mg/l) of amino acids in selected softwood black liquors.

Amino acid	D8-1	D10	EV3
Dry solids, %	21.1	17.6	47.4
Aspartic acid	5.6	0.9	13.7
Glutamic acid	12.4	13.4	24.3
Serine	0.6	0.5	0.5
Glycine	13.7	6.9	7.8
Arginine	21.9	16.6	28.8
Alanine	9	6	12.1
Tyrosine	6.4	4.6	10.1
Cystine	51.5	10.4	8.4
Valine	4.7	2.2	6.6
Methionine	6.8	6.8	10.6
Isoleucine	2.4	1.1	3.6
Leucine	9.8	9.4	17.9
Phenylalanine	–	–	7
Total	135.8	78.8	151.4


Fig. 3.20. Total nitrogen balances for the digester at one of the study mills. The figures are given as kg N/ton pulp and normalised to nitrogen in wood chips (100%).

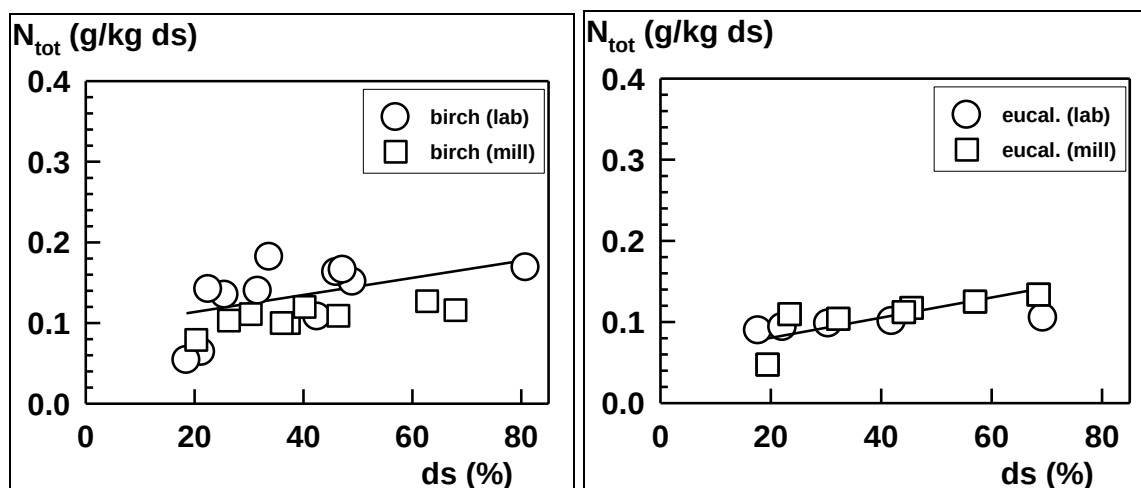


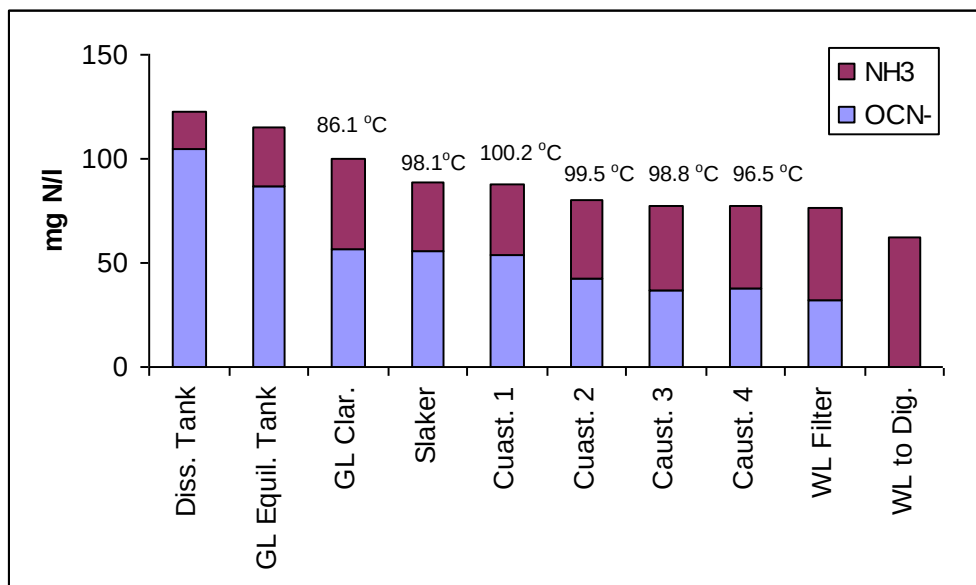
Fig. 3.25 and 3.26. Total release of nitrogen into condensate during laboratory evaporation of birch and eucalyptus black liquors (versus ds). The original nitrogen contents of the liquors were 0.069% for birch lab, 0.083% for birch mill, 0.051% for eucalyptus lab, and 0.086% for eucalyptus mill.

Table 3.10. Release of total nitrogen in laboratory evaporation of black liquors, with and without heat treatment. Procedure: pre-evaporation to 30–50% ds, then heat treatment (HT) and finally evaporation to about 70% ds. N released, amount of N released from the liquors in the laboratory evaporator; –, not determined. The numbers given must be considered rather rough since variations in total nitrogen concentrations in condensates under the same experimental conditions were common.

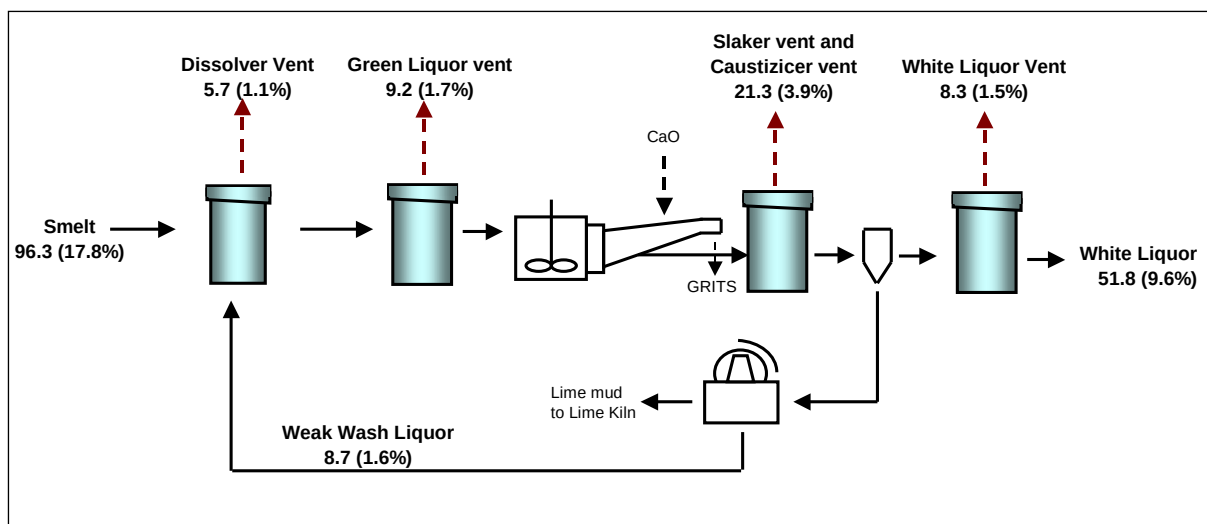
Black liquor	N_{tot} in BL, g/kg ds	Released, no HT	Released, with HT at 200 °C, 3 h	Released, with HT at 200 °C, 16 h	Released, with HT at 300 °C, 2 h
Pine lab	0.59	0.21 (35%)	0.25 (42%)	0.30 (51%)	–
Softw. mill	0.57	0.10 (18%)	0.25 (44%)	0.30 (53%)	–
Birch lab	0.71	0.17 (24%)	0.45 (63%)	–	–
Birch mill*	1.27	–	–	–	0.94 (74%)
Birch mill	0.83	0.14 (17%)	0.30 (36%)	–	–
Eucal. lab	0.51	0.10 (20%)	0.30 (59%)	–	–
Eucal. mill	0.86	0.13 (15%)	0.45 (52%)	–	–

Table 3.22. Rough concentrations (mg/l) of organic nitrogen compounds (calculated as nitrogen) identified in the investigated methanol samples.

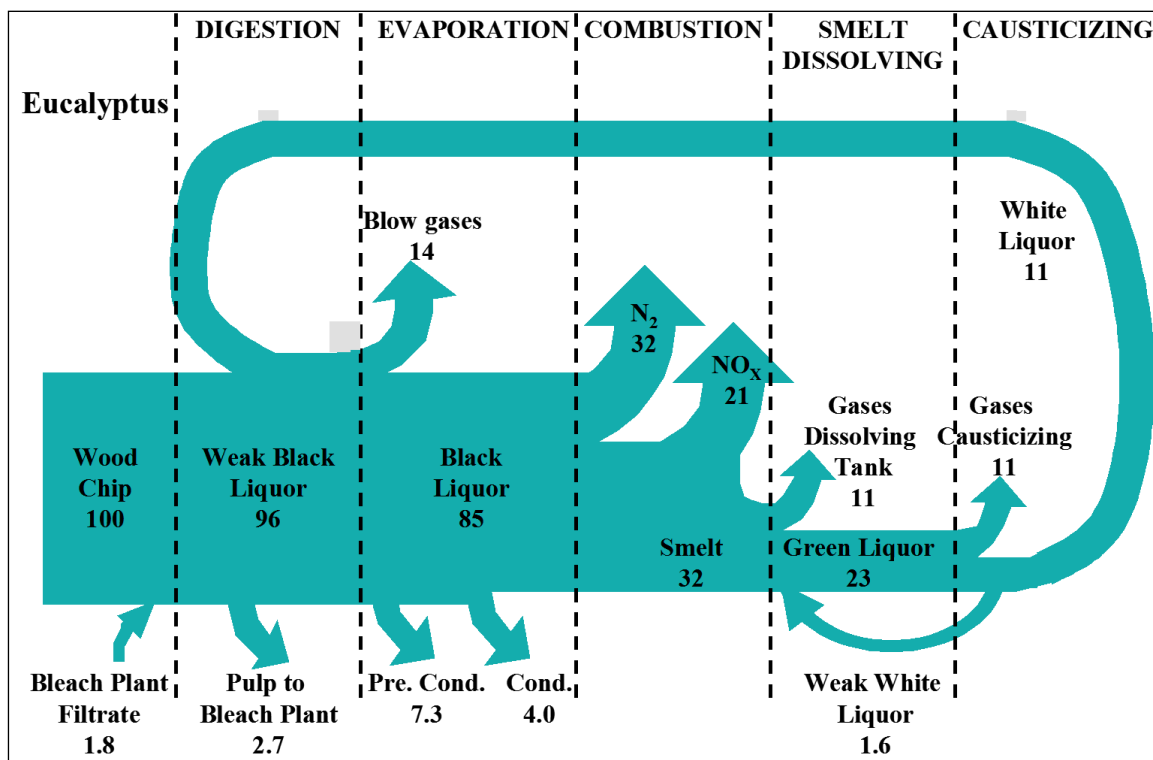
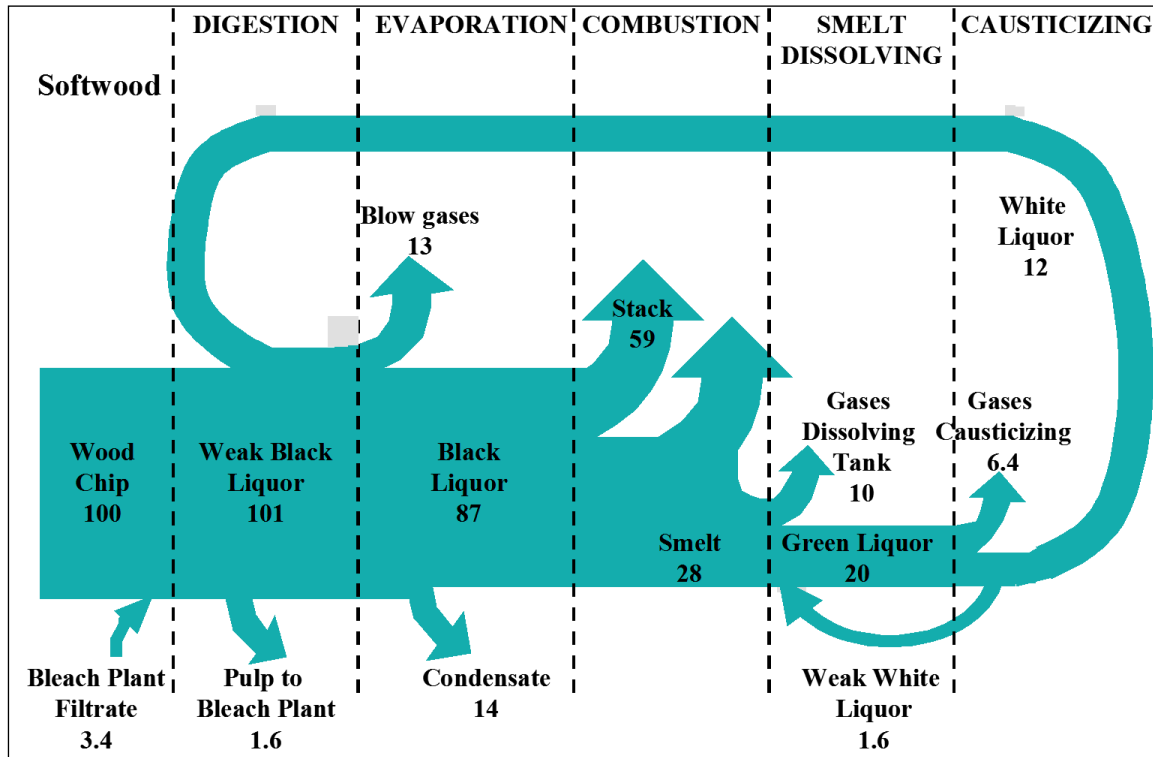
Compound (category)	Mill 1	Mill 2	Mill 3
Pyrrole	65	20	70
1-Methylpyrrole	20	–	30
Miscellaneous heterocyclic	traces	traces	traces
Aliphatic amines	220	150	190
Total	305	170	290



Figs. 3. Concentration of OCN⁻ and NH₃ in causticising liquors at at one of the study mills.



Figs. 3.132–3.134. Total nitrogen balance for the causticising areas at one of the study mills. The figures are given as kg N/ton of white liquor produced, and in brackets as percent of nitrogen entering the mills with wood chips.



Figs. 3.136 and 3.137. Normalised total nitrogen balances for two study mills. Nitrogen intake with wood chips normalised to 100%.

4. Summary and conclusions

The present review focused on the contents of nitrogen in the Nordic pine, spruce and birch trees, as well as on the nature of organic nitrogen constituents and their behaviour in the kraft process. For comparison, a lot of material was also collected addressing other softwood and hardwood materials, but the corresponding concentrations are not tabulated in detail.

During the comprehensive literature searches it became evident that there is a huge amount of information available on nitrogen contents in dozens of different softwood and hardwood species covering numerous industrially important genera. It also became clear that the studies cover all different tree parts, including twigs and branches, bark, roots, and needles. Furthermore, it is evident that practically taken all the main wood species contain equally low amounts of nitrogen in mature stemwood, as the figures above $>0.25\text{--}0.3\%$ have only seldom been reported.

For the Nordic wood species, the nitrogen contents in stemwood usually vary from c. $0.05\text{--}0.15\%$, although somewhat higher amounts have also been reported. For the variation, there are apparently many reasons, depending for example on the following factors:

- different applied analytical methods used at different laboratories
- different geographical locations, soil type, and potential fertilisation
- age of wood
- specific sampling point in wood, vs. a bulk sample
- purity of sample, e.g. carefully sorted sample vs. industrial chips

All those factors (known or unknown) make it hard to reach sufficiently detailed or correct final conclusions on the most representative values for the nitrogen contents of wood, especially for pulpwood used at the current pulp mills. Therefore it is now recommended to conduct a national sampling and analysis campaign to cover chips and black liquor samples from all national pulp mills, to be all analysed in the same laboratory. For the black liquors, VTT (KCL) has developed an improved Kjeldahl method (Niemelä and Tuominen 2005).

Appendix 1. Nitrogen and other nutrient concentrations (%) in a number of softwood and hardwood species (Meerts 2002). Softwoods cover genera from *Abies* to *Tsuga*.

Species	Taxon	Concentrations in sapwood (s) and heartwood (h) (mg kg ⁻¹)										Heartwood/sapwood				
		N _s	N _h	P _s	P _h	K _s	K _h	Ca _s	Ca _h	Mg _s	Mg _h	N	P	K	Ca	Mg
<i>Abies firma</i>	1					3000	2000			110	100			0.67		0.91
<i>Abies firma</i>	1			20	2	250	1000	300	400	100	100	0.10	4.00	1.33	1.00	
<i>Abies sacchalensis</i>	1					630	1000	800	1200	150	200			1.59	1.50	1.33
<i>Callitris columellaris</i>	1			10	10	320	230	3170	3710	460	510	1.00	0.72	1.17	1.11	
<i>Callitris hugelii</i>	1			55	10	600	380	2960	4710	160	480	0.18	0.63	1.59	3.00	
<i>Cedrus deodara</i>	1							1500	300						0.20	
<i>Chamaecyparis obtusa</i>	1					600	500	400	300	75	100			0.83	0.75	1.33
<i>Chamaecyparis thyoides</i>	1							600	200	80	40				0.33	0.50
<i>Cryptomeria japonica</i>	1							606	562	93	184				0.93	1.98
<i>Cryptomeria japonica</i>	1					1600	5600	1000	800	100	200			3.50	0.80	2.00
<i>Cryptomeria japonica</i>	1			70	5.5	375	1150	950	900	85	200	0.08	3.07	0.95	2.35	
<i>Larix decidua</i>	1			280	30	678	140	709	600	164	167	0.11	0.21	0.85	1.02	
<i>Larix laricina</i>	1			185	20	754	490	559	652	151	323	0.11	0.65	1.17	2.14	
<i>Larix leptolepis</i>	1					600	200	400	200	100	50			0.33	0.50	0.50
<i>Metasequoia glyptostroboides</i>	1							800	450	160	100				0.56	0.63
<i>Picea abies</i>	1	1600	800	95	5	900	300	600	700			0.50	0.05	0.33	1.17	
<i>Picea rubens</i>	1					873	522	936	810	166	412			0.60	0.87	2.48
<i>Picea rubens</i>	1							500	800	62	60				1.60	0.97
<i>Picea rubens</i>	1			67	33	776	875	597	673	74	85	0.49	1.13	1.13	1.15	
<i>Pinus densiflora</i>	1					450	250	700	900	100	200			0.56	1.29	2.00
<i>Pinus nigra</i>	1	950	910	94	20	900	400	570	660	180	255	0.96	0.21	0.44	1.16	1.42
<i>Pinus rigida</i>	1	870	970	70	20	490	240	810	1040	275	146	1.11	0.29	0.49	1.28	0.53
<i>Pinus strobus</i>	1	1000	450									0.45				
<i>Pinus sylvestris</i>	1	1060	640	100	17	740	130	580	710	240	230	0.60	0.17	0.18	1.22	0.96
<i>Pinus sylvestris</i>	1	790	600	68	33	473	385	796	969	106	140	0.76	0.49	0.81	1.22	1.32
<i>Pinus sylvestris</i>	1	470	400	61	3	300	3	500	600	150	150	0.85	0.05	0.01	1.20	1.00
<i>Podocarpus archboldii</i>	1	1800	2000	110	70	840	1080	1480	1080	220	170	1.11	0.64	1.29	0.73	0.77
<i>Thuyopsis dolobrata</i>	1							706	1330	40	239				1.88	5.98
<i>Tsuga diversifolia</i>	1	750	400									0.53				
<i>Acer rubrum</i>	2	900	400									0.44				
<i>Acer saccharum</i>	2					1260	1502	2874	2812	643	1084			1.19	0.98	1.69
<i>Acer saccharum</i>	2			80	25			8000	1000			0.31			0.13	
<i>Ackama paniculata</i>	2			53	53	1100	210	610	490			1.00	0.19	0.80		
<i>Aesculus turbinata</i>	2					500	1000	1250	3200	500	700			2.00	2.56	1.40
<i>Ardisia sp.</i>	2	1250	1620	90	30	860	130	420	440	160	70	1.30	0.33	0.15	1.05	0.44
<i>Banksia serratifolia</i>	2			58	15	1300	170	580	710			0.26	0.13	1.22		
<i>Betula lenta</i>	2	950	500									0.53				
<i>Carya sp.</i>	2	2500	1500									0.60				
<i>Castanea crenata</i>	2							366	363	210	20.1				0.99	0.10
<i>Castanea crenata</i>	2					1250	560	300	200	300	20			0.45	0.67	0.07
<i>Castanea sativa</i>	2	1588	762	124	6	607	220	377	291	292	115	0.48	0.05	0.36	0.77	0.39
<i>Casuarina cristata</i>	2			70	43	770	1800	8800	8600			0.61	2.34	0.98		
<i>Casuarina torulosa</i>	2			40	10	450	10	630	720	120	140	0.25	0.02	1.14	1.17	
<i>Cedrela tonduzii</i>	2	1200	600									0.50				
<i>Ceiba pentandra</i>	2	3900	1100									0.28				
<i>Ceratopetalum apetalum</i>	2			209	113	1940	1695	187	944			0.54	0.87	5.05		
<i>Ceratopetalum apetalum</i>	2	1700	1400	45	40	800	1100	3210	1930	240	370	0.82	0.89	1.38	0.60	1.54
<i>Cornus florida</i>	2	2000	2000									1.00				
<i>Cryptocarya sp.</i>	2	1000	1570	140	120	960	990	700	1200	950	3400	1.57	0.86	1.03	1.71	3.58
<i>Dryadodaphne crassa</i>	2	1370	1030	60	10	2300	540	540	4300	1220	710	0.75	0.17	0.23	7.96	0.58
<i>Elaeocarpus ptilanthus</i>	2	1200	1230	100	40	1180	720	1030	1700	210	1030	1.03	0.40	0.61	1.65	4.90
<i>Eucalyptus cameronii</i>	2			53	3	370	25	240	30			0.06	0.07	0.13		
<i>Eucalyptus campanulata</i>	2			53	3	160	32	60	25			0.06	0.20	0.42		
<i>Eucalyptus dalrympleana</i>	2	2000	1000	615	870	2250	600	580	1430	470	360	0.50	1.41	0.27	2.47	0.77

<i>Eucalyptus dives</i>	2	1200	700	75	10	1050	180	640	180	180	40	0.58	0.13	0.17	0.28	0.22
<i>Eucalyptus grandis</i>	2	3100	1500	130	5	1250	200	650	750	200	230	0.48	0.04	0.16	1.15	1.15
<i>Eucalyptus gummifera</i>	2			60	5	900	50	310	160	110	90		0.08	0.06	0.52	0.82
<i>Eucalyptus laevopinea</i>	2	1900	1100	70	15	650	20	260	240	130	80	0.58	0.21	0.03	0.92	0.62
<i>Eucalyptus maculata</i>	2	1800	1000	50	5	800	220	1240	2370	340	770	0.56	0.10	0.28	1.91	2.26
<i>Eucalyptus oleosa</i>	2			45	3	1600	540	1600	2700				0.07	0.34	1.69	
<i>Eucalyptus saligna</i>	2			110	3	1000	35	500	100				0.03	0.04	0.20	
<i>Fagus sylvatica</i>	2	1500	800	165	70	1100	950	700	850	180	225	0.53	0.42	0.86	1.21	1.25
<i>Flindersia maculosa</i>	2			70	43	900	790	4200	3500				0.61	0.88	0.83	
<i>Flindersia pimenteliana</i>	2	730	1710	60	20	640	20	170	1350	190	170	2.34	0.33	0.03	7.94	0.89
<i>Fraxinus americana</i>	2	1700	900									0.53				
<i>Galbulimima belgraveana</i>	2	1450	1470	50	330	2410	2070	1170	890	830	480	1.01	6.60	0.86	0.76	0.58
<i>Geijera parviflora</i>	2			190	120	900	3200	15000	12000				0.63	3.56	0.80	
<i>Hovenia dulcis</i>	2					2000	2000	1000	1600	450	450			1.00	1.60	1.00
<i>Jacaranda copaia</i>	2	1600	1400									0.88				
<i>Kalopanax pictus</i>	2							1090	2050	241	243				1.88	1.01
<i>Kalopanax pictus</i>	2					1500	1250	1000	1600	250	310			0.83	1.60	1.24
<i>Licaria cayennensis</i>	2	1100	1100									1.00				
<i>Liriodendron tulipifera</i>	2	1500	1000									0.67				
<i>Maclura pomifera</i>	2			390	10			4600	2700	700	300		0.03		0.59	0.43
<i>Magnolia obovata</i>	2					800	125	450	210	80	2			0.16	0.47	0.03
<i>Nothofagus truncata</i>	2	630	375			1200	550	1000	650	200	250	0.60		0.46	0.65	1.25
<i>Ochroma lagopus</i>	2	1800	500									0.28				
<i>Orites excelsa</i>	2			94	27	1300	400	92	270				0.29	0.31	2.93	
<i>Orvenia acidula</i>	2			81	11	1000	290	4900	7000				0.14	0.29	1.43	
<i>Oxydendron arboreum</i>	2	2500	2300									0.92				
<i>Phellodendron amurense</i>	2					1500	300	910	800		200			0.20	0.88	
<i>Planchonella firma</i>	2	1400	2500	100	70	1470	1900	750	1350	400	710	1.79	0.70	1.29	1.80	1.78
<i>Populus robusta</i>	2			390	44	980	1760	1400	4000	240	730		0.11	1.80	2.86	3.04
<i>Populus trichocarpa</i>	2			107	39	970	2800	980	1920	180	400		0.36	2.89	1.96	2.22
<i>Prunus sargentii</i>	2							510	532	233	68.5				1.04	0.29
<i>Prunus avium</i>	2	1100	600	130	10	800	400	1100	1800	230	180	0.55	0.08	0.50	1.64	0.78
<i>Quercus alba</i>	2			115		1311	900	1050	708	92	17		0.00	0.69	0.67	0.18
<i>Quercus alba</i>	2	1530	1880	190	50	1160	730	850	1020	178	113	1.23	0.26	0.63	1.20	0.63
<i>Quercus alba</i>	2			188	12	1609	548	994	713	108	19		0.06	0.34	0.72	0.18
<i>Quercus alba</i>	2	900	550	100	70	1000	700	3300	1000	140	150	0.61	0.70	0.70	0.30	1.07
<i>Quercus alba</i>	2	4000	1500									0.38				
<i>Quercus coccinea</i>	2	1000	1400	27	20	1360	610	520	500	165	56	1.40	0.74	0.45	0.96	0.34
<i>Quercus coccinea</i>	2			162	6.3	1056	485	532	201	140	22		0.04	0.46	0.38	0.16
<i>Quercus coccinea</i>	2	3000	2000									0.67				
<i>Quercus petraea</i>	2					1100	640	3000	2000	140	25			0.58	0.67	0.18
<i>Quercus prinus</i>	2	2000	1000									0.50				
<i>Quercus robur</i>	2	2500	1200	200	20	2200	600	600	400	300	30	0.48	0.10	0.27	0.67	0.10
<i>Quercus robur</i>	2	2150	1450	160	30	1750	900	1250	950	600	165	0.67	0.19	0.51	0.76	0.28
<i>Quercus robur</i>	2	1800	1100	325	52	1750	650	525	395	190	42	0.61	0.16	0.37	0.75	0.22
<i>Quercus robur</i>	2	2750	900	180	10	1500	300	340	220	160	50	0.33	0.06	0.20	0.65	0.31
<i>Quercus rubra</i>	2	3100	800									0.26				
<i>Quercus rubra</i>	2	950	650	100	70	800	650	1250	600	110	80	0.68	0.70	0.81	0.48	0.73
<i>Quercus rubra</i>	2	2300	900									0.39				
<i>Quercus serrata</i>	2					1600	1600	630	450	100	20			1.00	0.71	0.20
<i>Robinia pseudoacacia</i>	2			310	30	1800	1500	1700	1300	190	160		0.10	0.83	0.76	0.84
<i>Sloanea pulleniana</i>	2	830	860	80	150	1650	2460	4040	2700	710	880	1.04	1.88	1.49	0.67	1.24
<i>Sorbus alnifolia</i>	2							1000	1500	300	400				1.50	1.33
<i>Sphenostemon papuanum</i>	2	1560	1610	110	180	3800	4500	1410	1610	1290	2300	1.03	1.64	1.18	1.14	1.78
<i>Symphonia globulifera</i>	2	1900	500									0.26				
<i>Syncarpia glomulifera</i>	2			70	5	950	45	600	130	250	75		0.07	0.05	0.22	0.30
<i>Tarretia actinophylla</i>	2			91	80	2600	900	760	750				0.88	0.35	0.99	
<i>Tristania conferta</i>	2	1800	1700	75	5	1050	1050	800	1750	130	600	0.94	0.07	1.00	2.19	4.62
<i>Vouacapoua americana</i>	2	1300	1200									0.92				
<i>Zelkova serrata</i>	2							1600	1000	560	320				0.63	0.57

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**YTR: Selvitys tyypillisistä savukaasuvirroista [m³/ADt] eri puulajeilla
LUT – savukaasulaskentapohja 29.11.2018**

Calculations for flue gas flow of recovery boiler												
	Variables:											
	Results:											
	Cooking variables										Black liquor elemental analysis	
	Wood species in cooking	3			Wood species						Composition of formed black liquor dry solids	
	Air dry unbleached cellulose		3000 t/24 h		1 Pine			C	33,1	m-%		
	Yield in Oxygen delignification		95 %		2 Spruce			H	3,4	m-%		
	Yield from wood to dry unbleached cellulose		51 %		3 Birch			N	0,1	m-%		
	Pulp kappa before oxygen delignification		18		4 Euca			S	4,9	m-%		
	Pulp kappa after oxygen delignification		13		5 Other			Na	20,9	m-%		
	Washing efficiency unbleached pulp		99 %					K	1,5	m-%		
	Washing efficiency bleached pulp		99 %					Cl	0,3	m-%		
	Soap recovery efficiency		80 %					O by diff	35,7	m-%		
	Water created when wood acids are neutralized		100 kg/t Bleached pulp					Inorganics	27,6	m-%		
	NCG generation during cook		3 % wood					S/(Na2+K2	32,15	mol-%		
	Sulfur in NCG		2 kg/t Bleached pulp					Cl/(Na+K)	0,89	mol-%		
	White liquor							K/(Na+K)	4,05	mol-%		
	Active alkali, Na2O-% per wood		19 %									
	White liquor sulfidity		35 %									
	White liquor dry solids		15 %									
	Causticity		80 %					Cellulose		40 %		
	Reduction in white liquor		95 %					Hemicellulose		37 %		
	Black liquor dry solids		82,3 %					Lignin		20 %		
	Oxidized White liquor							Extractives		3 %		
	Oxidized White liquor used in Oxygen delignification		200 kg/t Bleached pulp					Summary		100 %		
	Methanol formation in Oxygen delignification		0,2 kg/t Bleached pulp					Wood type		hardwood		
	Heating value of black liquor dry-solids		13465 kJ/kg BLDS									
	Heat in to recovery boiler		19,664 GJ/t Bleached pulp									
	Heat in to recovery boiler per second		0,615 GJ/s									
	Massflow to recovery boiler		4128,9 tDS/24h									
	Massflow to recovery boiler		47,8 kgDS/s									
	Flue gas flow											
	Flue gas at 1.2 excess air	4,11	m3n/kgds	4,25	m3n/kgds							
	Flue gas per air dry ton of pulp	5998	m3n/Adt	6201	m3n/Adt							

Calculations for flue gas flow of recovery boiler

Suomeksi

Muuttujat:

Tulokset:

Keiton parametrit (alkuarvot)

Keiton puulaji

1

Puulaji

Ilmakuivattu valkaisuamaton selluloosa	3000 t/24 h	1 Mänty
Happivalkaisun saanto	96 %	2 Kuusi
Kuivatun valkaisuamattoman sellun saanto puusta	45 %	3 Koivu
Keiton kappaluku ennen happivalkaisua	28	4 Eukalyptus
Keiton kappaluku happivalkaisun jälkeen	14	5 Muu
Pesun tehokkuus valkaisuamattomalla sellulla	99 %	
Pesun tehokkuus valkaistulla sellulla	99 %	
Suovan erotuksen tehokkuus	80 %	
Puun happojen neutraloinnissa syntyvä vesi	100 kg/t valkaistua sellua	
Lauhtumattomien kaasujen tuotanto keitossa	3 % puusta	
Rikin määrä lauhtumattomissa kaasuissa	2 kg/t valkaistua sellua	

Valkoliipeä

Aktiivinen alkaliannos, Na ₂ O-% puusta	18,6 %
Valkoliipeän sulfiditeetti	35 %
Valkoliipeän kuiva-ainepitoisuus	15 %
Kaustisoituminen	80 %
Valkoliipeän reduktio	94 %
Mustaliipeän kuiva-ainepitoisuus	75 %

Hapettunut valkoliipeä

Hapettuneen valkoliipeän käyttö happivalkaisussa	200 kg/t valkaistua sellua
Metanolin muodostuminen happivalkaisussa	0,2 kg/t valkaistua sellua

**YTR: Evaluation of three different gas phase chemistry mechanisms for
predicting NO_x emission formation in recovery boilers
ÅA – väliraportti 13.11.2018**



Johan Gadolin

PROCESS CHEMISTRY CENTRE



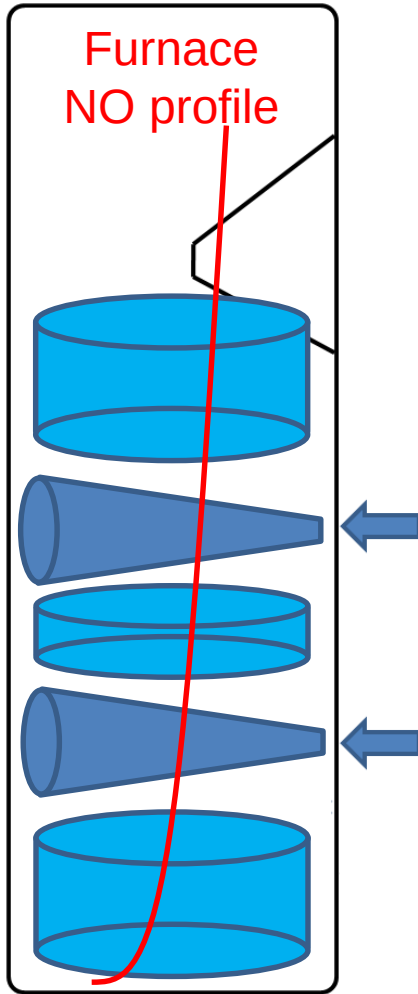
Evaluation of three different gas phase chemistry mechanisms for predicting NO_x emission formation in recovery boilers

Markus Engblom

13.11.2018



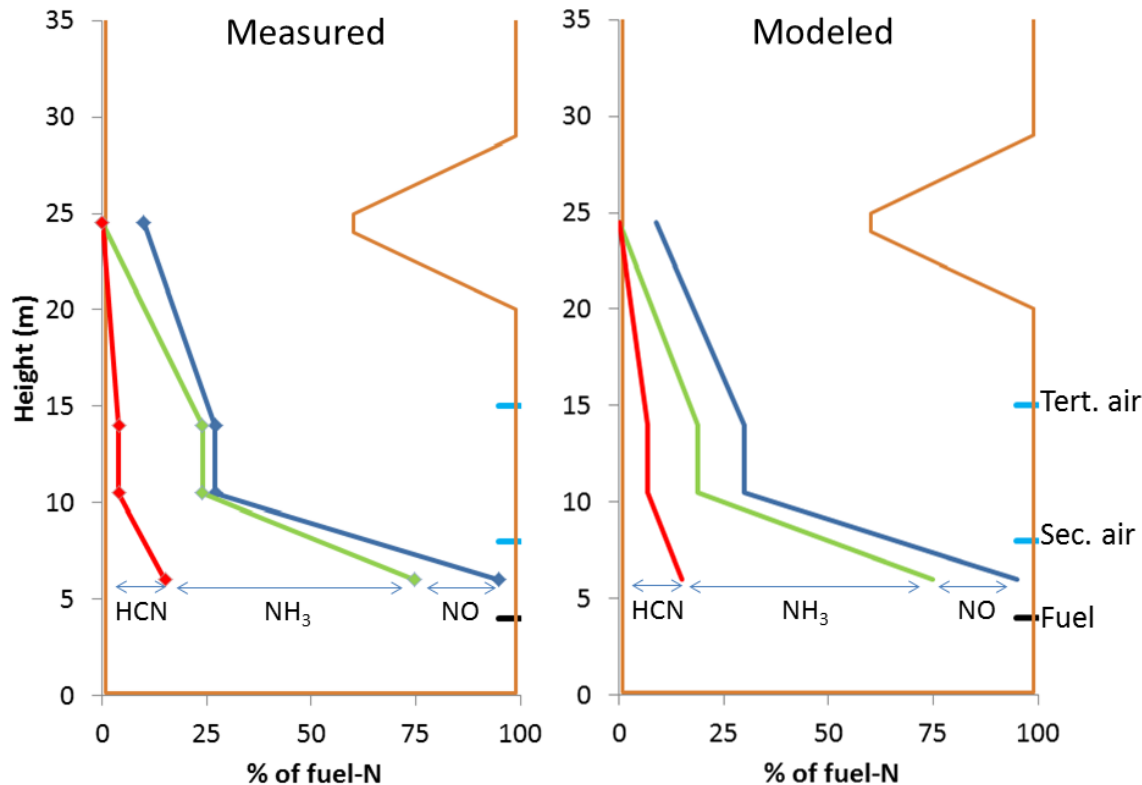
"Jet-NOx" model



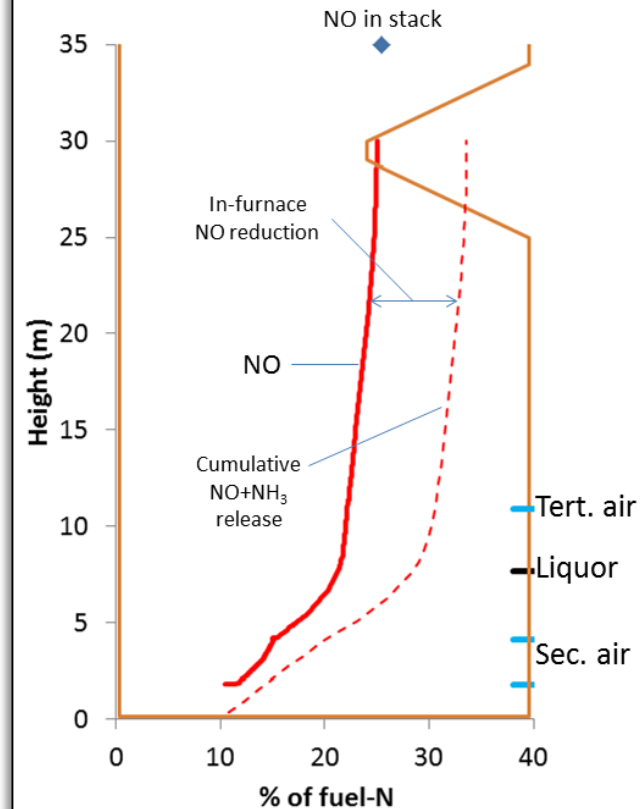
- Simplified fluid dynamics
 - Furnace sections and air jets
 - CFD for input
- Detailed kinetics
 - ÅA mechanism
 - CHEMKIN reactor network
 - "Zwietering" reactors
- Prediction result is profiles of NO and other species as function of boiler height

"Jet-NOx" model

Bubbling Fluidized Bed boiler



Kraft recovery boiler



- Tool for understanding and predicting boiler NOx chemistry
- Boiler NO in general well predicted

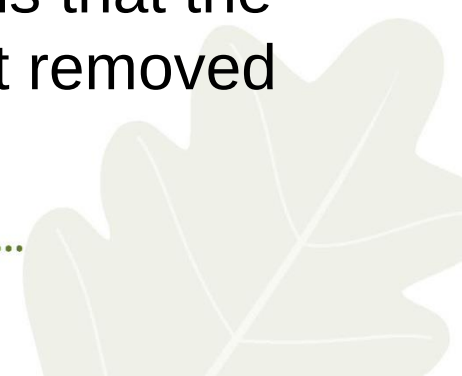
Objective

- Evaluate three different gas phase chemistry mechanisms in terms of NO formation predictions
 - 1) Detailed mechanism: reference. In terms of chemistry this type of mechanism is the most comprehensive. In some cases, this types of mechanisms have been combined with CFD, but mostly in simulation of laminar flames, not boiler simulations.



Objective

- Evaluate three different gas phase chemistry mechanisms in terms of NO formation predictions
 - 2) Skeletal mechanism: Based on a detailed mechanism, but with some reactions removed. Could be considered possible to be used in CFD boiler simulations. The key is to have a mechanism which still describes the chemistry well when compared to detailed mechanism. In practice this means that the relevant reactions have been retained, not removed



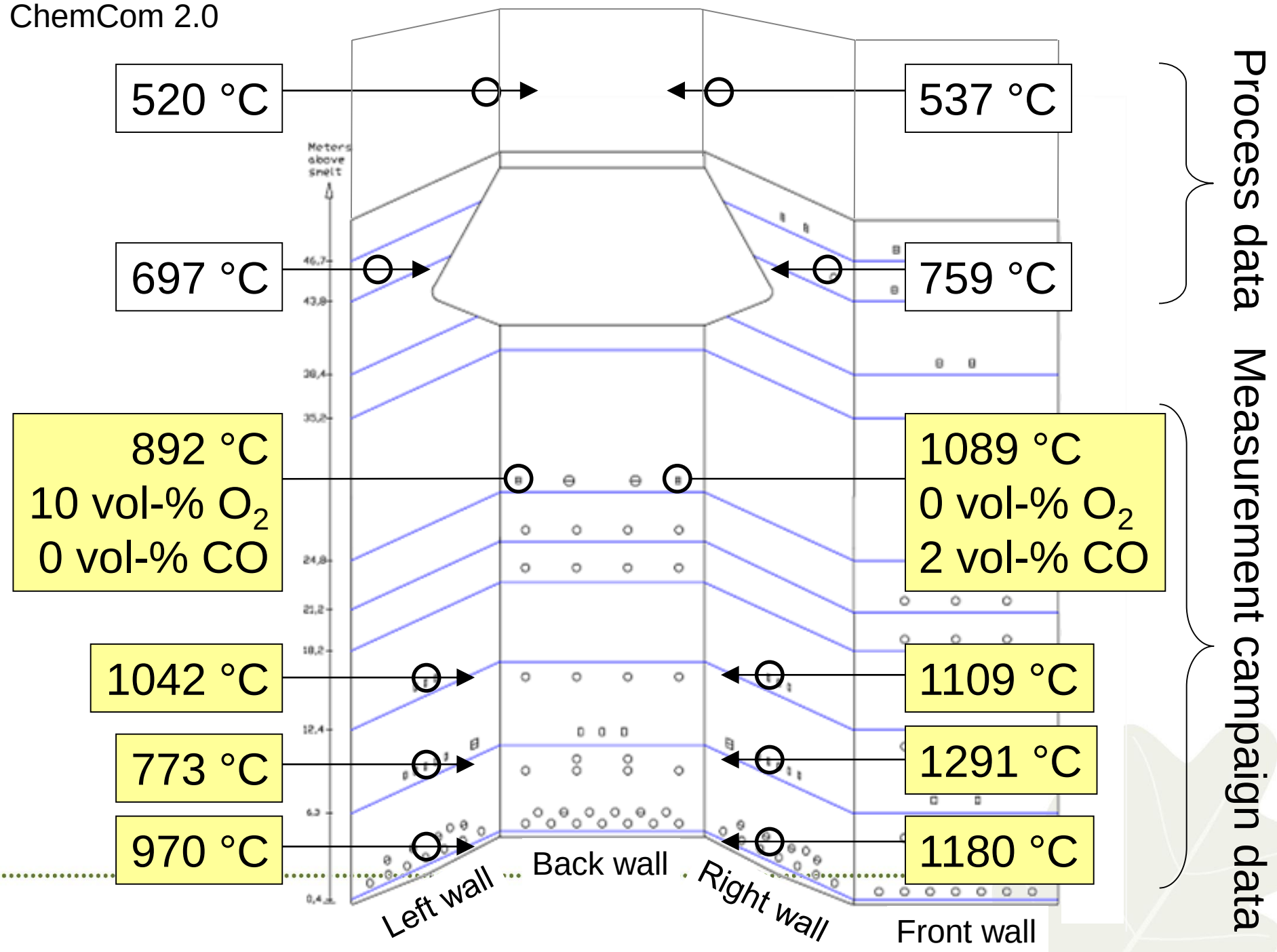
Objective

- Evaluate three different gas phase chemistry mechanisms in terms of NO formation predictions
 - 3) Global reaction mechanism, typically only two or a few reactions. Traditionally this type of mechanism has been used in CFD boiler simulations. Perhaps the most important objective of this work is to compare predictions using this type of simplified mechanism with predictions using detailed and skeletal mechanisms

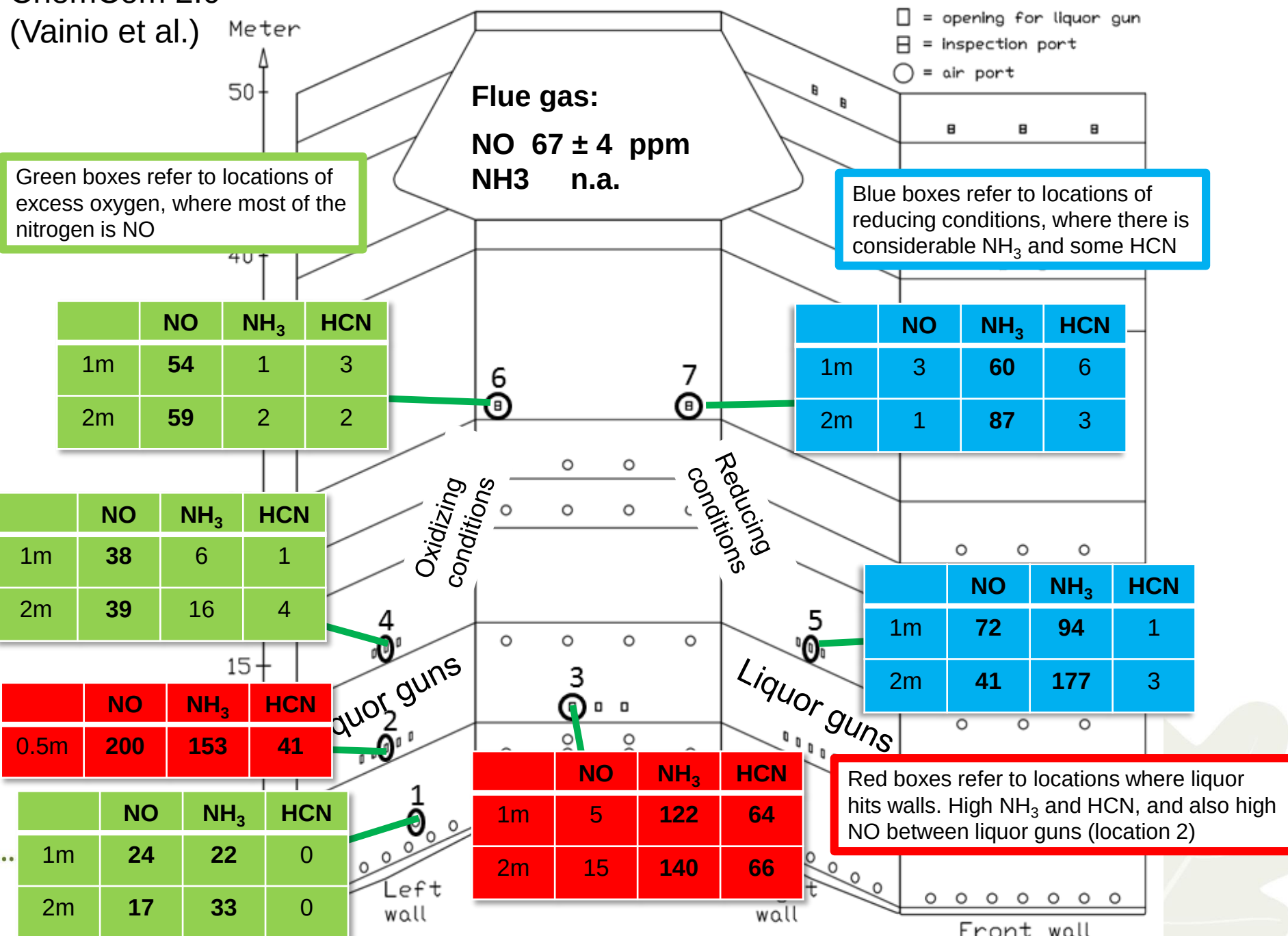


Simulation cases

- Model an actual boiler operation situation, for which there is in-furnace data on nitrogen species (see slides below)
- The operational situation is characterized by asymmetric combustion
 - Right side of boiler operating with high fuel/air ratio, reducing conditions, higher temperatures. The right side and locations where liquor hits walls, are characterized by higher NH_3 and HCN compared to NO
 - Left side having an excess of oxygen, operating under oxidizing conditions and lower temperatures. The left side is characterized by lower NH_3 and HCN, and higher NO compared to right side
- Simulation strategy: model right and left side of boiler separately, using three chemistry mechanisms



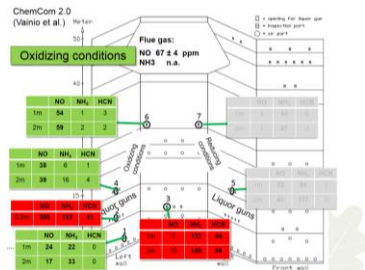
ChemCom 2.0 (Vainio et al.)



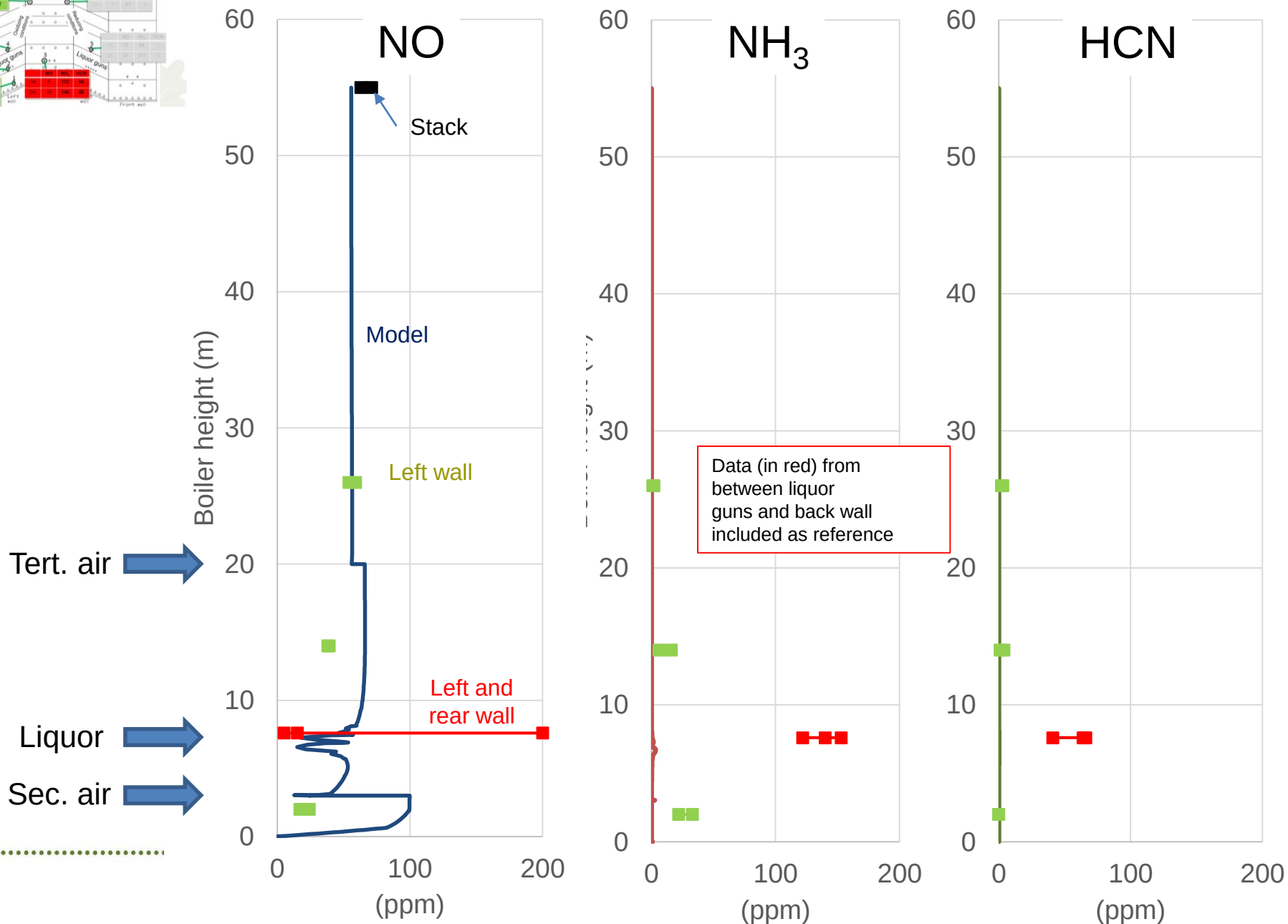
Results (1/2)

- Detailed chemistry mechanism
- Model correctly captures low NH_3 and low HCN on left side of boiler, most of the nitrogen is NO
- Final NO is also relatively well predicted





Modeled boiler left side - Oxidizing conditions

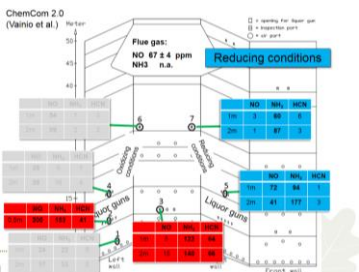


Results (2/2)

- Detailed chemistry mechanism
- Model correctly captures high NH_3 and existence of some HCN on right side of boiler
- NO level including final NO relatively well predicted

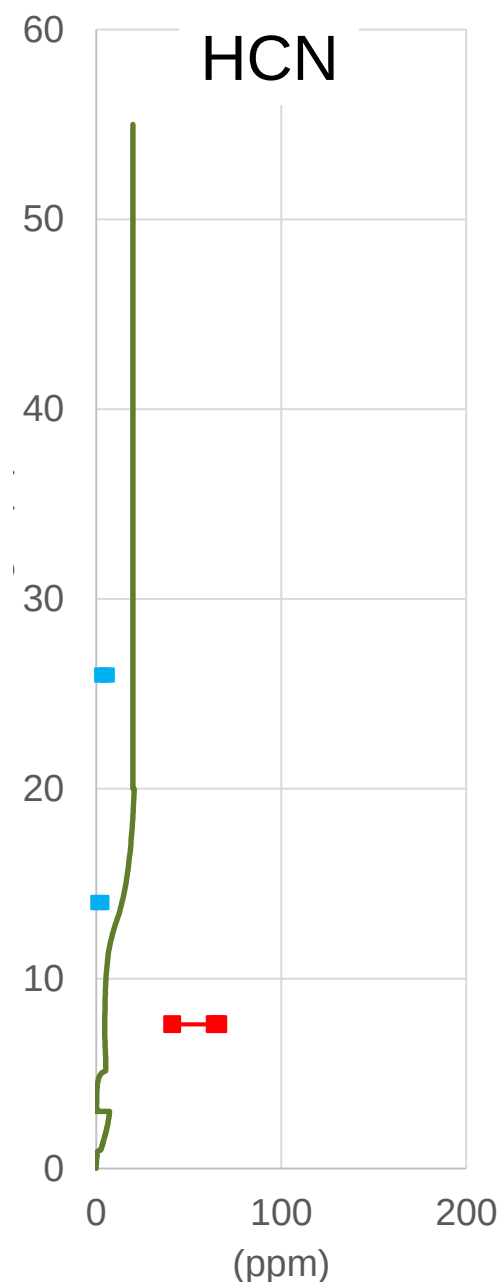
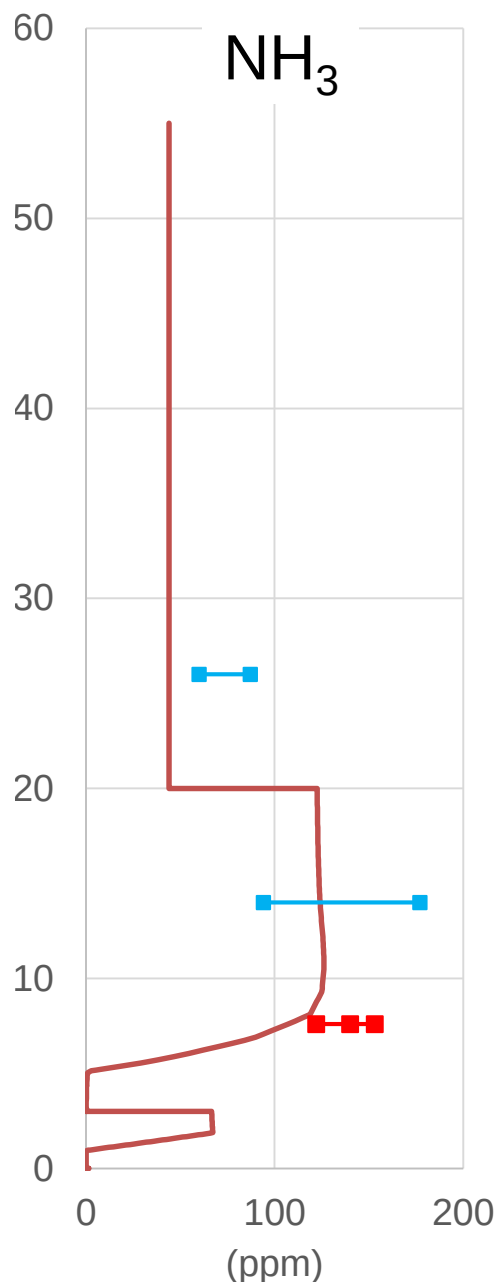
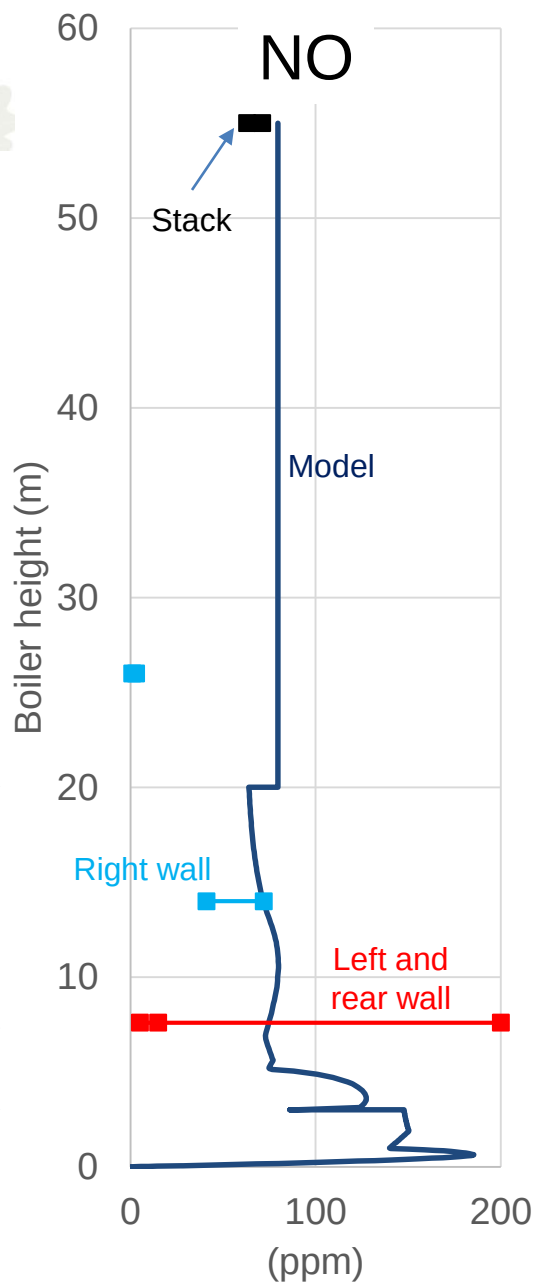


Modeled boiler right side - Reducing conditions



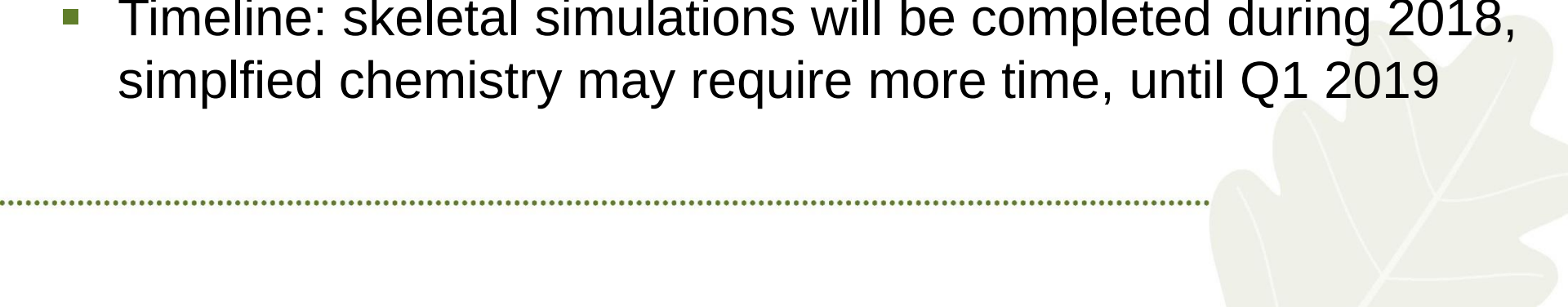
Liquor →

Sec. air 

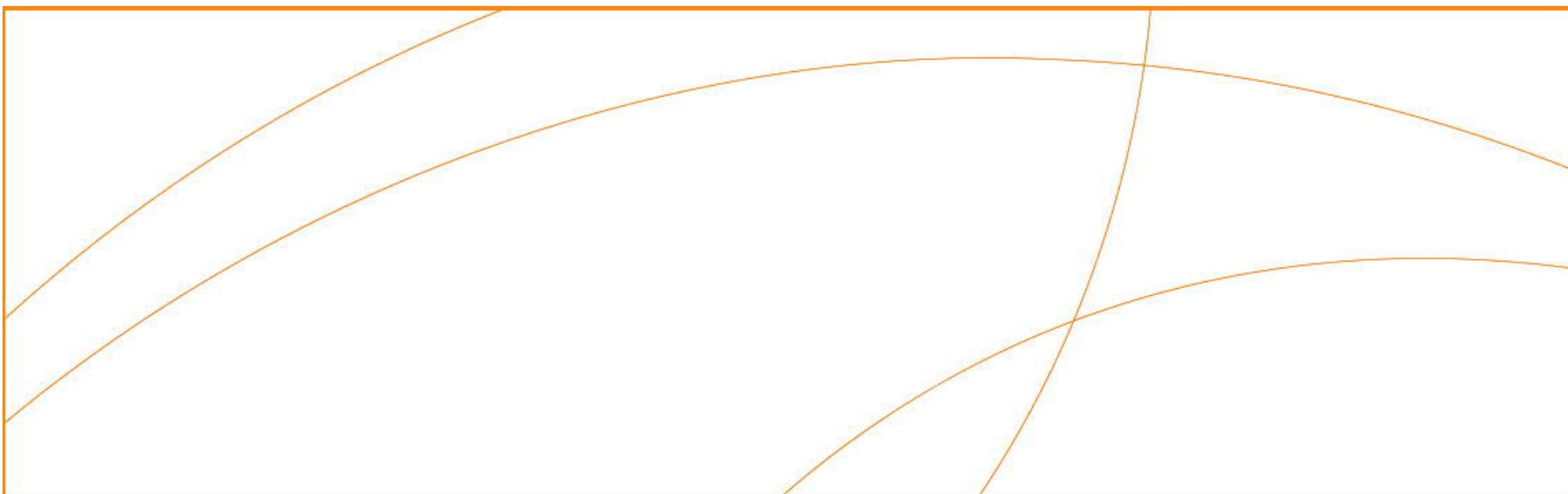


Summary

- Simulations using detailed chemistry done
 - Model correctly predicts trends when comparing left and right side of boiler
- Simulations using skeletal mechanism not done
 - However, with the simulation cases now set up, changing to skeletal mechanism straightforward
- Simplified chemistry simulations not done
 - Further work needed to implement simplified chemistry into Chemkin software. Requires adding own code
- Timeline: skeletal simulations will be completed during 2018, simplified chemistry may require more time, until Q1 2019



**ATR: Suositus vesi-höyrypiirin määramittauksista, standardeista, mittarien
tyypeistä, valintakriteereistä, tarkkuuksista
Pöyry – SKP esitys 25.10.2018**



VESI-HÖYRYPIIRIN VIRTAAUSMITTAUKSET

Pöyry Finland Oy
Sintrol Oy



SISÄLTÖ

- Johdanto
 - Yleistä
 - voimalaitoksen virtausmittausten toteutus
- ISO 5167
 - Yleistä, ISO 5167 ja muut ISO 5167 liittyvät standardit
 - Asennusten vaatimukset -> suorien pituudet
 - Laskentaesimerkki, suorien pituudet, painehäviöt & epävarmuudet
- Päätelmiä
 - kokemuspohjaisia nyrkkisääntöjä
 - normista pääteltyjä nyrkkisääntöjä
- Yhteenveto

MIKSI MITTAUKSILLA ON VÄLIÄ?

- Taselaskentaan ja raportointiin vaaditaan luotettavia mittauksia
- Laitoksen takuut perustuvat aina standardeihin. Jos niitä ei voida todentaa standardien mukaan, ei ole takuita, on vain riitoja.
- Virheellisesti toteutetut mittaukset voivat johtaa isoihin sakkoihin, vaikka päälaitetoimituksessa ei olisi vikaa.
- Takuiden kannalta kriittiset mittaukset saattavat olla toisen toimittajan alueella. Esim. turbiinitakuiden vuoksi halutaan mitata KP-sivulauhteen määrä ja se on kattilatoimittajan alueella.
- Kolmannen osapuolen toteuttamien takuukokeiden kannalla laitosmittausten kalibrointitodistuksilla (laboratorio tai merkkiaine) ei ole mitään merkitystä. Vain standardin mukaiset mittaukset otetaan huomioon.

VOIMALAITOSPROSESSIN MITTAUSTEN SUUNNITTELU

Suunnittelussa tulee huomioida prosessin käytönvalvonnan ja säädön lisäksi takuukokeiden ja kunnonvalvonnan mittaustarpeet:

- luotettavat mittaukset (absoluuttinen arvo)
- yhteisesti sovittujen standardien mukaiset mittalaitteet & asennukset
 - määrämittaus: yleisesti käytössä ISO 5167 (lisäksi ISO/TR:t)
- mittausepävarmuuden & prosessihäviöiden optimointi
 - mittaustarkkuutta voi lisätä painehäviön kustannuksella

Virtausmittaukset on otettava huomioon suunnittelussa heti projektin alussa

- epäonnistuneet virtausmittaukset aiheuttavat haittaa ja lisäkustannuksia

ISO 5167 - YLEISTÄ

Suunnittelussa ja myynnissä huomioitavia asioita:

- ISO-5167 normi sisältää paljon asiaa josta putkistosuunnittelun ja kattilanvalmistajan pitäisi olla tietoisia
- Se sisältää myös runsaasti laitevalmistusta varten tarvittavaa tietoa jota yllä mainitun kohderyhmän ei välttämättä tarvitse tietää mitään.
- Kokenut asiantuntija voi pienellä vaivalla tehdä laskelmat joista ilmenee tärkeimmät prosessi ja asennustekniset asiat sekä laitteen mittaustarkkuus
- Samanlaisen ISO-5167 mukaisen laitteen mittaustarkkuus on laskennallisesti sama riippumatta sen valmistajasta
 - mittaustarkkuus ja asennusvaatimukset määräytyvät standardin mukaisesti, niitä ei voi muuttaa

ISO 5167 - YLEISTÄ

ISO 5167:2003 *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full*

- Part 1: General principles and requirements
- Part 2: Orifice plates
- Part 3: Nozzles and Venturi nozzles
- Part 4: Venturi tubes
- Part 5: Cone meters (Lisätty vuonna 2016)
 - perustoleranssi 5 % → ei varteenotettava vaihtoehto!

Standardi määrittelee mm.

- asennusvaatimukset (suorien pituudet ym.)
- käyttörajoitukset
- laskentayhtälöt
- virtauslaskenta
- painehäviöarvion
- virtauslaskennan epävarmuudet

ISO 5167 - RAJOITUKSET

- Rajoitukset: putken halkaisija, halkaisijasuhde & Reynoldsin luku

		Laippa	ISA 1932	Venturi- suutin	Venturi- putki ⁽¹⁾
D_{min}	mm	50	50	65	200
D_{max}	mm	1000	500	500	1200
β_{min}	-	0.10	0.3	0.316	0.4
β_{max}	-	0.75	0.8	0.775	0.7
Re_D	10^6	inf	10	2	2

¹⁾ Hitsattu (Rough-welded)

- Laite ei ole ISO-5167 normin mukainen mikäli taulukossa esitetyt rajoitukset eivät täyty
- Mittaustulos ja epävarmuus voidaan laskea ainoastaan ISO 5167 normin mukaisille laitteille

ISO 5167 - ASENNUSVAATIMUKSET

- Vaaditut suorat osuudet on esitetty ISO-5167 taulukossa 3
 - annetaan kuristuselimen halkaisijasuhteen funktiona putken halkaisijan kerrannaisina

Diam- eter ratio β	Upstream (inlet) side of orifice plate																						Down- stream (outlet) side of the orifice plate			
	Single 90° bend Two 90° bends in any plane $(S > 30D)^a$		Two 90° bends in the same plane: S -configur- ation $(30D \geq S > 10D)^a$		Two 90° bends in the same plane: S -configur- ation $(10D \geq S)^a$		Two 90° bends in perpen- dicular planes $(30D \geq S \geq 5D)^a$		Two 90° bends in perpen- dicular planes $(5D > S)^{a, b}$		Single 90° tee with or without an extension Mitre 90° bend		Single 45° bend Two 45° bends in the same plane: S -configur- ation $(S \geq 2D)^a$		Concentric reducer $2D$ to D over a length of $1,5D$ to $3D$		Concentric expander $0,5D$ to D over a length of D to $2D$		Full bore ball valve or gate valve fully open		Abrupt symmetrical reduction			Ther- mometer pocket or well ^c of diameter $\leq 0,03D^d$		Fittings (columns 2 to 11) and the densi- tometer pocket
1	2		3		4		5		6		7		8		9		10		11		12		13		14	
—	A ^e	B ^f	A ^e	B ^f	A ^e	B ^f	A ^e	B ^f	A ^e	B ^f	A ^e	B ^f	A ^e	B ^f	A ^e	B ^f	A ^e	B ^f	A ^e	B ^f	A ^e	B ^f	A ^e	B ^f	A ^e	B ^f
$\leq 0,20$	6	3	10	9	10	9	19	18	34	17	3	9	7	9	5	9	6	9	12	6	30	15	5	3	4	2
0,40	16	3	10	9	10	9	44	18	50	25	9	3	30	9	5	9	12	8	12	6	30	15	5	3	6	3
0,50	22	9	18	10	22	10	44	18	75	34	19	9	30	18	8	5	20	9	12	6	30	15	5	3	6	3
0,60	42	13	30	18	42	18	44	18	65 ^h	25	29	18	30	18	9	5	26	11	14	7	30	15	5	3	7	3,5
0,67	44	20	44	18	44	20	44	20	60	18	36	18	44	18	12	6	28	14	18	9	30	15	5	3	7	3,5
0,75	44	20	44	18	44	22	44	20	75	18	44	18	44	18	13	8	36	18	24	12	30	15	5	3	8	4

- huomioitava myös suoran pituus toiseen häiriötekijään:

6.2.8 In addition, between fitting 1 and the next fitting further from the orifice plate (fitting 2), a straight length at least equal to half the product of the diameter of the pipe between fitting 1 and fitting 2 and the number of diameters given in Table 3 for an orifice plate of diameter ratio 0,67 used in conjunction with fitting 2 shall be included between fittings 1 and 2 irrespective of the actual β for the orifice plate used. If either of the minimum straight lengths is selected from Column B (i.e. prior to taking the half value from fitting 1 to 2 of Table 3, a 0,5 % additional uncertainty shall be added arithmetically to the discharge coefficient uncertainty.

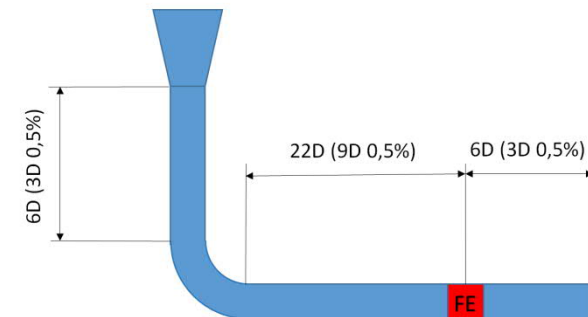
ISO 5167 - ASENNUSVAATIMUKSET

- suorien osuuksien ollessa taulukon 3 sarakkeen A mukaisia, käytetään 0% lisäepävarmuutta
- mikäli suorien osuus lyhyempi kuin sarakkeessa A, käytetään laskennassa 0,5% lisäepävarmuutta sarakkeen B mukaisesti
- suorita osuuksia on mahdollista lyhentää virtauksen oikaisimella
- asennus ei ole ISO-5167 normin mukainen mikäli taulukon 3 kohdassa A tai B esitetyt arvot eivät täyty.

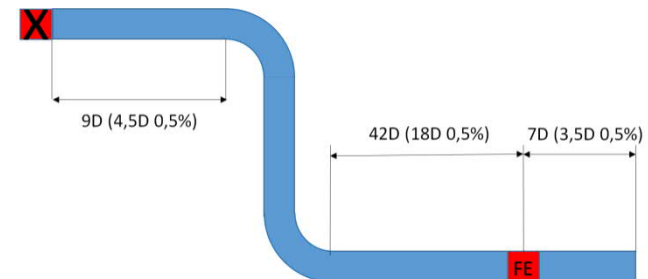
Suorien pituudet ISO 5167 mukaan Laskentaesimerkki, tulohöyrylinja 62 kg/s, 525 °C, 112 bar ($D = 276 \text{ mm}$, $\beta = 0.707$)	Device - Fitting 1		Fitting 1 - 2	
	A (m)	B (m)	A (m)	B (m)
	+ 0.0 %	+ 0.5 %	+ 0.0 %	+ 0.5 %
Single 90° bend Two 90° bends in any plane ($S > 30D$)	12.1	5.5	6.0	2.7
Two 90° bends in the same plane: S-configuration ($30D \geq S > 10D$)	12.1	5.0	6.0	2.4
Two 90° bends in the same plane: S-configuration ($10D \geq S$)	12.1	5.7	6.0	2.7
Two 90° bends in perpendicular planes ($30D \geq S \geq 5D$)	12.1	5.5	6.0	2.7
Two 90° bends in perpendicular planes ($5D > S$)	18.4	5.0	8.3	2.4
Single 90° tee with or without an extension Mitre 90° bend	10.9	5.0	5.0	2.4
Single 45° bend Two 45° bends in the same plane: S-configuration	12.1	5.0	6.0	2.4
Concentric reducer 2D to D over a length of 1.5D to 3D	3.4	1.9	1.7	0.8
Concentric expander 0.5D to D over a length of D to 2D	8.7	4.3	3.9	1.9
Full bore ball valve or gate valve fully open	5.7	2.9	2.5	1.2
Abrupt symmetrical reduction	8.3	4.1	4.1	2.0
Thermometer pocket or well of diameter $\leq 0.03D$	1.4	0.8		
Thermometer pocket or well of diameter between 0.03D & 0.13D	5.5	2.8		
Downstream	2.1	1.0		

ISO 5167 - ASENNUSESIMERKIT

- Esimerkki 1: 90° putkimutka ja supistus
 - halkaisijasuhteen ollessa 0,5 (Taul3: rivi 3)
 - suoraa putkea laipan jälkeen 6 D (Taul3: sarake 13)
 - suoraa putkea ennen laippaa 22 D (Taul3: sarake 1)
 - suoraa ennen mutkaa 6 D (Taul3: rivi 5 & sarake 8)



- Esimerkki 2: Kaksi putkimutkaa ja venttiili
 - halkaisijasuhteen ollessa 0,6 (Taul3: rivi 4)
 - suoraa putkea laipan jälkeen 7 D (Taul3: sarake 13)
 - suoraa putkea ennen laippaa 42 D (Taul3: sarake 3)
 - suoraa ennen mutkia 9 D (Taul3: rivi 5 & sarake 10)



ISO 5167 - LASKENTAESIMERKKI

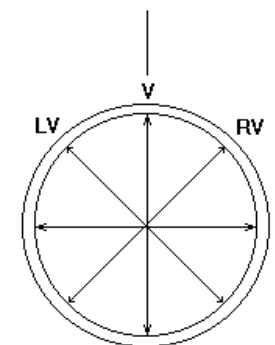
- Tulohöyrylinja 62 kg/s, 525 °C, 112 bar (pituudet laskettu yhdelle 90° mutkalle)

ISO 5167		Laippa	ISA 1932	ISA 1932	Venturi- suutin	Venturi- putki
Kuristus	mm	196	197	167	158	483
Putki	mm	278	278	278	500	1200
Halkaisijasuhde	-	0.71	0.71	0.60	0.32	0.40
Reynoldsin no.	10 ⁶	9.46	9.46	9.46	2.00	2.00
Virtaus	kg/s	62	62	62	23.6	56.7
Painehäviö	bar	0.7	0.2	0.6	-	-
Suoran pituus, A	m	12.1	8.1	5.0	(5.3)	(9.6)
Epävarmuus	%	0.8 %	1.1 %	0.9 %	(1.3 %)	(1.5 %)
Suoran pituus, B	m	5.5	4.0	2.5	(3.0)	(3.6)
Epävarmuus	%	1.3 %	1.6 %	1.4 %	(1.8 %)	(2.0 %)
ISO/TR 12767						
Suoran pituus, 16D	m	4.4	-	-	-	-
Epävarmuus	%	1.5 %	-	-	-	-
Suoran pituus, 12D	m	3.3	-	-	-	-
Epävarmuus	%	1.7 %	-	-	-	-
Suoran pituus, 8D	m	2.2	-	-	-	-
Epävarmuus	%	1.9 %	-	-	-	-
Suoran pituus, 4D	m	1.1	-	-	-	-
Epävarmuus	%	2.4 %	-	-	-	-

ISO 5167 – TARKISTUSMITTAUKSET

- Laipasta mitattava: halkaisija, paksuus, terävyys, aukon & viiston kulma

- vastaavat mittaukset suuttimille & venturiputkille
- valmistaja varmistaa että mittalaite on standardin vaatimusten mukainen
 - tarkistusmittaa laipan halkaisijan => käytetään laskennoissa
- mittalaitevalmistaja mittaa!



- Putkesta mitattava

- putken halkaisija 2 D ennen mittalaitetta mitataan tarkasti
 - 12 mittauksen keskiarvoa käytetään laskennoissa
- putken halkaisija 10 D matkalta ennen mittalaitetta tarkastettava ($\frac{D_i}{D} \leq 0,3\%$)
- mittalaitteen keskeisyys
- mittalaitevalmistaja mittaa ja tarkistaa ns. “kalibroidun putken” osalta
- **muuten mitattava laitoksella ennen asennusta!**
 - vaikka putki olisi valmistustoleranssin mukainen voi mittaukseen tulla usean prosentin virhe

ISO 5167 – LIITTYVIÄ STANDARDEJA

- **ISO/TR 12767:2007** *Measurement of fluid flow by means of pressure differential devices — Guidelines on the effect of departure from the specifications and operating conditions given in ISO 5167*
- **ISO/TR 9464:1998** *Guidelines for the use of ISO 5167-1:1991*
- **ISO/TR 15377:2018** *Measurement of fluid flow by means of pressure-differential devices — Guidelines for the specification of orifice plates, nozzles and Venturi tubes beyond the scope of ISO 5167*
- **ISO 2186:2007** *Fluid flow in closed conduits — Connections for pressure signal transmissions between primary and secondary elements*

Kumottuja

- **DIN 1952:1982** *Measurement of fluid flow by means of orifice plates, nozzles and venturi tubes inserted in circular cross-section conduits running full*
- **VDI/VDE 2040:1991** *Calculation principles for the measurement of fluid flow - Using orifice plates, nozzles and venturi tubes*

PÄÄTELMIÄ – ISO 5167

- Venturisuutinta tai venturiputkea ei voi asentaa standardin mukaisesti (tulo)höyrylinjaan
- Laippa on tutkituin ja varmin vaihtoehto
 - löytyy kaavoja myös ISO 5167 vaatimuksista poikkeaville laippa-asennuksien määrä- ja epävarmuuslaskennoille
- Kuristuselimet ja putket on mitattava ja dokumentoitava ennen asennusta
 - ohjeet vaadittaviin mittauksiin löytyy standardeista (ISO 5167, VDI 2040)
- asennukset on aina tarkistettava
 - esim. väärin päin asennettu laippa voi näyttää jopa 20 % liian vähän

Kokemuspohjaisia nyrkkisääntöjä:

- virtausmittausten asennusta pystyputkiin vältettävä
 - pyörre aiheuttaa liikanäyttöä 1-5 % (erityisesti suuttimet)
- painehäviöt pumppujen jälkeen ja ennen turbiinia mahdollista kompensoida pumpputyöllä
 - pitää ottaa huomioon jo esisuunnitteluvaiheessa
- mittalaite **EI SAA** olla asennettuna puhalluksen aikana!
- koko mittausskaalan paine-ero on mitoitettava tarpeeksi suureksi
 - alle 50 mbar paine-eroja ei voi mitata luotettavasti

YHTEENVETO

- Takuuasiat ovat rahallisesti merkittäviä
 - huonosti toteutetut mittaukset ovat suuri riski
- Annettujen takuiden on oltava mitattavissa
- Laitosmittausten kalibrointitodistuksilla (laboratorio tai merkkiaine) ei ole mitään merkitystä. Vain standardin mukaiset mittaukset otetaan huomioon.
- Kokenut asiantuntija voi pienellä vaivalla tehdä laskelmat joista ilmenee tärkeimmät prosessi ja asennustekniset asiat sekä laitteen mittaustarkkuus

YHTEYSTIEDOT



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 - Oili Tikka
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 - Tuotepäällikkö
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OTR: Soodakattilapäivän palaute 25.10.2018



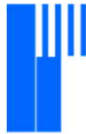
Soodakattilapäivä 25.10.2018, palaute

- Palautettuja lomakkeita 84 kpl
- Ilmoittautuneita 127 hlö
- Vastausprosentti 66 %

Kuinka arvioisit luennoitsijaa ja esityksen sisältöä?

Asteikko 1-5

Antti Tikkanen, Suomen Soodakattilayhdistyksen	3,8
Keijo Salmenoja, Korkean käytettävyyden soodakattila	4,3
Kari Haaga, Äänekosken uusi soodakattila	4,7
Asta Humalajoki / Jukka Kiuru, Rikkihapon valmistus Äänekosken tehtaassa hajukaasuista	4,5
Pekka Ruohonen / Sami Lehtonen, Soodakattilan vesi-höyrypiirin virtausmittaukset	3,5
Petri Nyberg, Unplugging recovery boilers	3,8
Jarno Peltonen, Kraft-sellutehtaan muutos liukosellutehtaaksi	3,6
Kajsa Fougner, Sodahuskommittén - Ruotsalais-norjalainen soodakattilakomitea	3,6
Kimmo Penttinen, Soodakattilan tukkeutuminen	4,4



Mielipiteesi tilaisuuden muista järjestelyistä

	Asteikko 1-5
Salijärjestelyt (pöytäjärjestys, kuuluvuus, näkyvyys)	4,4
Ilmoittautumis- ja vastaanottopalvelut	4,7
Tilat	4,5
Tarjoilut	4,6
Yleisvaikutelma tilaisuudesta	4,5



Energia –messuja koskevat kysymykset

Energiamessut

Osallistuitko Energia 2018 –messuille tai siihen liittyviin tapahtumiin?

Kyllä 43 hlö

Ei 41 hlö

Kannatatko vuoden 2020 Soodakattilapäivien järjestämistä samalla viikolla Energia-messujen kanssa Tampereella?

Kyllä 63 hlö

Ei 14 hlö



Toivottuja luentoaiheita

- Uusimmat tiedot soodakattilapedin sekä carry over –ilmiön hallinnasta
- Uudet teknologiat
- Soodakattilan apulaitteet
- Vesihöyrykierto ja mahdolliset ongelmat
- Vuodon valvonta
- Luotettavat mittausratkaisut mustalipeäruiskutuksen hallitsemiseksi
- Polttolipeän kuiva-aine, virtausmittaus, paine, lämpötila, lajikohtaiset vaikutukset mittauksin
- Materiaalijuttuja, vaurioita
- BAT/BREF, sellutehtaan Na/S –taseen hallinta
- Soodakattilan käytettävyyden ja tuotannon häiriöiden vaikutukset kaustisointiin
- Yhdistyksen rahoittamien projektien tulosten esittely (esim. 15 min/projekti)
- ATEX -> määrittelyiden perusteet, määritelläänkö ATEX-värkit turhan varman päälle
- Katsaus BLTBACin aiheista
- O₂ mittaus tehtaan väkevistä hajukaasuista
- Mahdollisuudet osallistua muuttuvahintaisille sähkömarkkinoille ja vähitellen avautuville kaukolämpömarkkinoille, näihin hyvä investointilaskenta



Toivottuja luentoaiheita

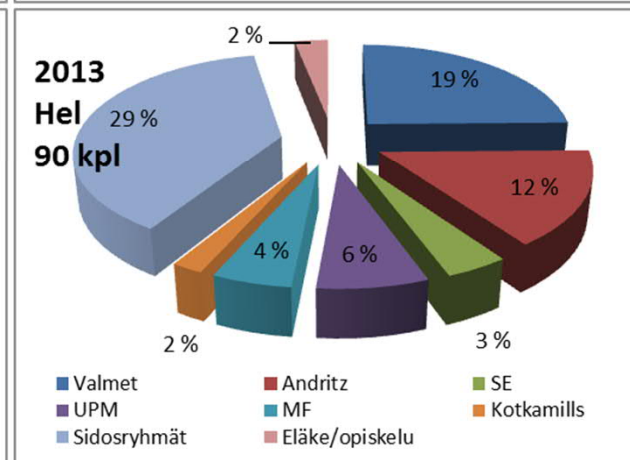
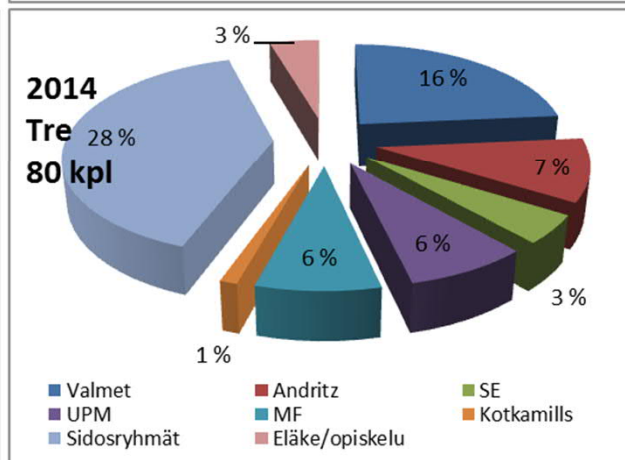
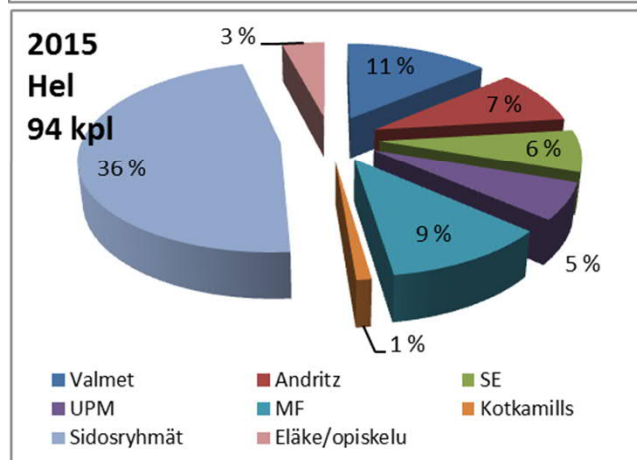
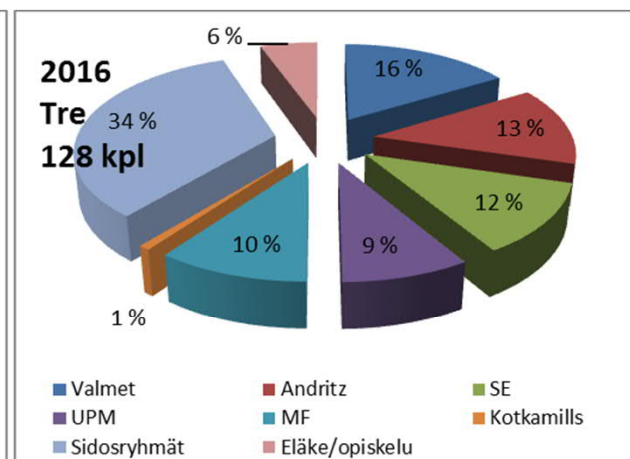
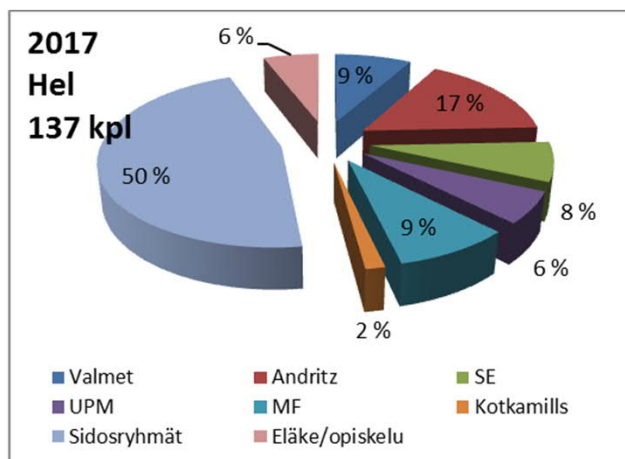
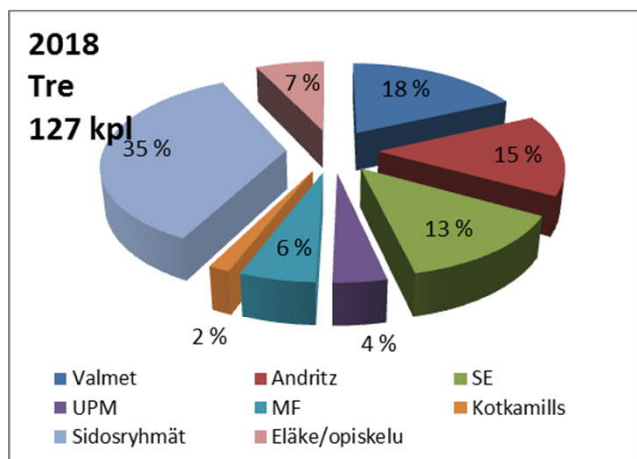
- Soodakattilan huolto ja kunnossapito (kunnonvalvonta, tarkastukset, etäyhteydet, tiedonkeruu)
- Soodakattilan vesikemia – käytännönläheinen tietoisuus aiheesta
- Soodakattilaan liittyvät prosessit
- Uudet NDT –tarkastusmenetelmät, viimeaikaisten kattilavaurioiden läpikäynti
- Soodakattilan ohjeiden läpikäynti step by step
- Soodakattiloiden kapasiteetin nostoprojektit



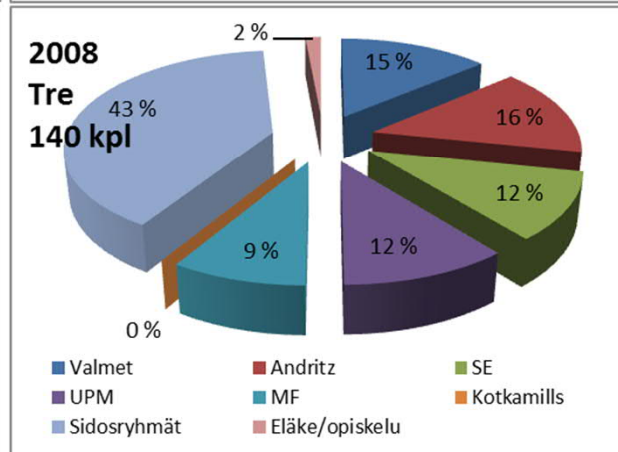
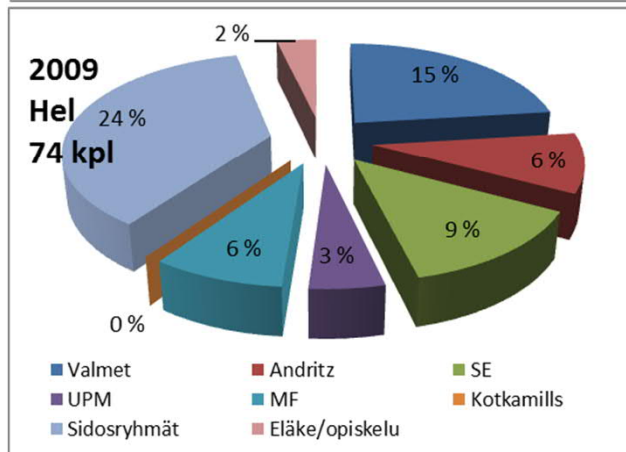
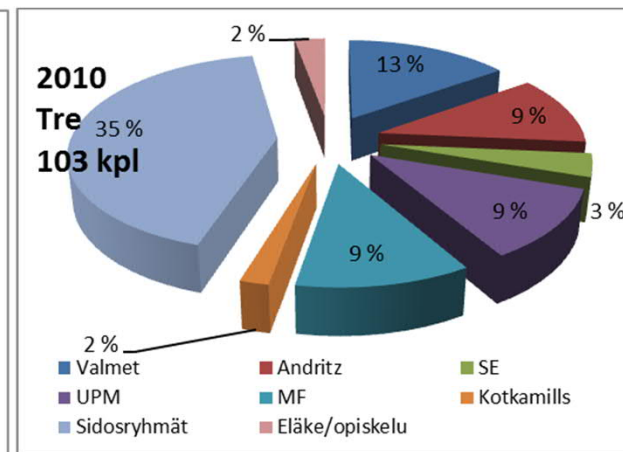
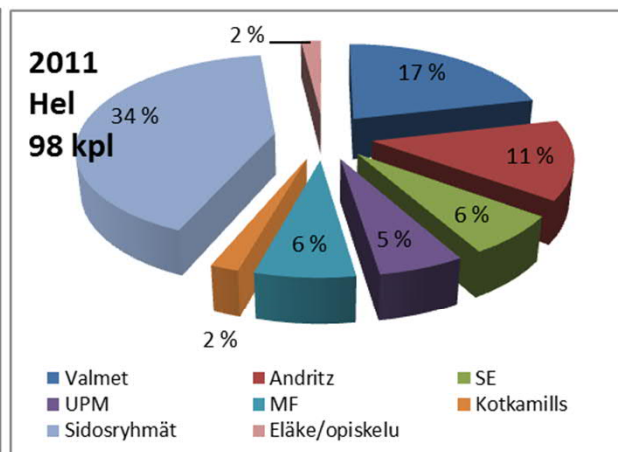
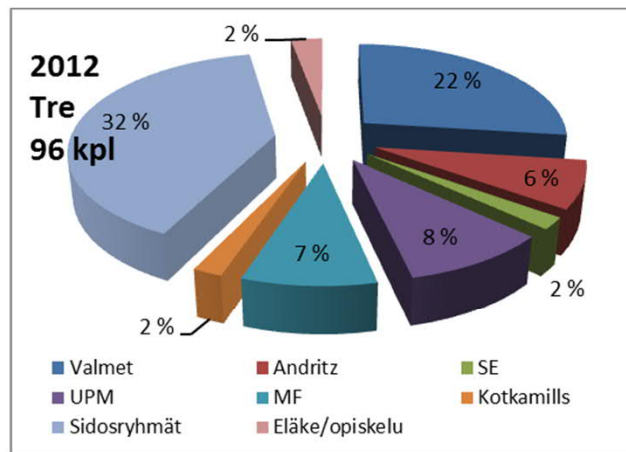
Muuta palautetta

- Hyvin organisoitu tilaisuus. Kiitos Antti ja Päivi.
- Kiitos hyvin toteutetusta tilaisuudesta
- Ohjelma hyvin aikataulutettu ja taukoja oli sopivasti
- Kaikki eivät päässeet, halukkaita varmasti olisi, jos maksu olisi vähän pienempi
- Hyvin järjestetty tilaisuus, aikataulu piti hyvin
- Kiitos hyvästä ja valaisevasta tilaisuudesta. Paljon olitte vaivaa nähneet ja työtä tehneet meitä ajatellen
- Esityksiin toivoisin videoita, valokuvia tehtailta ja muuta havainnollistavaa materiaalia
- Hyvin toimi
- Kattovalojen suuntaus huono, ”paistoi” suoraan silmiin
- Ilmastointi kovalla, veto
- Ruokaa oli riittävästi ja se oli hyvää. Hyviä luentoaiheita
- Salissa vinkuva ääni, joka pidemmän päälle alkaa häiritä
- Houkutelkaa lisää väkeä tehtailta
- Nimilappu: tarra, helpompi kiinnittää esim. villapaitaan
- Kynästä liukeni logo 2 h käytön jälkeen
- Ruokailijoilta taisi jäädä santsikierros hakematta, kun veivät ruoat pois niin äkkiä
- Koulujen syyslomaviikot tulisi huomioida, myös Tampereen ulkopuolella olevat alueet

SKP osallistujajakauma 2018-2013



SKP osallistujajakauma 2012-2008



OTR: 55-juhlakonferenssin budjetti

TAULUKKON ALVITTOMAT HINNAT!

Osallistujat 150

MENOT

	kpl	á hinta	€
<i>Osallistujalahja (reppu)</i>	<i>150</i>	<i>40 €</i>	<i>6 000 €</i>
<i>Konferenssikirja</i>	<i>150</i>	<i>50 €</i>	<i>7 500 € ?</i>
<i>Muistitikku</i>	<i>200</i>	<i>6 €</i>	<i>1 200 €</i>
<i>Nimikortit</i>	<i>150</i>	<i>4 €</i>	<i>600 €</i>
Ohjelmalehti	150	3 €	450 €
5.6 Tilavuokra Get together			500 €
5.6 Get togerher ruoka/juoma 5.6.	120	40 €	4 800 €
6.6 Tilavuokra kokoinen seminaaripäivä			sisältyy kokouspakettiin
6.6 Kokouspaketti (tilat/lounas)	120	52 €	6 240 €
6.6 juhlatila vuokra + henkilöstö + vahtimestari			1 730 €
6.6 koristelu + ohjelmanumero			2 000 €
6.6 Illallinen (ruoka/juoma)	120	100 €	12 000 €
6.6 Menukortit, koristeet			500 €
Kokousmenoja mm. langattomat mikit			500 €
Tavaroiden kuljetus, vuokrapaku?			500 €
Bussikuljetus lentokentälle Turku/Helsinki?			800 €
Puolisoiden ohjelma			1 000 €
Excursio?			1 000 €
Luennoitsijoiden majoitus	10	300 €	2 727 €
Sihteeristön työkustannus	2018		1 000 €
	2019		20 000 €
<i>Kongressitoimisto ilmoittautuminen/maksuliikenne</i>	<i>-150</i>		<i>0 €</i>
<i>Kongressitoimisto paikanpäällä</i>			
Apulaiset			1 000 €

Yhteensä		72 047,27 €
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TULOT

Osallistujamaksu	100	570	57 000,00 €
Tuote-esittely / näyttely	10	1450	14 500,00 €
			71 500,00 €

sisältyy näyttelypaikka + 2 seminaariosallistumista

Erotus -547,27 €

**KTR: Materiaalisuosituksen päivitys: Putken kuorinta ja S0-linjaus –
Projektiehdotus II 5.12.2018**

Taustaksi:

Tässä toisessa projektiehdotuksessa olisi tarkoitus saada yhteinen linja aikaiseksi kattilanomistajien, kattilanvalmistajien ja tarkastuslaitosten kesken. Postissa on mukana pohjatiedoksi tätä edeltävä projektiehdotus, palaverimme muistio, Valmetin esimerkki casen tiedot siivottuna asiakastiedoista ja saadut kustannusarviot.

Projektiehdotus II:

Meillä on esimerkkitapauksena UPM-Kymin soodakattila, jonka compound – alueen laskennallinen minimi ts. S0 on 4,19 mm. Tässä tapauksessa soodakattilayhdistyksen ja Suomen tarkastuslaitosten linjaus, olla tunkeutumatta laskennallisen minimin puolelle on mahdotonta toteuttaa. Kohteessa joudutaan menemään nyt poikkeuksellisen paljon laskennallisen puolelle ja ainakin palaverissa olevat tarkastuslaitoksen edustajat eivät tule asiaa hyväksymään ilman lisätutkimuksia ja -tarkennuksia

Tarkoituksena on teettää standardisoidut menetelmäkokeet, tarkennettuna korotetun lämpötilan vetokokeilla. Tämä lämpötila on +380°C (+330 + 50°C* (* säteilyvaikutus)).

Menetelmäkokeita varten ajatetaan kolmella hitsarilla kolme työkoetta, jotka vielä kahdennetaan. Työkokeet tehdään 304 – compound liitokselle 309 - lisäaineella, normaalille sanicro 38 liitokselle ja 304 – compoundin liitokselle Sanicro – lisäaineella. Hitsarit olisi hyvä valita tästä hitsareiden alihankinta – poolista, jota kummatkin suomalaiset kattilanvalmistajat pääsääntöisesti käyttävät.

Tämän tarkennetun menetelmäkokeen lisäksi näytteille tehdään **muutosvyöhykkeen kemiallinen analyysi**, jolla varmistetaan muutosvyöhykkeen sekoittumisaste ja lisävarmistetaan liitoksen laadullisia kriteerejä. Tässä työssä päästään myös tarkastelemaan eri hitsareiden käsialaa ja tunkeuman syvyyksiä.

Tällä työllä pyritään täyttämään alla olevan standardin velvoite, kohdan A2.2.2 a) lisäaineen ja hitsiaineen lujuus- ja sitkeysominaisuudet täyttävät ferriittisen painetta kantavan sisäosan materiaaliominaisuudet;
, niin että kaikille osapuolille saataisiin yhteinen linjaus. Ja soodakattilan korjauksien hankinnat ja toteutukset tulisivat tulevaisuudessa selkeämmiksi.

Standardi ei salli compound – jatkohitsin kemiallista kuormaa kantavan päällehitsauksen ottamista mukaan lujuuteen. Päivänselvään on, että se oikein ja laadukkaasti tehtynä lisää lujuutta, jonka paikkaansa pitävyyttä tässä nyt varmistetaan. Samalla saamme lisää varmuutta, jos joudutaan paljonkin tunkeutumaan laskennallisen puolelle tulevilla projekteilla.

OTE STANDARDISTA 12952-6

Liite A

(velvoittava)

Kompoundputkien erityisvaatimukset

A.1 Yleistä

Tämä liite määrittää soodakattiloille, joiden määritelmä on standardin EN 12952-5:2011 kohdassa E.2, valmistuksen aikaisen tarkastuksen, dokumentoinnin ja merkinnän vaatimukset. Nämä erityisvaatimukset tulevat kaikkien muiden edelleen voimassa olevien tämän standardin vaatimusten lisäksi.

A.2 Erityisvaatimukset sulahitsauksen hitsausohjeiden hyväksymiselle

A.2.1 Yleistä

Tämän eurooppalaisen standardin, erityisesti kohdan 6, vaatimuksia täydennetään soveltamalla kohdan A.2.2 erityisvaatimuksia.

Leimuhitsaus tulee suorittaa standardin EN 12952-5:2011 kohdan E.6 mukaan.

A.2.2 Standardin EN ISO 15614-1 soveltaminen compoundputkiin

A.2.2.1 Hyväksynnän pätevyysalue

Vain compoundputkilla saatua hitsausohjeen hyväksyntää saa soveltaa compoundputkien hitsaukseen.

Nimellisseinämänpaksuus t on compoundputken nimellinen kokonaisseinämänpaksuus.

Halkaisija D on compoundputken nimellishalkaisija.

Hyväksynnän pätevyysalue koskee vain niitä samoja hitsityyppejä, joita käytettiin menetelmäkokeissa. Menetelmäkoe koskee vain niitä compoundputken materiaaliyhdistelmiä, joita se edustaa.

A.2.2.2 Vaaditut lisäkokeet

A.2.2.2.1 Pinnoitteen hitsin tunkeuman syvyys

Makrohietutkimuksessa määritetään pinnoitteen hitsin tunkeuman syvyys ferriittiseen painetta kantavaan sisäosaan tai hitsiin. Tunkeuma ei saa olla olennaisesti ferriittisen painetta kantavan sisäosan pinnan alapuolella. Ilman tunkeumaa olevan alueen täytyy aina olla vähimmäispaksuuden suuruinen.

Pinnoitteen hitsi voi tunkeutua lasketun ferriittiseen painetta kantavaan sisäosaan vähimmäispaksuuteen asti seuraavissa tapauksissa:

a)lisäaineen ja hitsiaineen lujuus- ja sitkeysominaisuudet täyttävät ferriittisen painetta kantavan sisäosan materiaaliominaisuudet;

b)hitsausohjeiden hyväksyntä vastaa standardin EN ISO 15614-1 sekä standardissa EN 12952 esitettyjä lisävaatimuksia;

c)pinniotteen hitsin enimmäistunkeuma laskettuun ferriittisen painetta kantavan sisäosan vähimmäispaksuuteen on
1,5 mm;

d)ennen tuotantoa tehdään työkoe. Käsinhitsauksessa jokainen hitsaaja tekee työkokeen. Mekanisoidussa hitsauksessa tehdään yksi työkoe kutakin hitsausohjetta kohti;

e)rikkomaton aineenkoetus suoritetaan päällehitsauksen jälkeen standardin EN 12952 mukaisesti.

A.2.2.2.2 Kovuuskoe

Kovuuskoe tehdään ferriittisen painetta kantavan sisäosan materiaalin ulkopinnalla ja pinnoituksen pinnalla. Kohdan 6.2.2.5 vaatimukset tulee täyttää. Pinnoitteen hitsin kovuusarvojen tulee vastata lisäaineenvalmistajan antamia kovuusarvoja.

A.2.2.2.3 Taivutuskoe

Taivutuskoe tehdään pinnoitetulla putkella.

**LTR: Pulp mill deposit formation and aging – role of intra-deposit alkali
chloride transport, part 1
ÅA – loppuraportti 21.9.2018**



Johan Gadolin

PROCESS CHEMISTRY CENTRE



Deposit sampling at pulp mill – Deposit formation, aging, and Cl transport, Phase 1

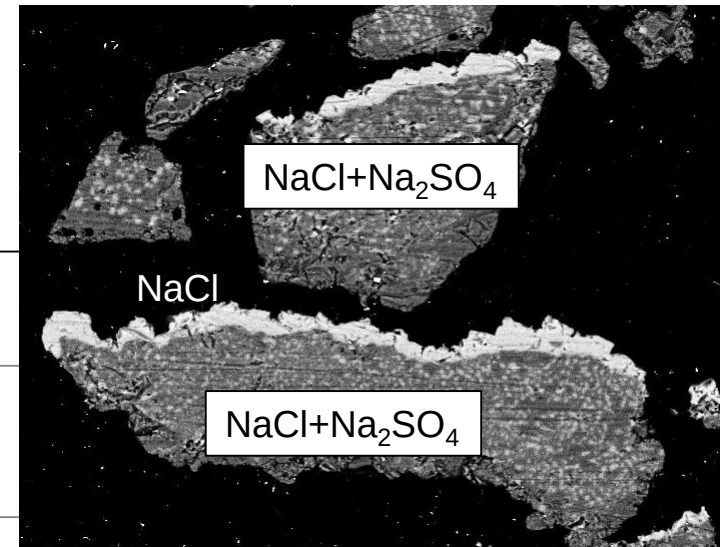
Roland Balint, Markus Engblom
Åbo Akademi University
September 2018



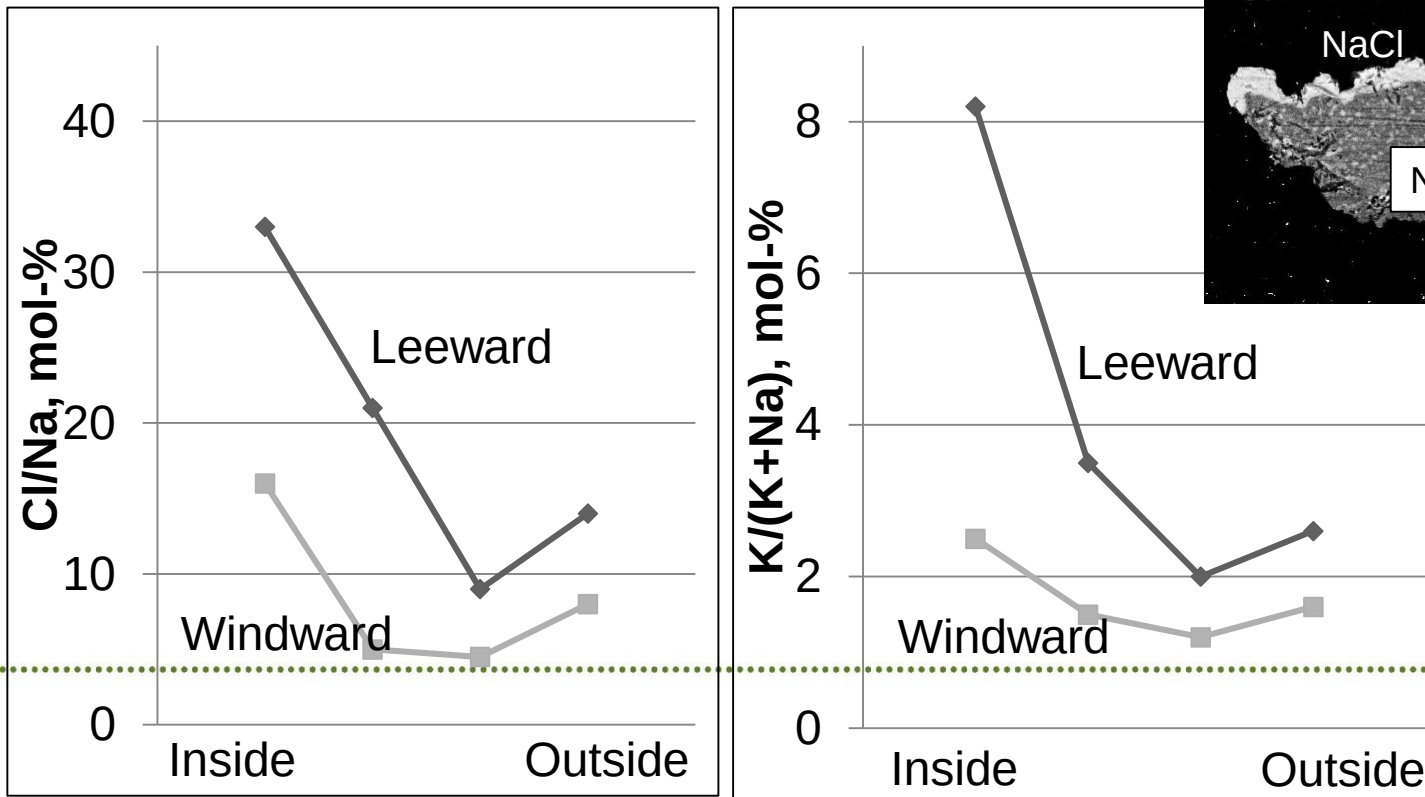
Background

- Intradeposit alkali chloride transport

ÅA laboratory deposit



Boiler deposits, Reeve et al. 1981, Tappi Journal



Objective and approach (1/2)

- Better understanding of time dependent changes in deposit morphology and chemistry
- Deposit temperature gradient
 - Cl transport - corrosion
 - Morphology / porosity – deposit removability
- Sampling and analysis of deposits of different age

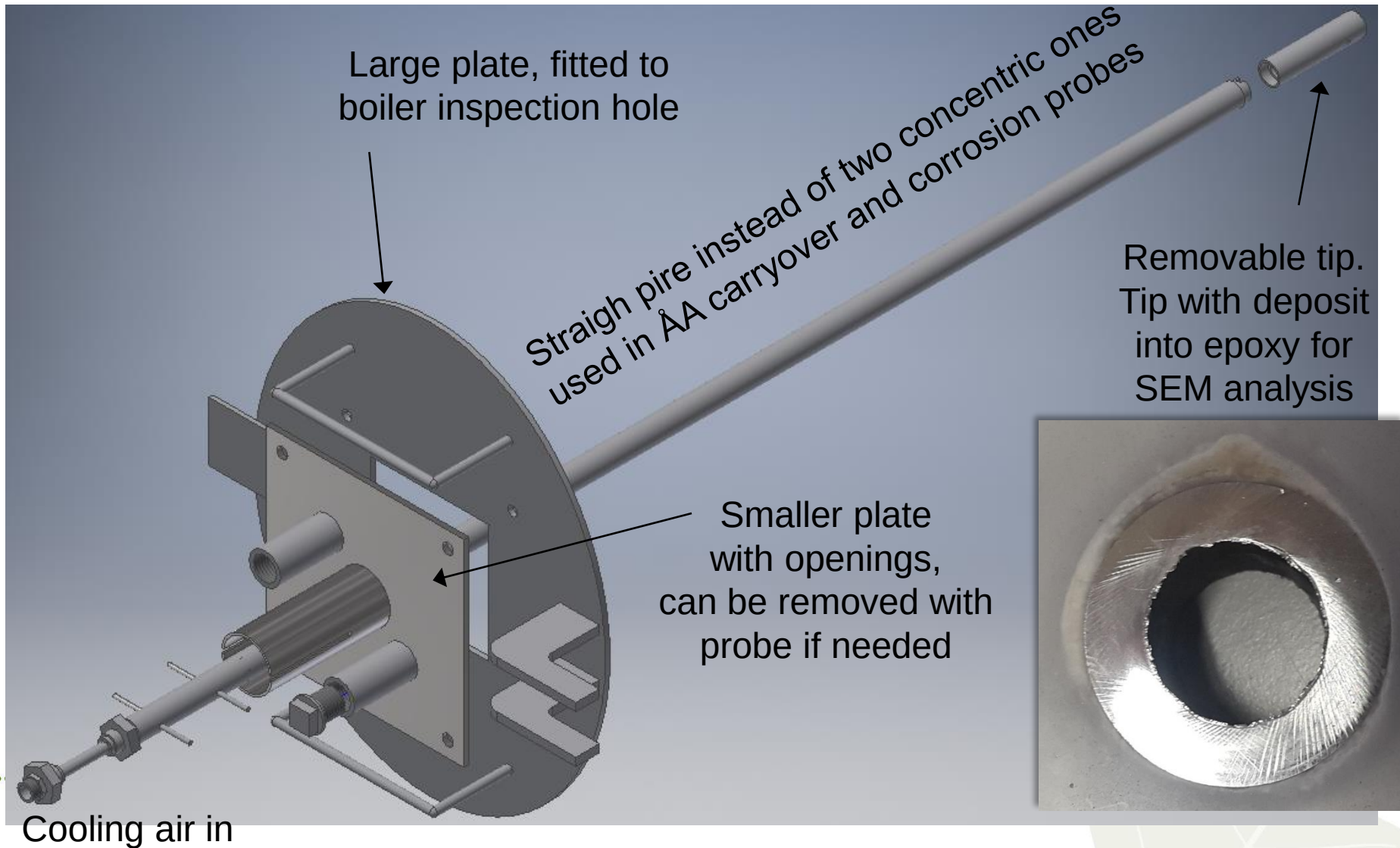


Objective and approach (2/2)

- **Phase 1:**
 - **Construct and test new probe design**
 - **Extend sampling time**
 - 2 hours, 24 hours, one week
- **Phase 2:**
 - Decision and detail plan after Phase 1
 - E.g 1000 hour sampling
 - MSc thesis work



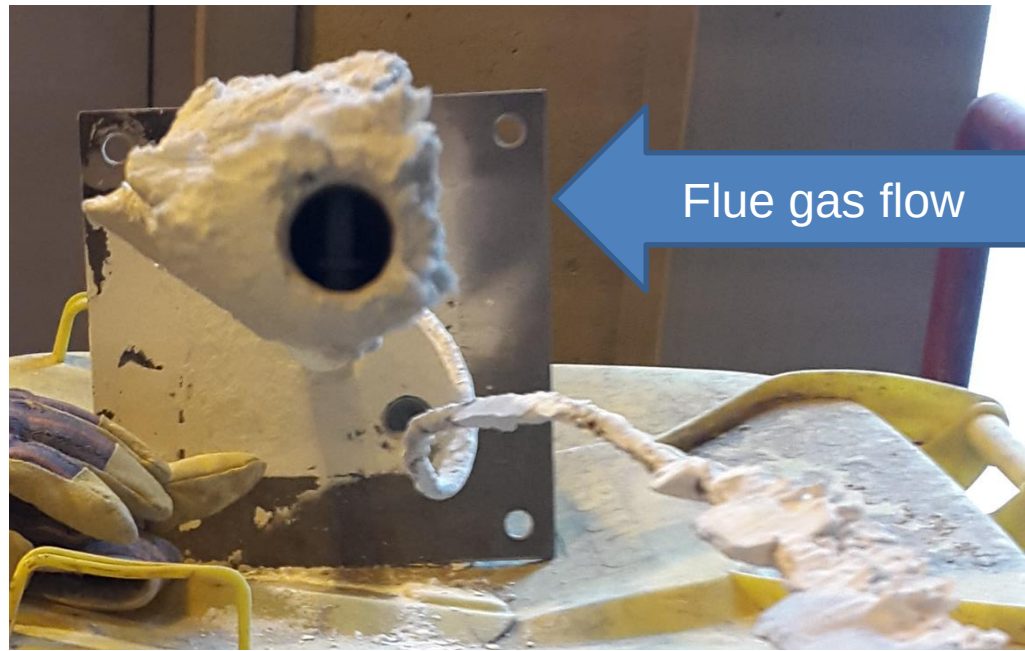
New probe design



New probe design in action

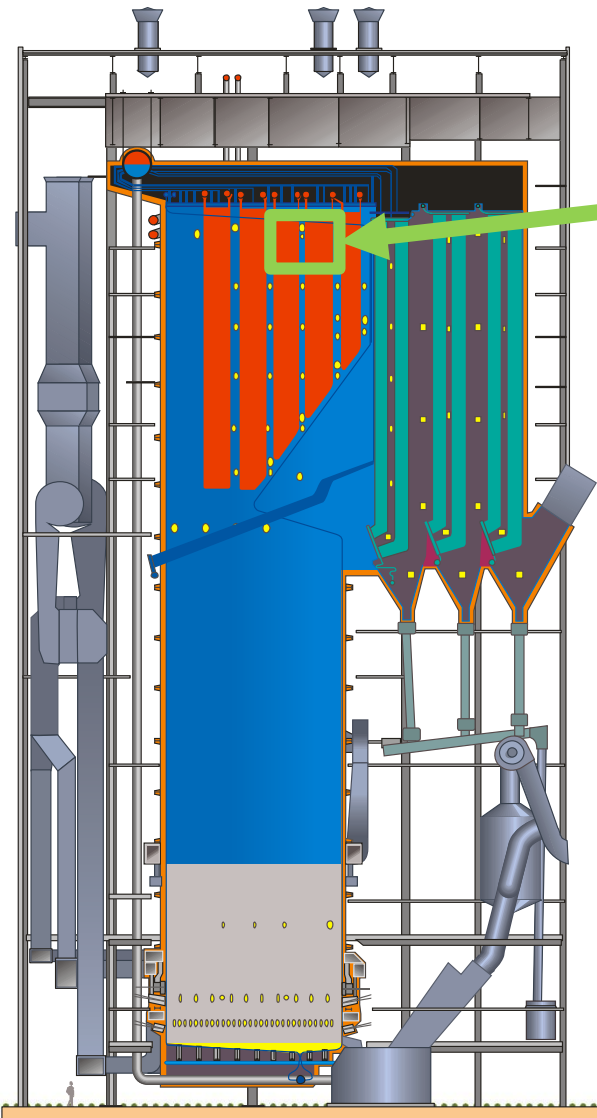


Pictures from
one-week exposure



Deposits were observed to become harder with time, most likely due to sintering.

Measurement location



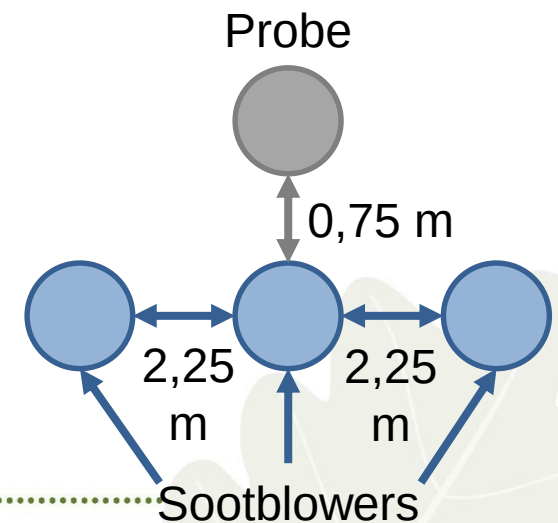
Measurement location (tertiary superheater)



Sample after an exposure of 3 hours with sootblowing



Complete set-up during measurement



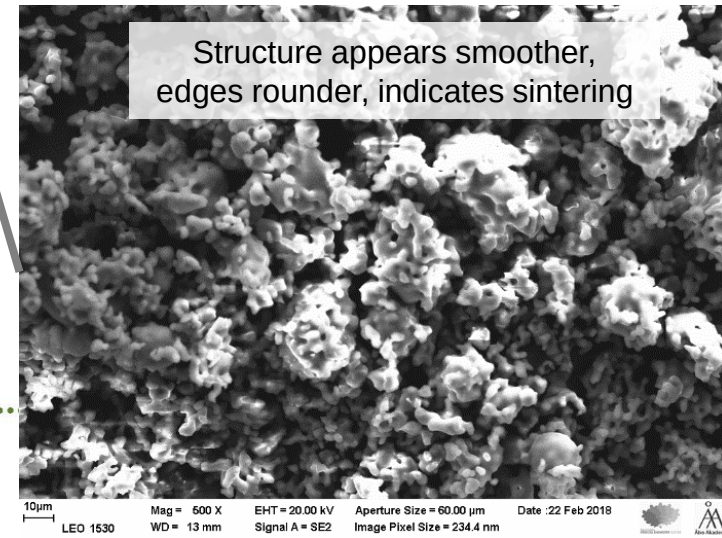
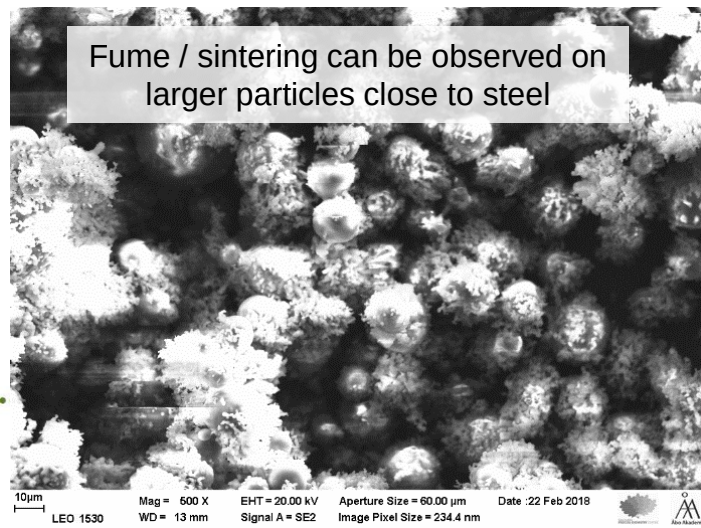
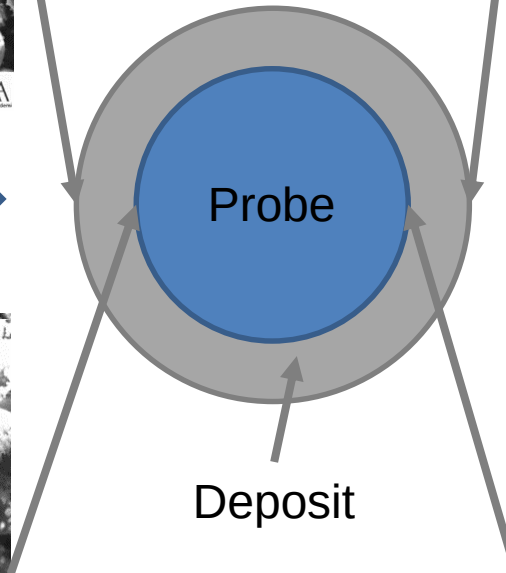
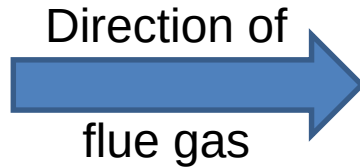
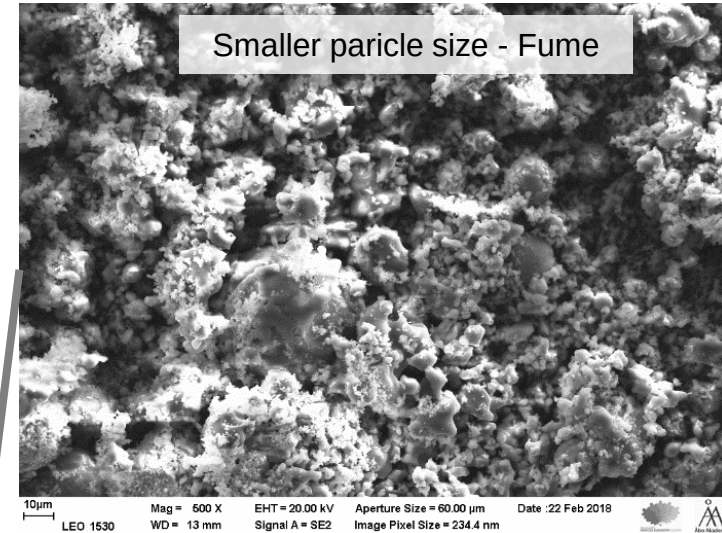
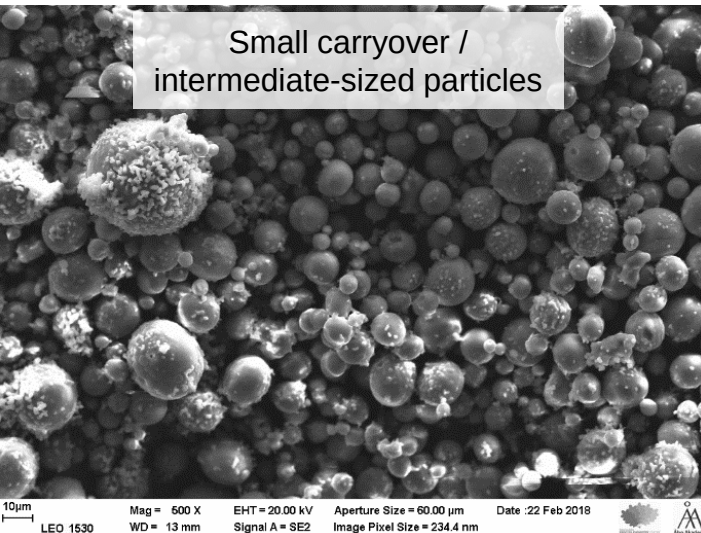
Experimental overview

Exposure time	Steel temperature [°C]	Flue gas temperature [°C]
30 minutes	445	608
2 hours	418	629
3 hours without sootblowing	457	633
3 hours with sootblowing	456	649
24 hours	446	608
7 days	446	623

Two thermocouples in probe tip – temperature control and logging

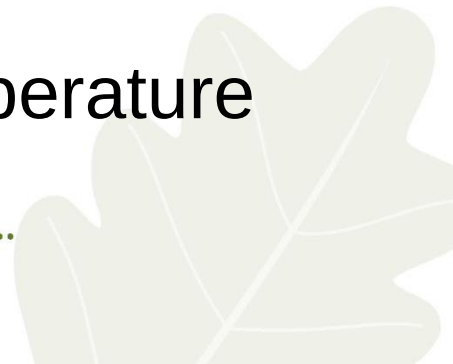


Deposit particles – 24 h

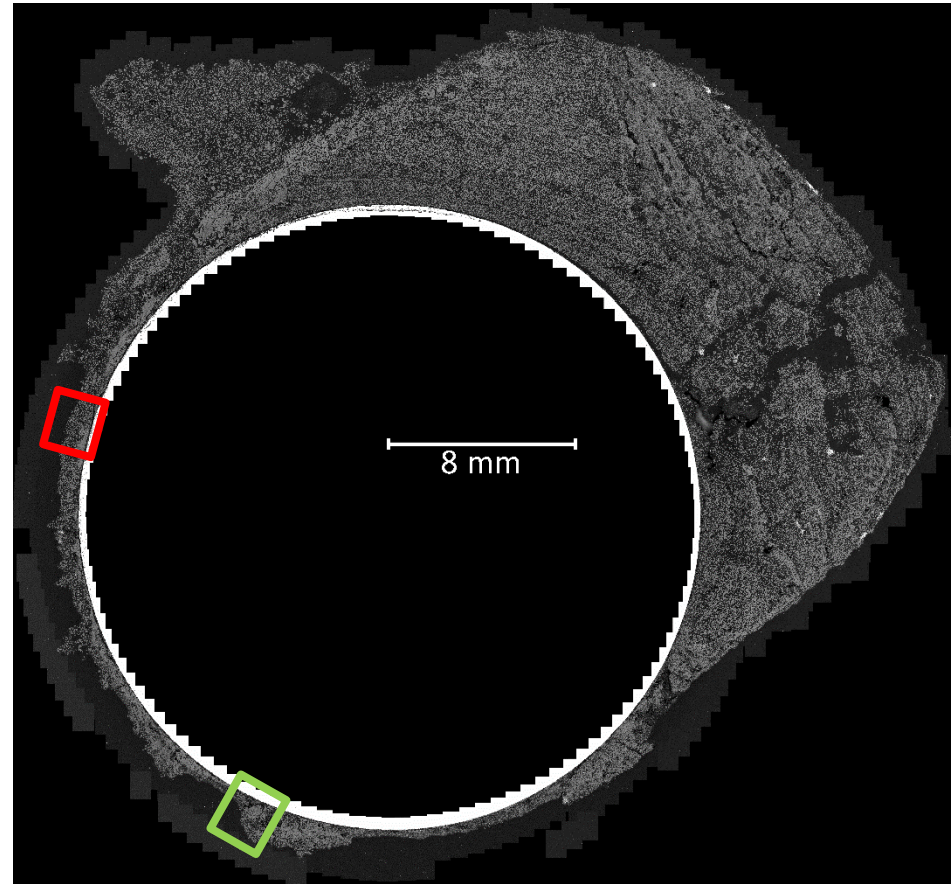
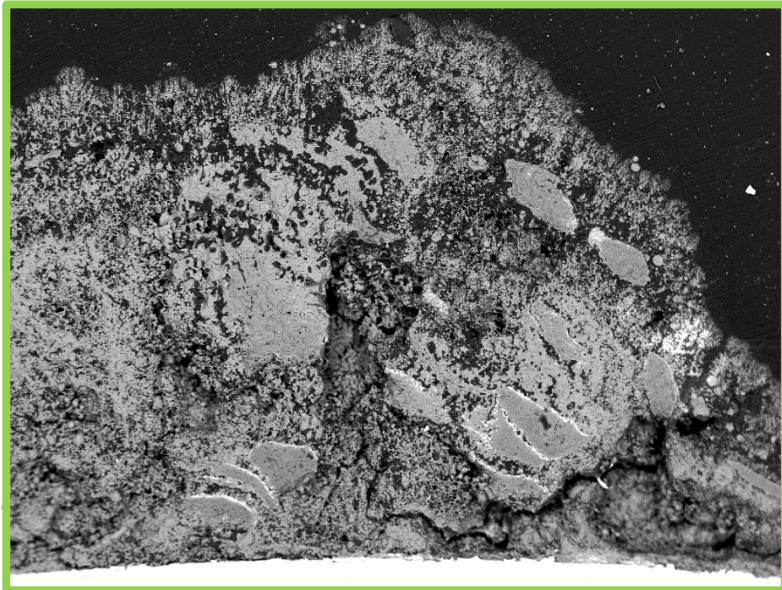
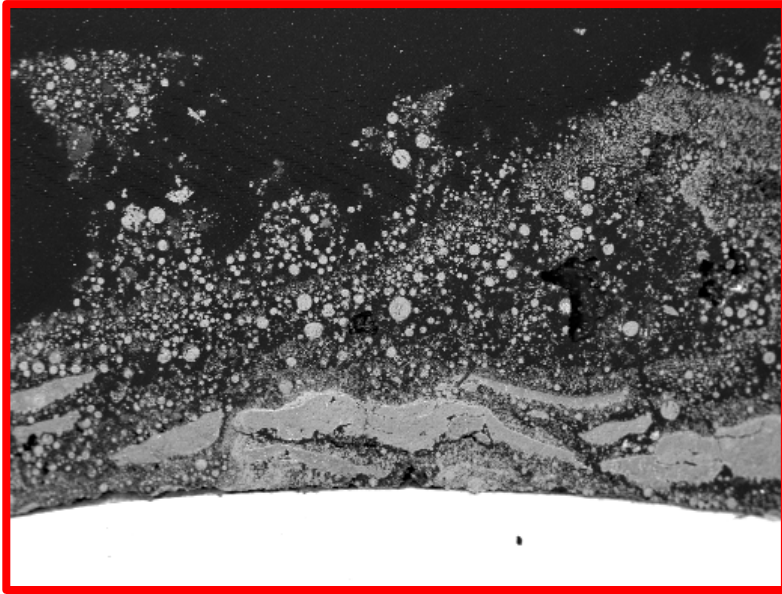


Sample analysis

- Main focus on structure and elemental composition
 - Can we see local enrichment of chlorine?
 - $\text{Cl} / (\text{K} + \text{Na})$ as indicator for amount of smelt
 - $\text{K} / (\text{K} + \text{Na})$ as indicator for melting temperature



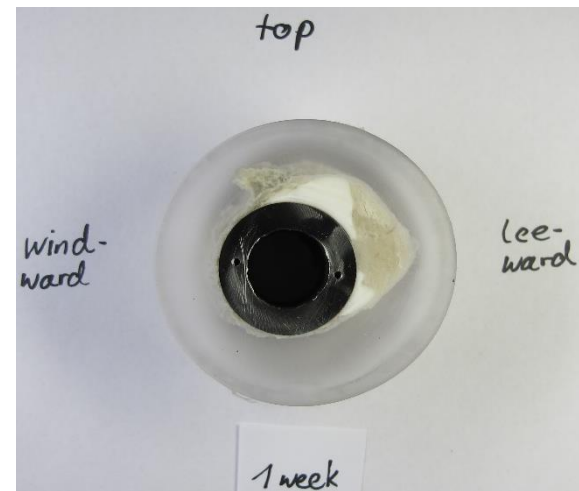
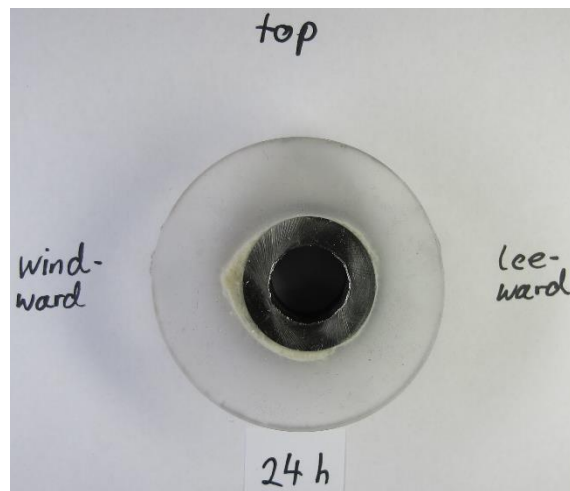
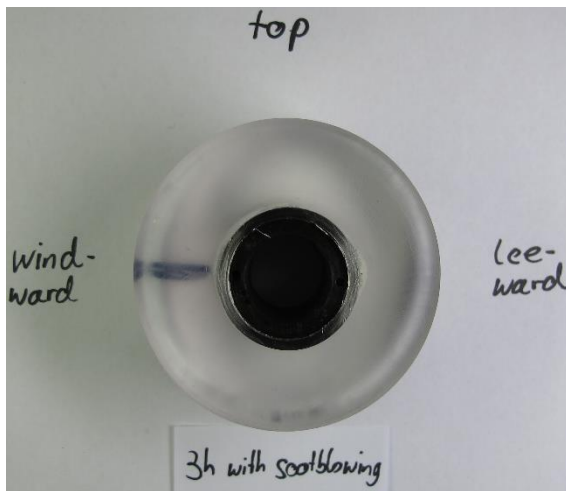
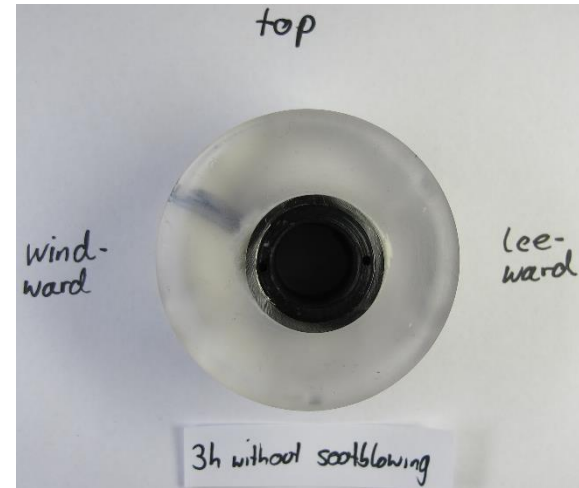
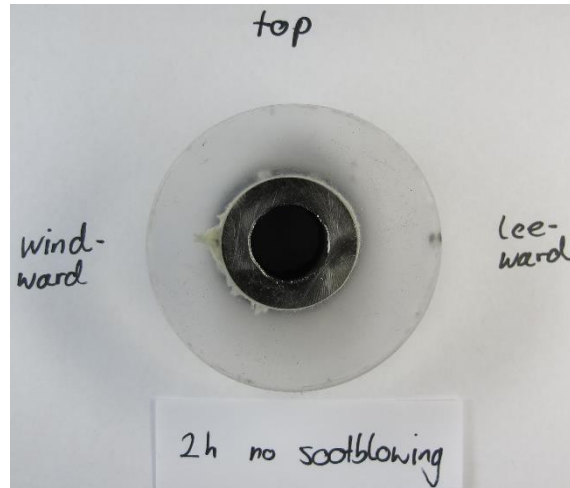
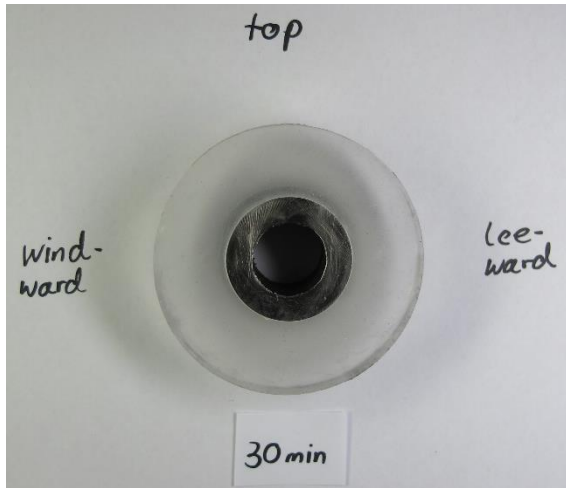
Examples of sample analysis



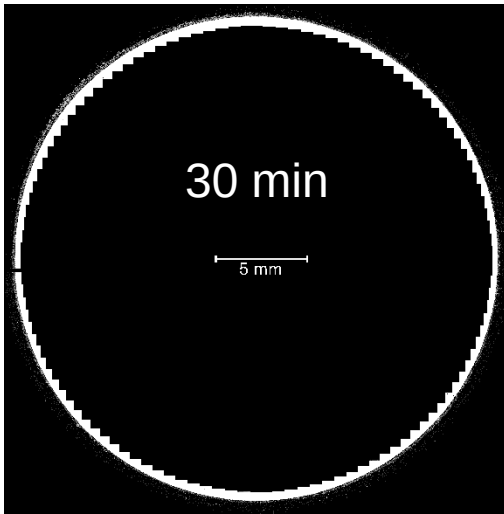
Panorama pictures are prepared from a large number of smaller SEM images (see horizontal/vertical edges on inside of probe) covering the whole probe/deposit.

- More detailed elemental analysis is done in selected locations. For all samples, elements analyzed on wind and lee sides

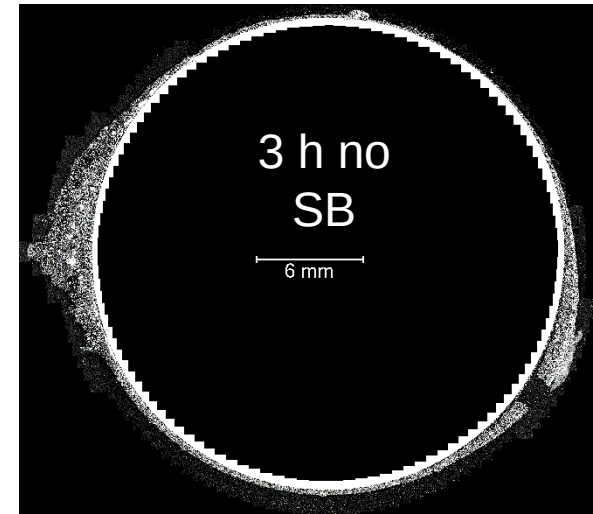
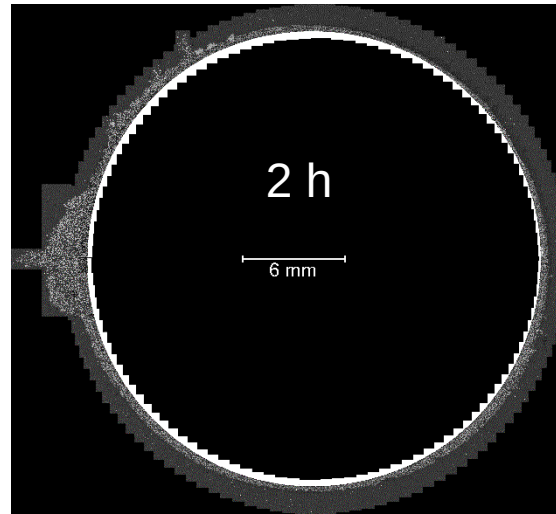
Obtained samples



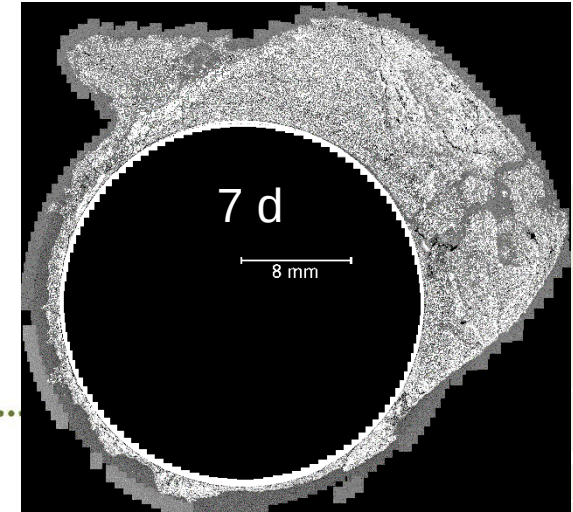
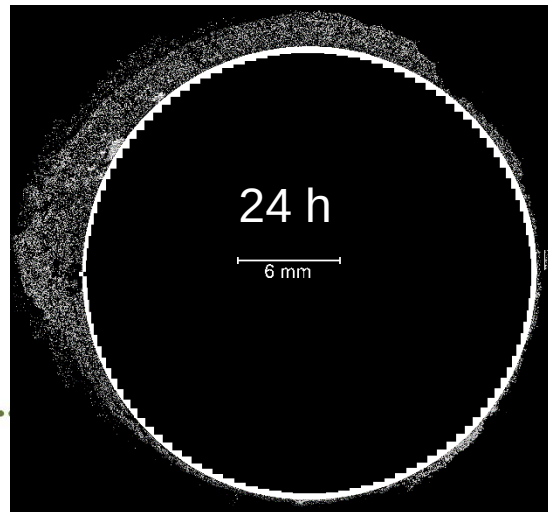
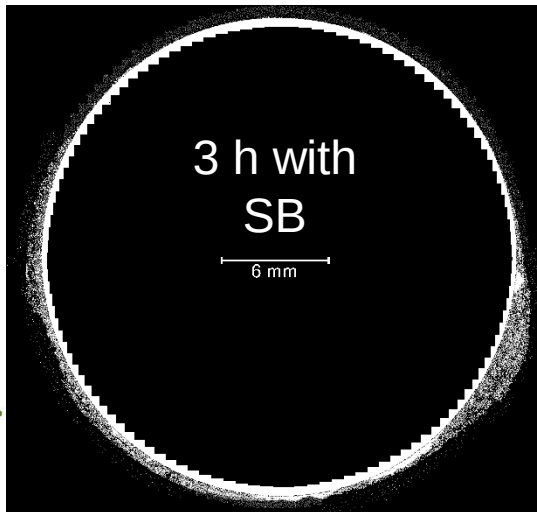
Panorama pictures



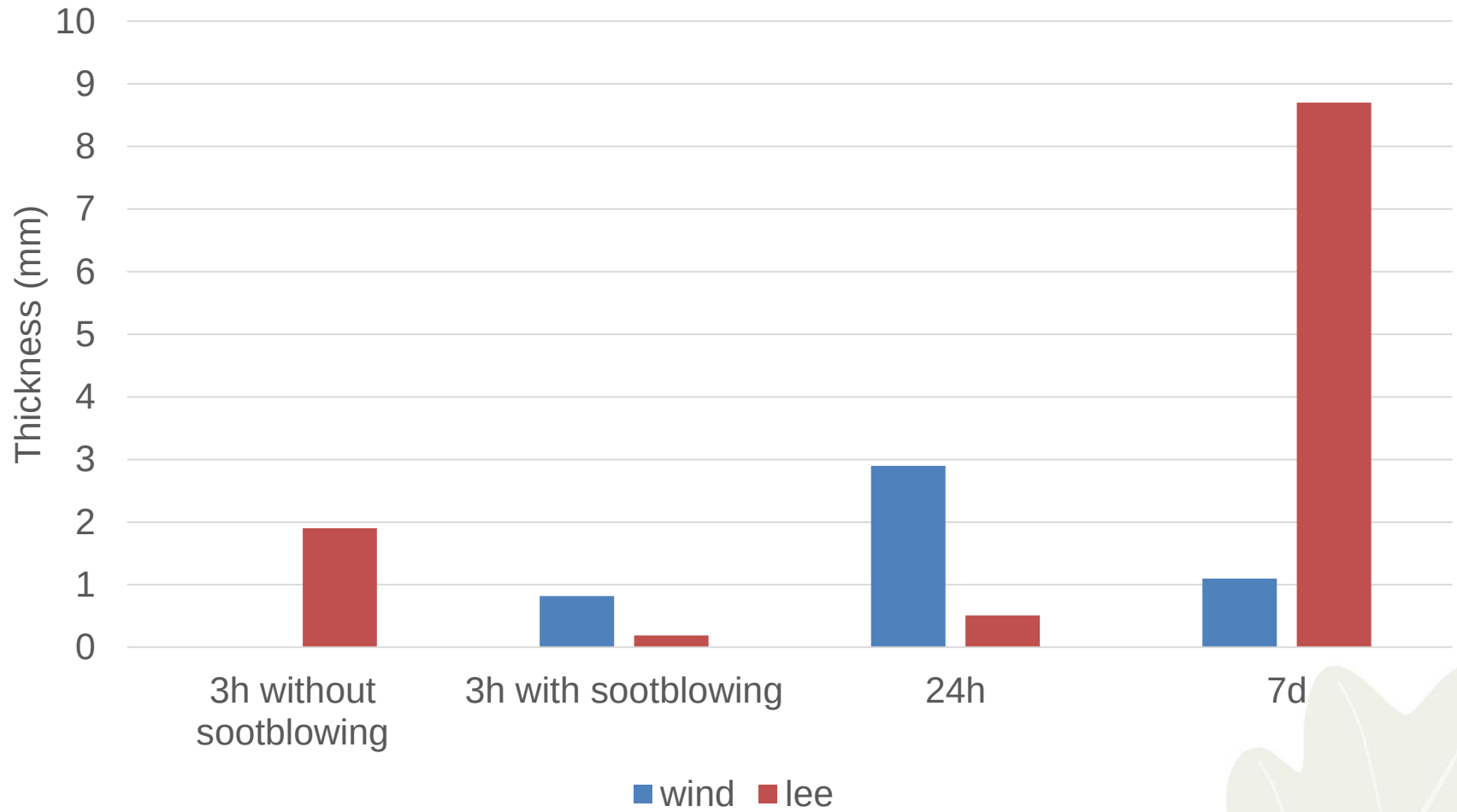
Deposit very thin



Flue gas direction

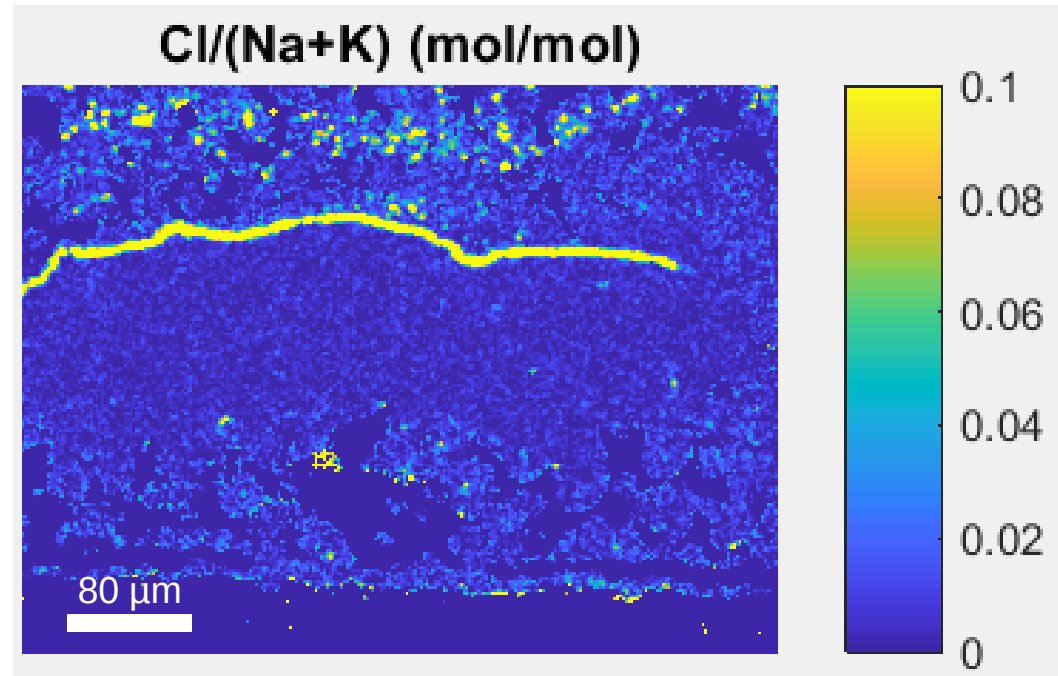
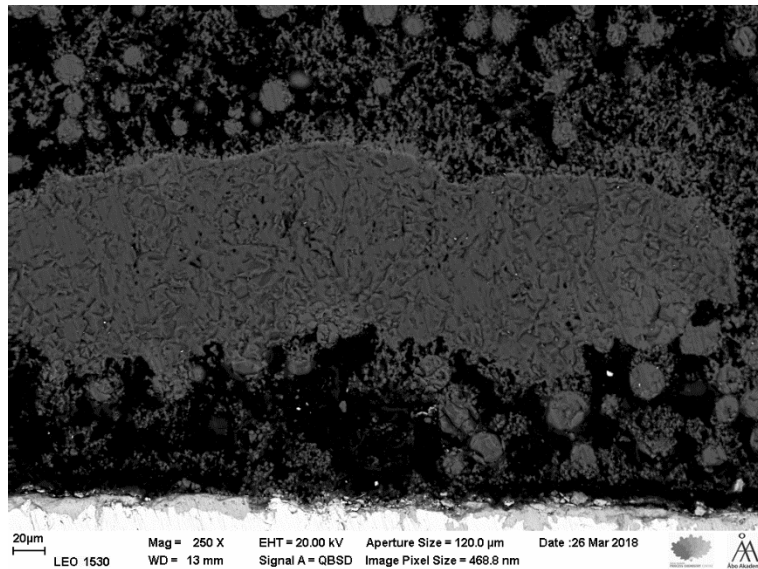


Deposit thicknesses



Deposit thicknesses determined for those samples where Cl could be detected;
see element analysis in slides further below

Enrichment of Cl



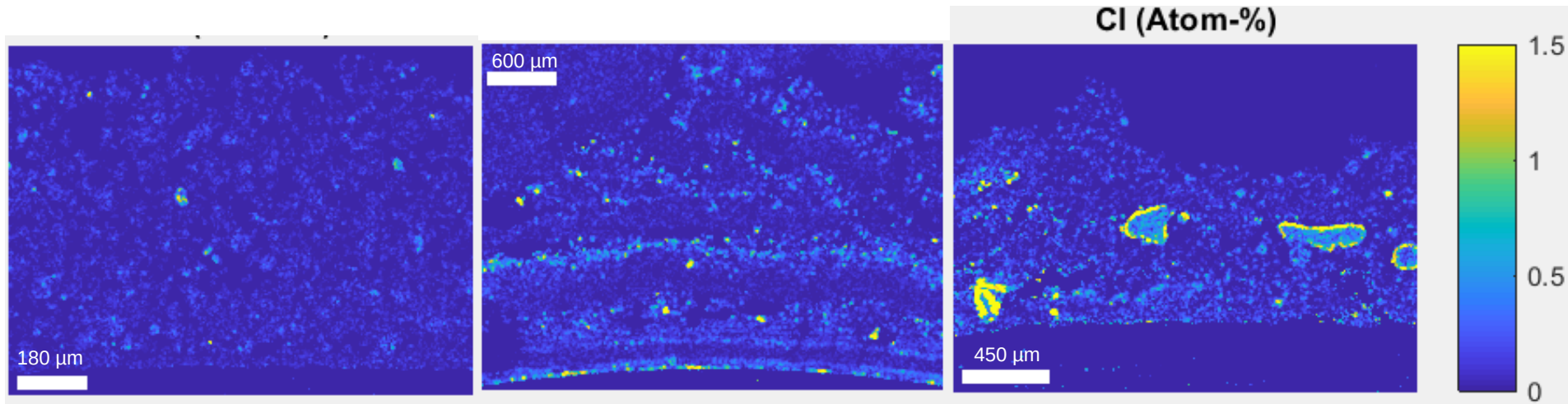
Detected after 3 h on top of sintered particles within the deposit
For deposits of age < 3h, chlorine was not detected

Cl-distribution on the wind side

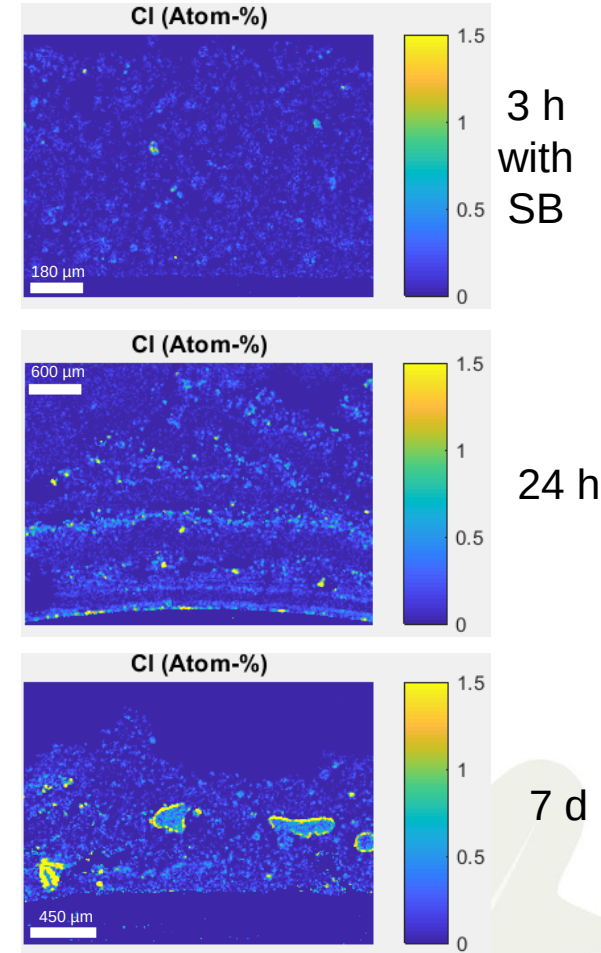
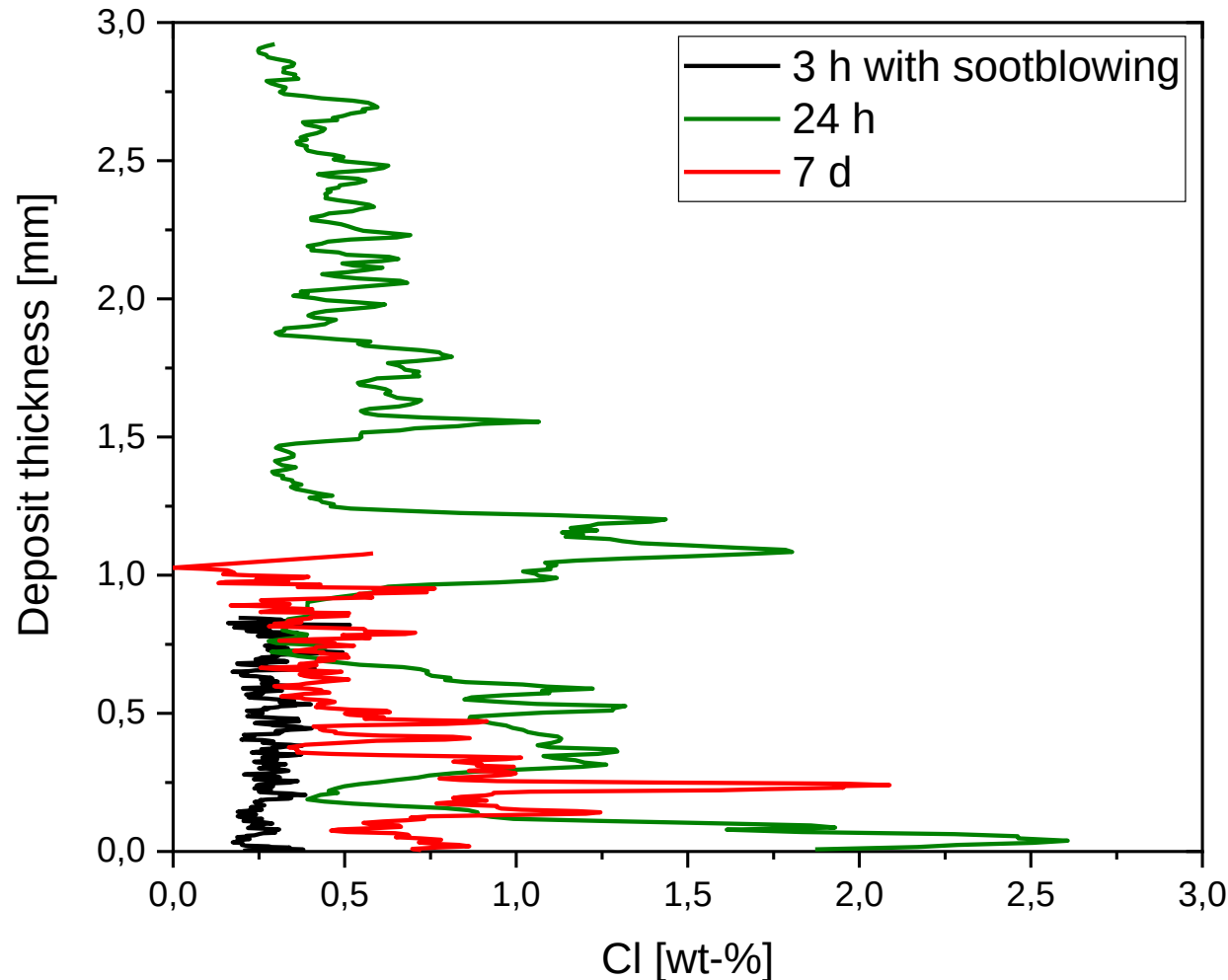
3 h with sootblowing

24 h

7 d



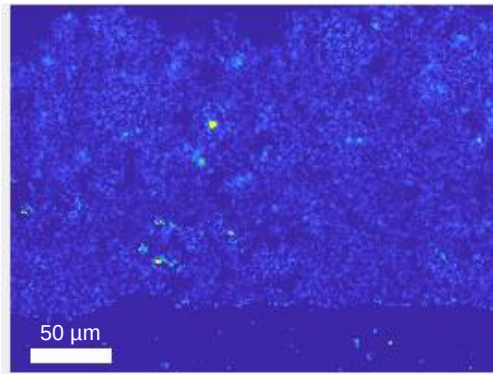
Cl-profiles on wind side



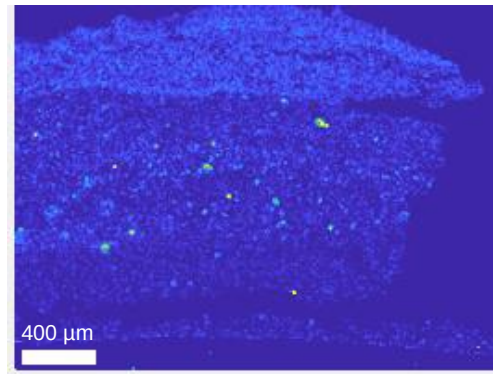
The profiles are calculated from maps on right by averaging over the horizontal plane

Cl-distribution on lee side

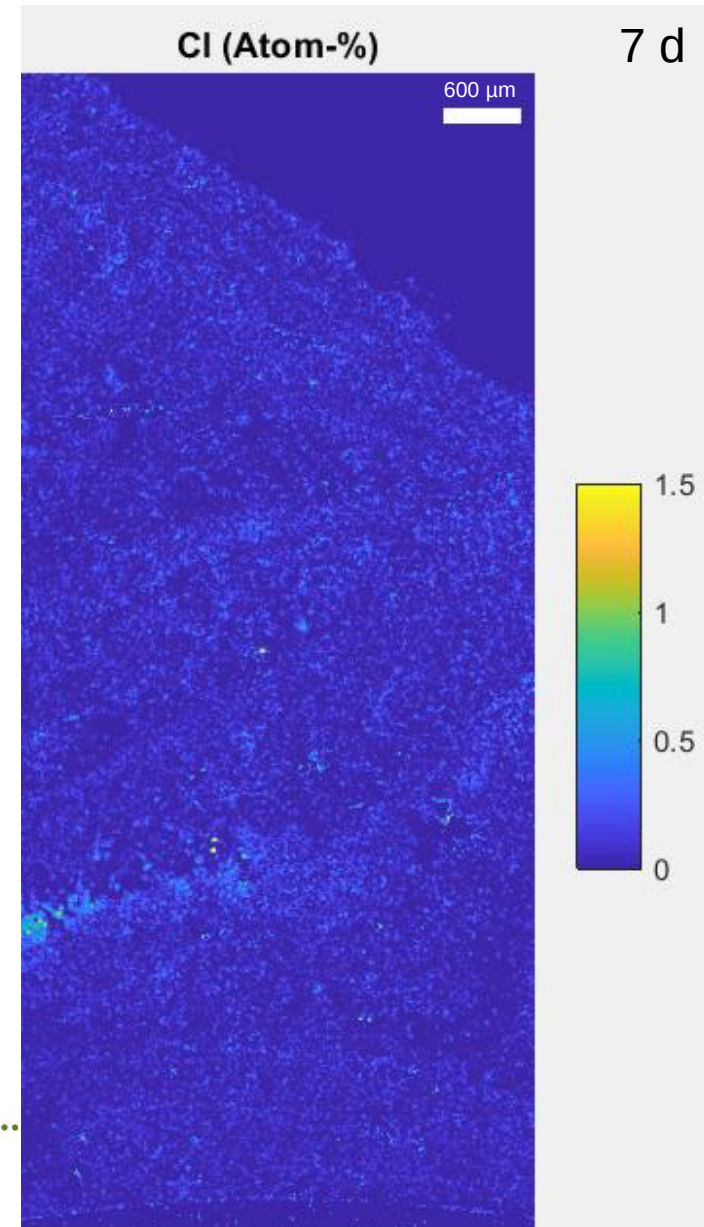
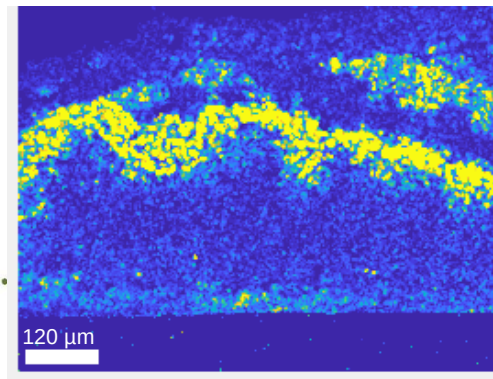
3 h
with
SB



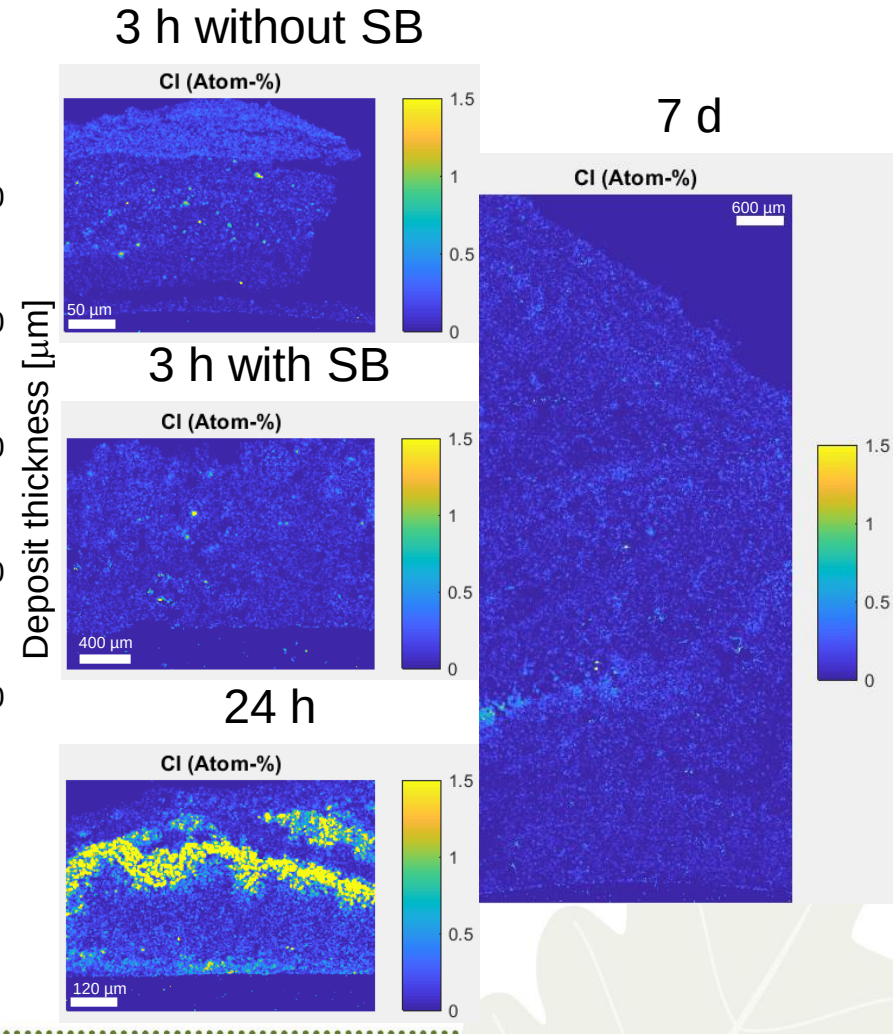
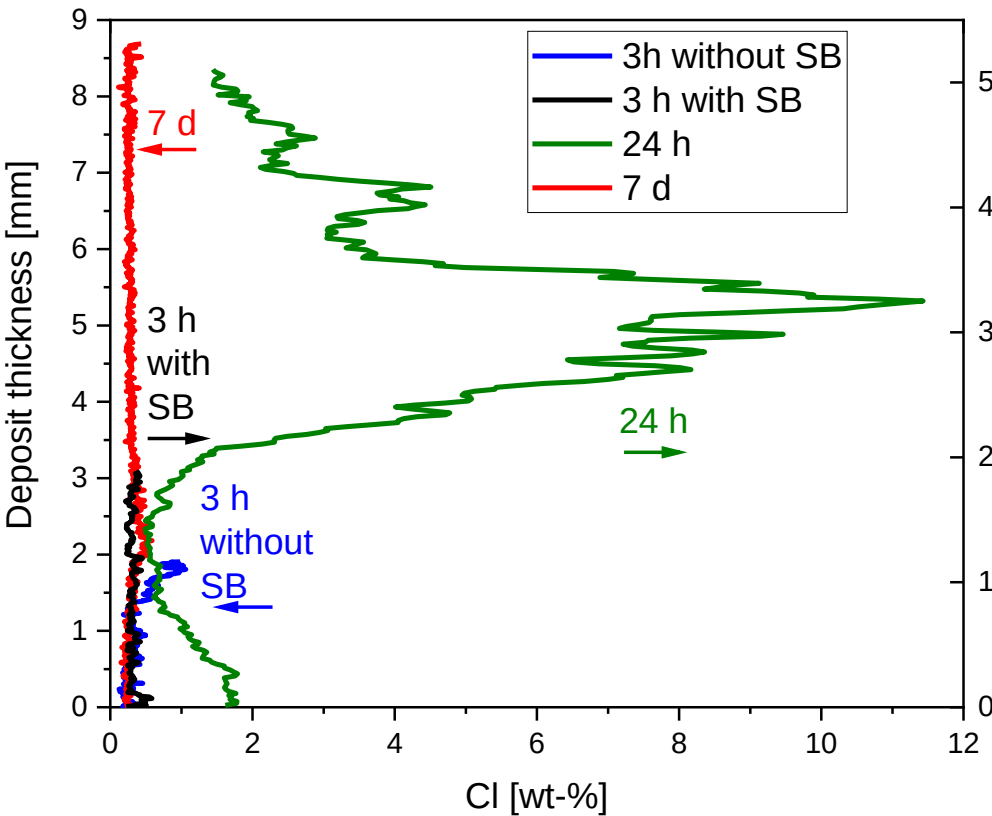
3 h
without
SB



24 h



Cl-profiles on the lee side



The profiles are calculated from maps on right by averaging over the horizontal plane

Cl/(K+Na) ratio on wind side

3 h with sootblowing

24 h

7 d

Cl/(Na+K) (mol/mol)

0.1
0.08
0.06
0.04
0.02
0

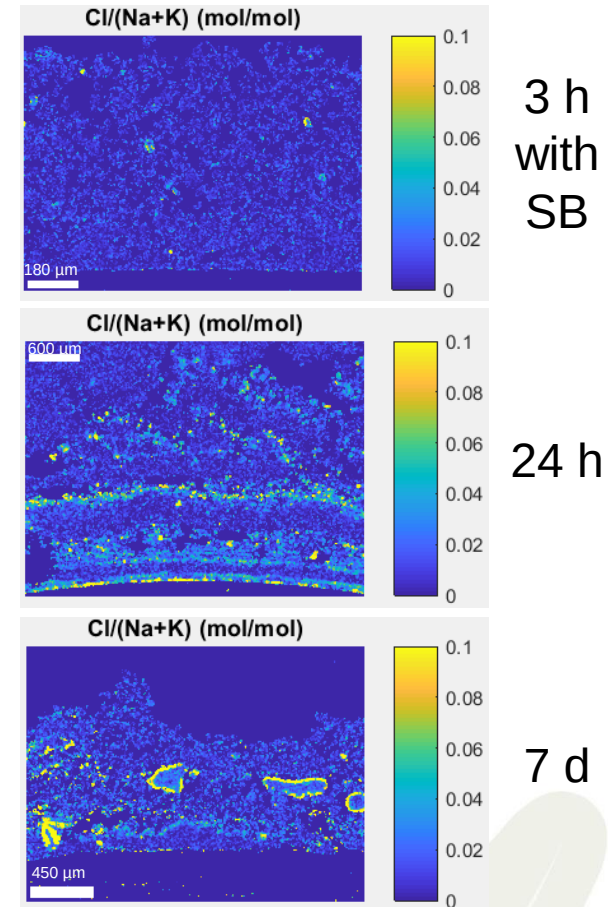
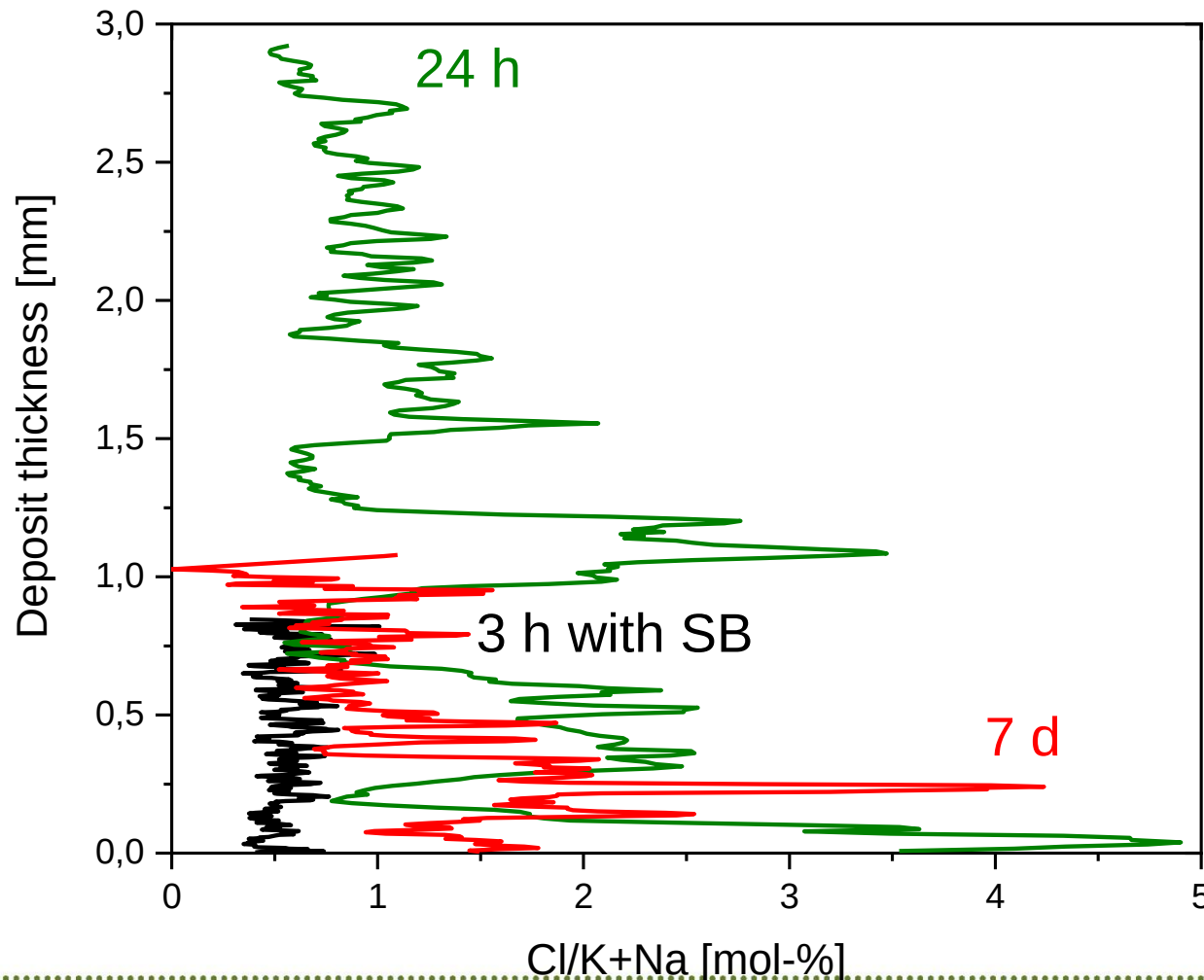
180 μm

600 μm

450 μm

Local enrichment of Cl observed at 24 h and 7 d

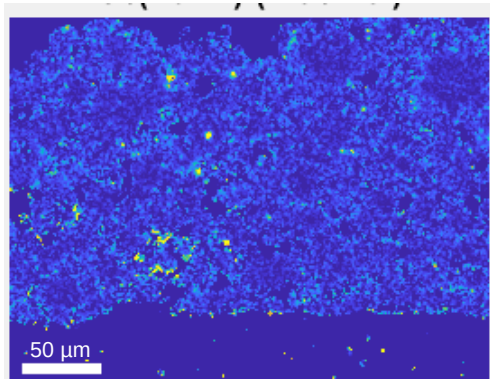
Cl/(K+Na) profiles on wind side



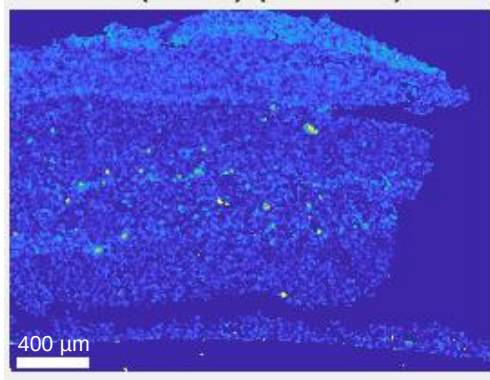
The profiles are calculated from maps on right by averaging over the horizontal plane

Cl/(K+Na) on lee side

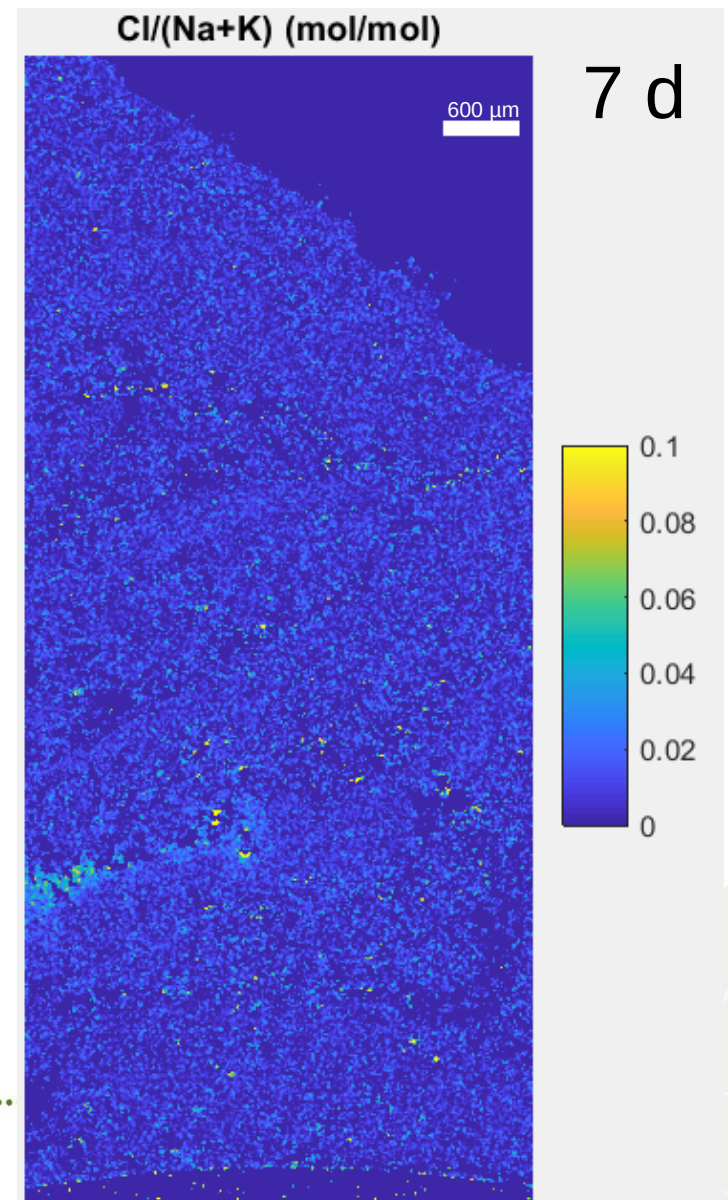
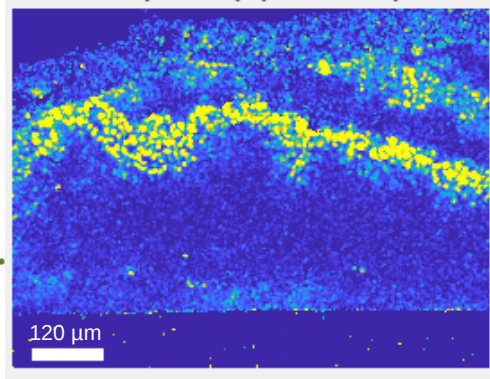
3 h
with
SB



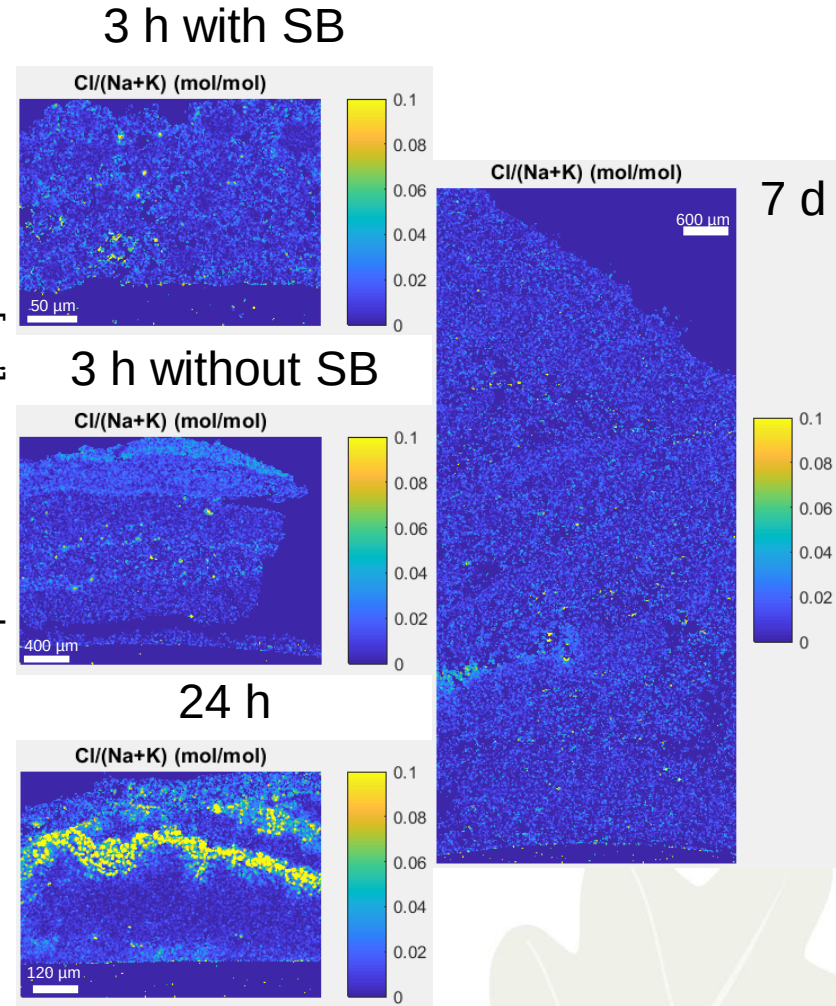
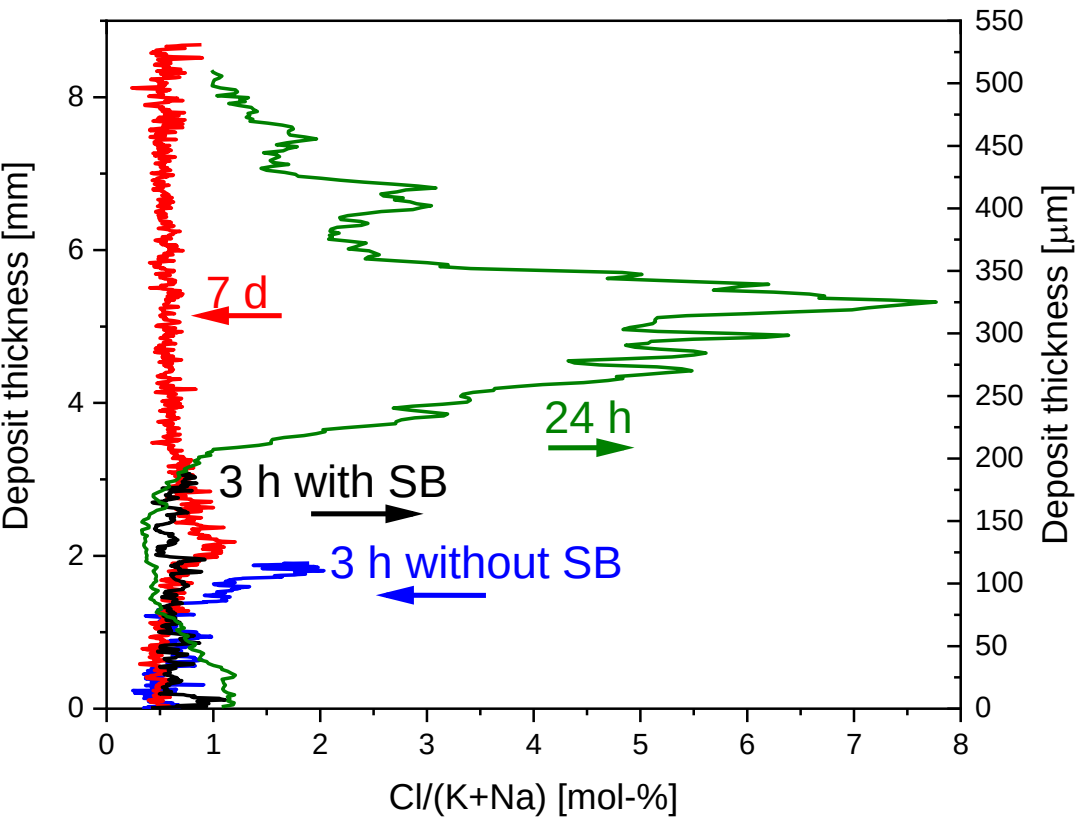
3 h
without
SB



24 h



Cl/(K+Na) profiles on lee side



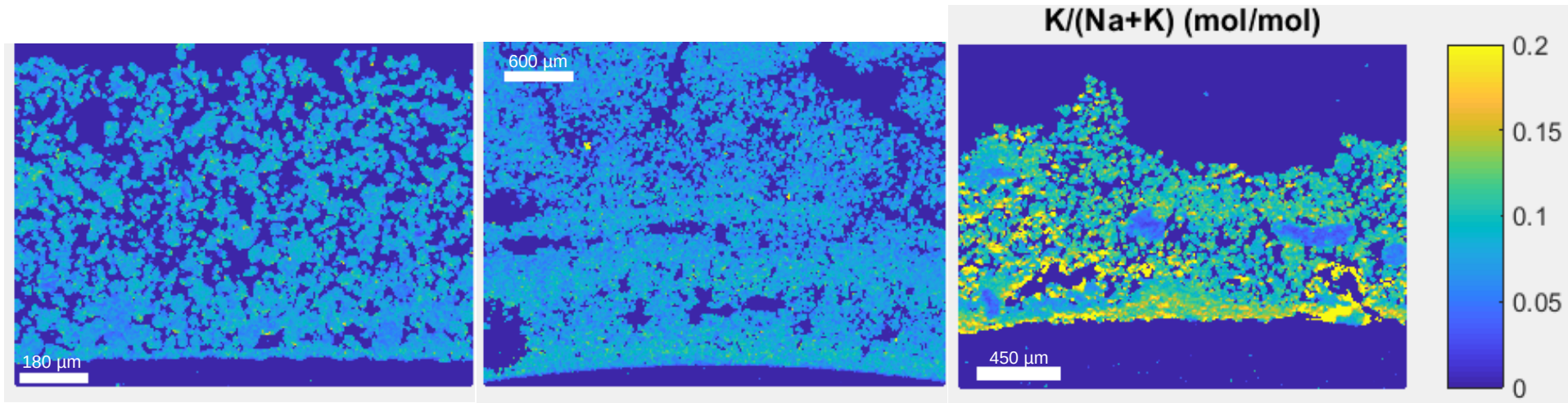
The profiles are calculated from maps on right by averaging over the horizontal plane

$K/(Na+K)$ on wind side

3 h with SB

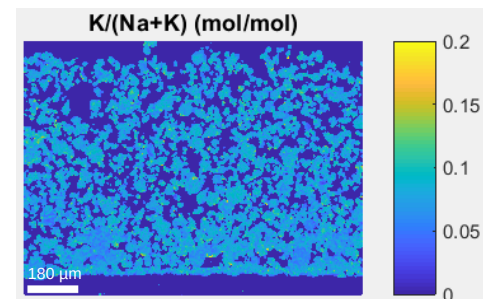
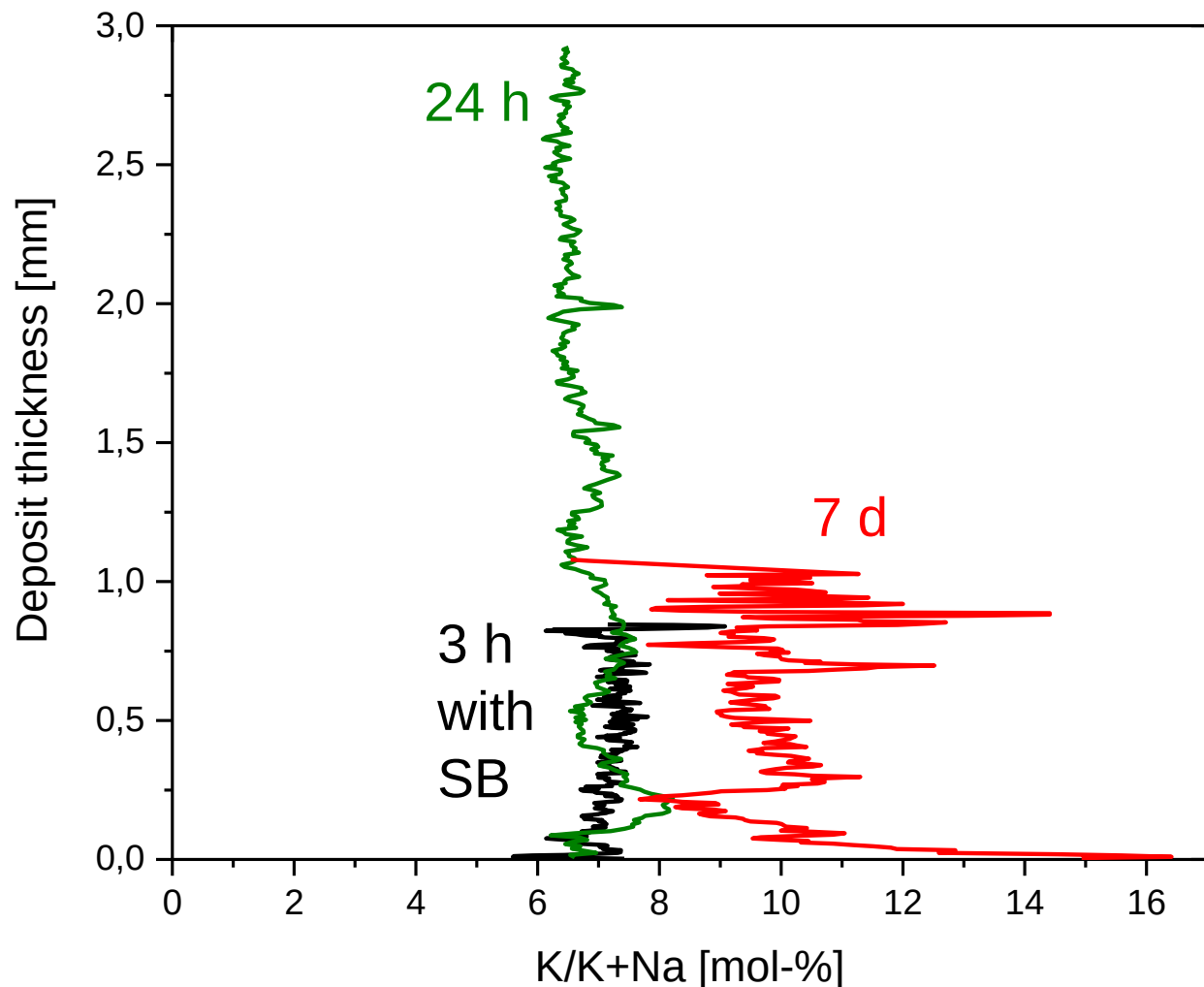
24 h

7 d

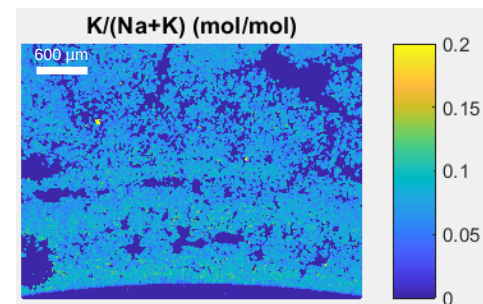


Enrichment in K throughout the whole deposit after 7 d

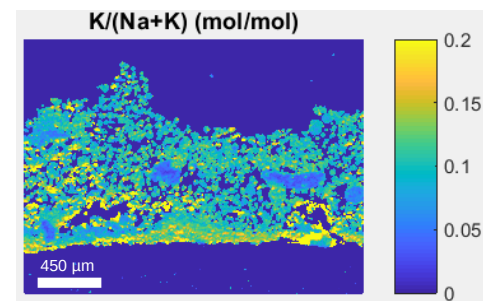
K/(Na+K) profiles on wind side



3 h
with
SB



24 h

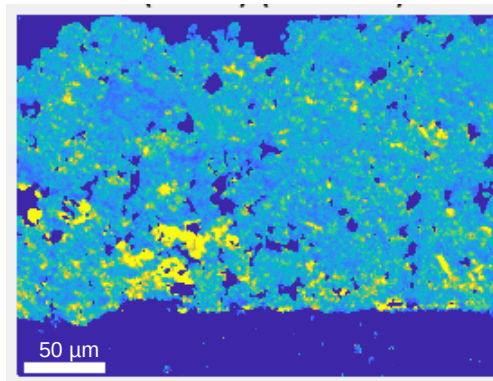


7 d

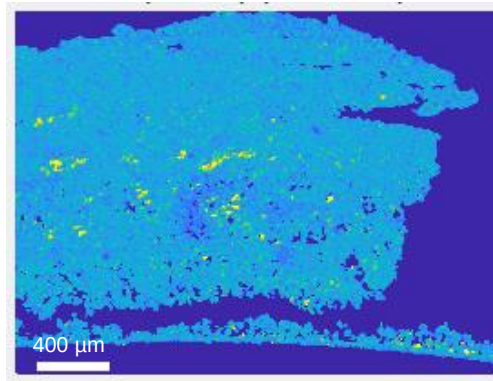
The profiles are calculated from maps on right by averaging over the horizontal plane

$K/(Na+K)$ on lee side

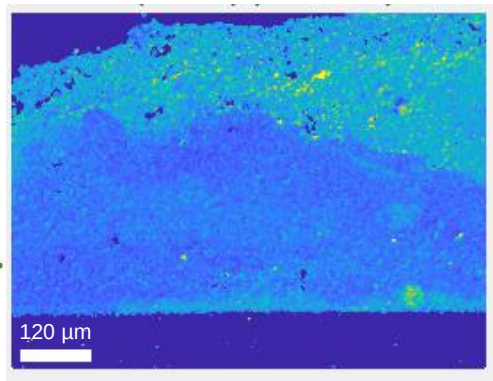
3 h
with
SB



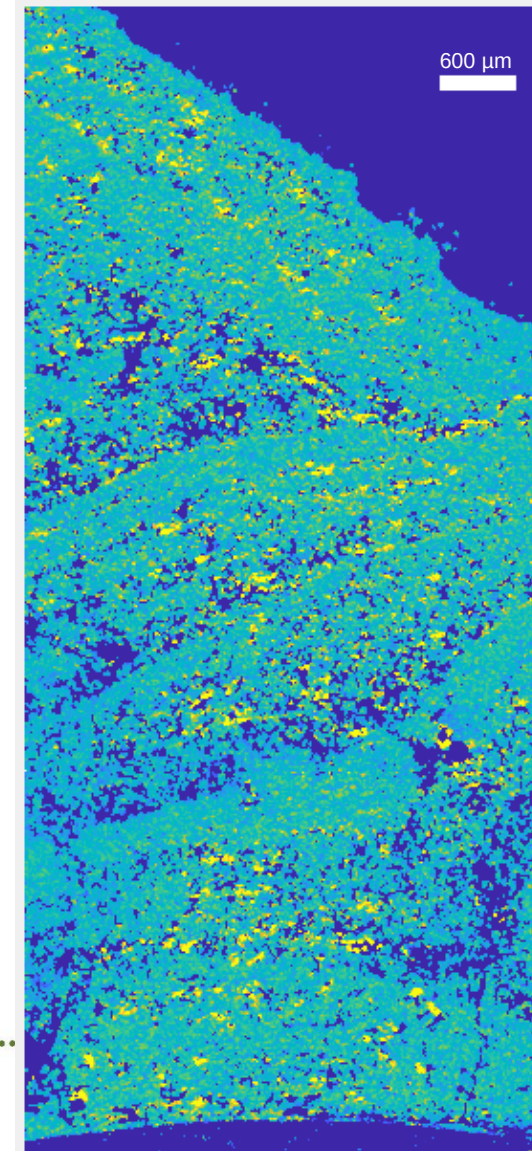
3 h
without
SB



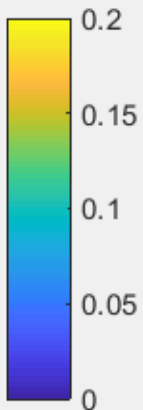
24 h



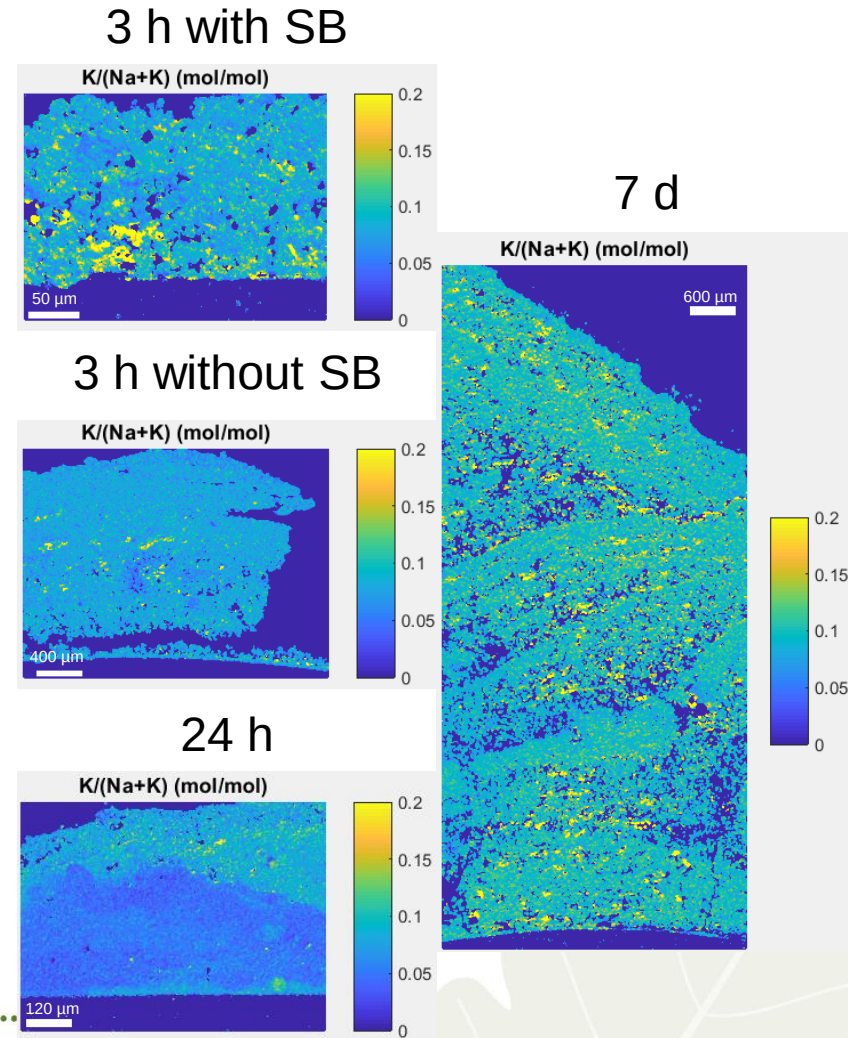
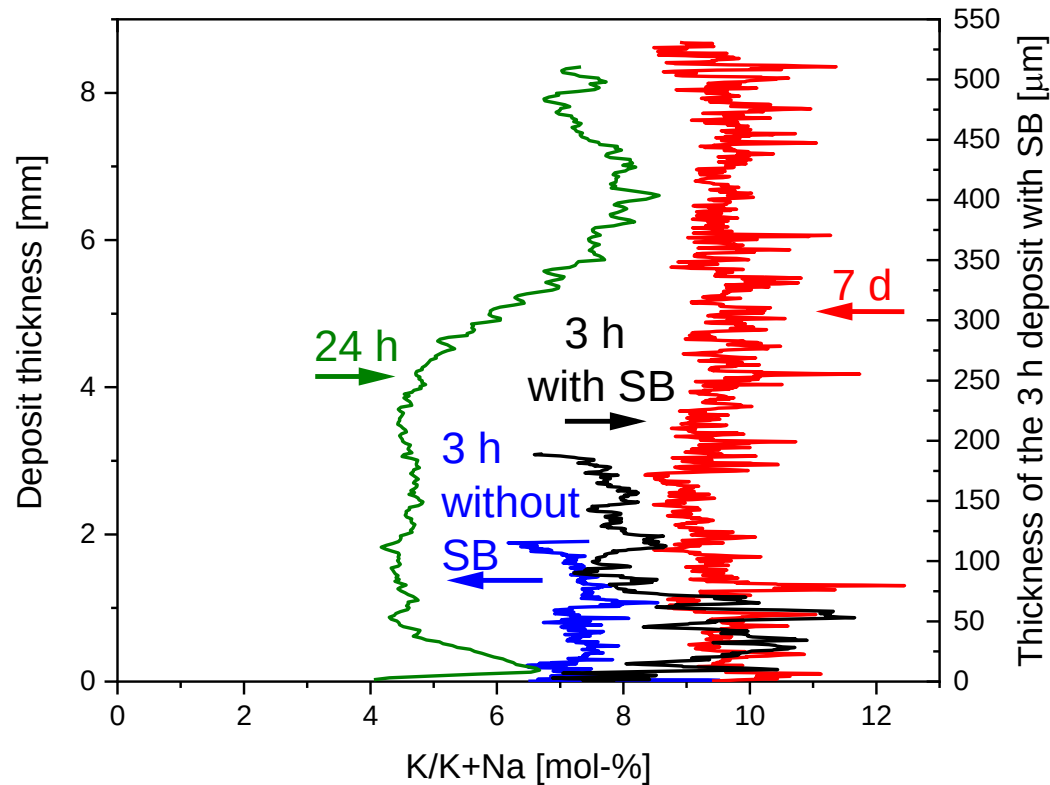
$K/(Na+K)$ (mol/mol)



7 d



K/(K+Na) on lee side



The profiles are calculated from maps on right by averaging over the horizontal plane

Conclusions

- New probe tested in experiments of exposure times up to one week
- Changes within deposit over time
 - Localized Cl-enrichment within the deposit, but no clear and general trend of Cl-enrichment with time
 - $K/(K+Na)$ highest in 7 day deposit
- Samples tended to become harder with time, most likely due to sintering
- The thicknesses of the collected deposit samples did not increase with time, most likely due to sootblowing
- Sampling campaigns with longer exposure times and more repetitions needed for further investigation



Oulu yliopisto – ulkojäsenhakemus 20.11.2018



20.11.2018

Suomen Soodakattilayhdistys ry

c/o Pöyry Finland Oy
PL 4
01621 Vantaa

Asia: Soodakattilayhdistyksen ulkojäsenyys

Viite: puhelinkeskustelu Markus Nieminen / Timo Kauppi

Jäsenyyshakemus

Oulun yliopisto / materiaali- ja konetekniikan tutkimusyksikkö (myöhemmin MaKo) hakee Suomen Soodakattilayhdistys ry:n ulkojäsenyyttä.

MaKo tekee terästen ominaisuuksiin, mikrorakenteeseen ja käytettävyyteen (mm. hitsattavuus) liittyvää tutkimustyötä sekä vastaa materiaalitekniikan syventävien ammattioppiaineiden opetuksesta DI - koulutuksessa. Tutkimusyksikkö on toiminut 1970 – luvun puolestavälistä lähtien ja siellä on tehty yli 20 väitöskirjaa terästen valmistukseen, ominaisuuksiin ja sovelluksiin liittyen. Yksikössä on 5 professoria, 2 emeritusprofessoria, 12 opettajaa, 34 tutkijaa, ja 6 laboratoriohenkilökuntaa. Se on selkeästi Suomen teräsosaamisen keskus ja on Oulun terästudkimuskeskuksen veturi, kts. <http://www.oulu.fi/casr/> ja <http://www.oulu.fi/materialsengineering/>

Lähes koko toimintansa ajan tutkimusyksikössä on tehty vaurio- ja asiantuntijaselvityksiä Suomen teollisuudelle. Viime vuosina tutkimusyksikössä on vahvistettu erityisesti hitsausmetallurgian tutkimusta ja suunnattu sitä myös kuumalujien terästen hitsattavuuteen.

MaKo haluaa liittyä Suomen Soodakattilayhdistys ry:n jäseneksi, koska haluaa laajentaa toimialaosaamistaan ja hyödyntää saatavaa kokemusta ja syntyvää tutkimustietoa myös opetuksen kehittämisessä.

MaKo:n henkilöstöllä on korkeatasoista fysikaalisen ja hitsausmetallurgian tietämystä, jota voidaan hyödyntää SKY:n toiminnassa esim. koulutustilaisuuksissa ja kehitysprojekteissa.

Oulussa 20.11.2018

Professori

TkL, IWE


Jukka Kömi

Timo Kauppi