SUOMEN SOODAKATTILAYHDISTYS
FINNISH RECOVERY BOILER COMMITTEE

Suomen Soodakattilayhdistys ry

CFD Modeling of Reduced Lignin Black Liquor Combustion, Phase 2

Markus Engblom ja Nikolai DeMartini
Åbo Akademi, 13.1.2016

Raportti 3/2016

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Reduced Lignin CFD phase 2 – Executive Summary

Prepared by: Markus Engblom and Nikolai Demartini

CFD modelling was carried out with the objective to investigate what operational changes may be needed when burning reduced lignin black liquor in a Kraft recovery boiler.

The main activities of this work consisted of

- experimental determination of the split of black liquor organic carbon between volatile and char carbon for the original liquor as well as for three levels of lignin removal from the liquor;
- CFD modelling of Wisaforest recovery boiler at 100% MCR (solids basis) as reference case;
- altogether 8 additional cases to study the effects of lignin removal (10% and 20% lignin removed) as function of liquor spraying (liquor temperature), air distribution (prim/sec/tert), and boiler load.

The main findings of the study are:

- With lignin removal, there is less char carbon in the liquor;
- Split of organic carbon between volatile and char carbon does not change with lignin removal as previously thought; the organic carbon is split 50/50 between volatiles and char (see ***Figure 1***);
- Less char carbon is delivered to the lower furnace if spray droplet size stays the same as in the reference case;
- Changes in operation are needed to compensate for the changed furnace char carbon amount and distribution;
- For up to 20% lignin removal (see ***Figure 2***)
    - If air distribution is unchanged (p22%/s43%/t35%) a decrease in liquor firing temperature by approximately 1 °C is needed;
    - To compensate for the decrease in liquor heating value due to lignin removal, one potential strategy is to increase lower furnace temperature by delivering more air and liquor to the lower furnace. In case air delivery to lower furnace is increased to (p28%/s40%/t32%) a decrease in liquor temperature by approximately 3.6 °C is needed;
    - These changes are not minor but can be considered to be applicable with existing equipment.

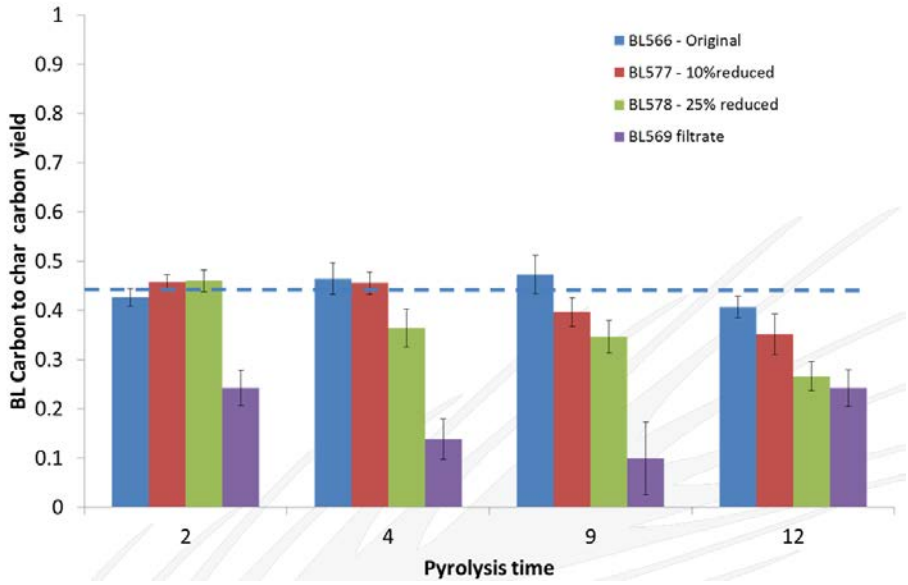


Figure 1. Share of black liquor carbon found in char after different pyrolysis times for different levels of lignin removal (note: filtrate corresponds to about 65% lignin removed). For the original liquor as well as for 10% and 25% lignin removed it was concluded that about 10% of the liquor carbon forms carbonate, and the remaining 90% is split equally between volatiles and char.

Liquor feed and combustion air (Runs 1, 6&7, 10&11, 14&15)

	Original Black Liquor	10% lower lignin Run 6	20% lower ligning Run 7	10% lower lignin Run 10	20% lower ligning Run 11	10% lower lignin Run 14	20% lower ligning Run 15
Liquor feed (tds/d)	5320	5160	5000	5160	5000	5160	5000
Of MCR (%)	100	97	94	97	94	97	94
Air (kg/s)	272	256	232	256	232	256	232
Air (Nm3/s)	211	199	180	199	180	199	180
Primary	22%	22%	22%	25% *	28% *	22%	22%
Secondary	43%	43%	43%	40%	40%	43%	43%
Tertiary	35%	35%	35%	35%	32%	35%	35%
Target flue gas O_2 (% wet)	3.0	3.0	3.0	3.0	3.0	3.0	3.0
	Phase 1	Phase 1	Phase 1	Phase 2	Phase 2	Phase 2	Phase 2
Vol-C/char-C	**50/50**	**62/38**	**70/30**	**50/50**	**50/50**	**50/50**	**50/50**
Dp average (mm)	**5.7**	**12.5**	**23.0**	**6.5**	**11**	**6.3**	**7.2**
ΔT spray (°C)	**0**	**-4.7**	**-11.9**	**-0.6**	**-3.6**	**-0.4**	**-1.0**

Air distribution changed after which average droplet size "optimized" for carbon balanced situation.
Air change based on discussion with industry: "with a lower HV/quality liquor, more of the combustion (air+liquor) to lower furnace".
*) these percentages give ~same mass flow (kg/s) primary

Figure 2. CFD simulation results showing required changes in liquor firing temperature with and without simultaneous change in air distribution (runs 10-11 and runs 14-15); shown also model sensitivity to carbon split "Vol-C/char-C" (runs 6-7).

PROCESS CHEMISTRY CENTRE

ÅBO AKADEMI UNIVERSITY

CFD Modeling of Reduced Lignin Black Liquor Combustion – Phase 2

Markus Engblom, Niko DeMartini
Åbo Akademi

SKY meeting 11.11.2015

Background and objective

- CFD modeling for studying what operational changes may be needed when firing reduced lignin black liquor
- Phase 1 conclusion: vol-C / char-C split an important model parameter
  - Phase 1 assumption

Modeled Black Liquors (3/3)

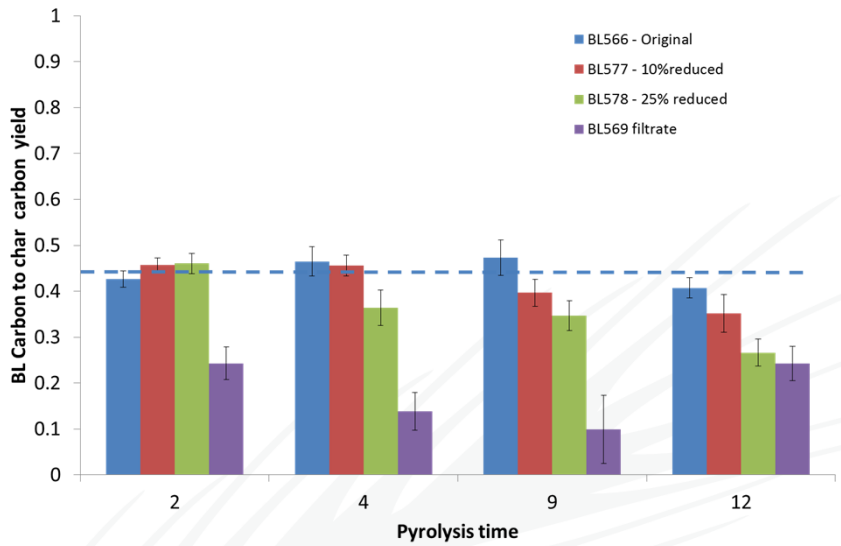
	Original Black Liquor	10% lower lignin	20% lower lignin
Liquor d.s. (wt-%)	81.3	81.3	81.3
Volatiles (kg/kg d.s.)	0.337	0.337	0.337
Char-C (kg/kg d.s.)	0.143	0.103	0.074
Inorganics (kg/kg d.s.)	0.516	0.555	0.585
Na_2S (kg/kg d.s.)	0.115	0.120	0.121
Na_2SO_4 (kg/kg d.s.)	0.080	0.101	0.118
Na_2CO_3 (kg/kg d.s.)	0.320	0.335	0.345
HHV (MJ/kg d.s.)	13.2	12.4	11.6
LHV (MJ/kg liquor)	8.4	7.8	7.2

  - Phase 2 objective
    - Determine vol-C / char-C experimentally
    - CFD runs 8-15
      - Including simultaneous change in air and spraying

CFD runs 8-15

- **Run 1:** Wisa Base Case, 100% MCR, flue gas O_2 3% (wet)
- **Runs 8-15:** using vol-C / char-C based on experimental data
  - **Runs 8 and 9:** 10% (97% MCR) and 20% (94% MCR) lignin removed, total air adjusted for flue gas O_2 3% (wet), other variables unchanged (similar to Phase 1 runs 2&3) (results in carbon balance ≠ 0)
  - **Runs 10 and 11:** 10% (97% MCR) & 20% (94% MCR) lignin removed, modifications to air distribution **and** liquor spraying for carbon balance = 0
  - **Runs 12 and 13:** same as runs 10&11 but with 100% MCR
  - **Runs 14 and 15:** 10% (97% MCR) & 20% (94% MCR) lignin removed, modifications to liquor spraying for carbon balance = 0 (similar to Phase 1 runs 6&7)

Experimental results



Modeled Black Liquors (1/3)

	Original Black Liquor (wt% d.s.)	Lignin [1] (wt% d.s.)
C	32.2	64.5
H	3.3	6
N	0.09	0.1
Na	21.4	0.3
K	2.4	0.05
Cl	0.3	0
Tot. S	6.4	2.5
SO4	5.4	0
OH	1.74	0
HHV (MJ/kg d.s.)	13.2	26.5

Composition of reduced lignin BL based:

- Lignin content of BL: 36 wt-%
- 175 kg H_2SO_4/ton lignin precipitated [1]

1 Tomani, P. The lignoboost process. In Proceedings to The 2nd Nordic Wood Biorefinery Conf., 2-4 Sept. 2009, Helsinki, Finland, pp. 181-188.

Modeled Black Liquors (2/3)

	Original Black Liquor (wt% d.s.)	10% lower lignin (wt% d.s.)	20% lower ligning (wt% d.s.)
C	32.2	30.9	28.9
H	3.3	3.2	3.03
N	0.09	0.09	0.09
Na	21.4	22.8	23.9
K	2.4	2.6	2.7
Cl	0.3	0.32	0.34
Tot. S	6.4	7.0	7.5
SO_4	5.4	6.7	7.87
OH	1.74	1.4	1.1
HHV (MJ/kg d.s.)	13.2	12.4	11.6

Modeled Black Liquors (3/3)

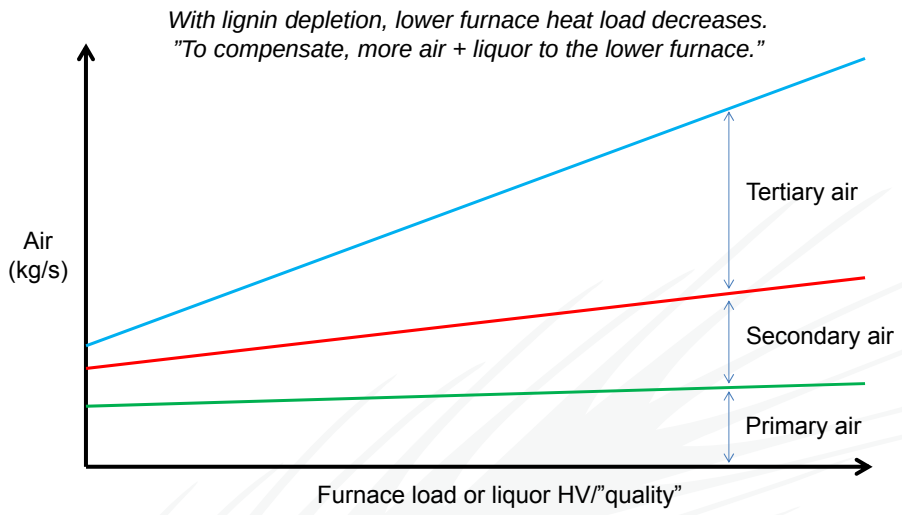
Phase2: Vol-C/char-C 50/50 split based on laboratory data, This split is the same as used for the original liquor

	Original Black Liquor	10% lower lignin	20% lower ligning
Liquor d.s. (wt-%)	81.3	81.3	81.3
Volatiles (kg/kg d.s.)	0.337	0.337 / 0.305	0.337 / 0.286
Char-C (kg/kg d.s.)	0.143	0.103 / 0.136	0.074 / 0.125
Inorganics (kg/kg d.s.)	0.516	0.555	0.585
Na_2S (kg/kg d.s.)	0.115	0.120	0.121
Na_2SO_4 (kg/kg d.s.)	0.080	0.101	0.118
Na_2CO_3 (kg/kg d.s.)	0.320	0.335	0.345
HHV (MJ/kg d.s.)	13.2	12.4	11.6
LHV (MJ/kg liquor)	8.4	7.8	7.2

Liquor feed and combustion air (Runs 1 and 8&9)

	Original Black Liquor	10% lower lignin	20% lower ligning
Liquor feed (tds/d)	5320	5160	5000
Of MCR (%)	100	97	94
Air (kg/s)	272	256	232
Air (Nm3/s)	211	199	180
Primary	22%	22%	22%
Secondary	43%	43%	43%
Tertiary	35%	35%	35%
Target flue gas O_2 (% wet)	3.0	3.0	3.0
HHRR (MW/m^2) based on (HHV / LHV)	3.6 / 2.9	3.3 / 2.6	3.0 / 2.3
$T_{adiabatic}$	1580 °C	1490 °C	1450 °C

Guidelines for changes to combustion air



Schematic illustration of combustion air delivery strategy
as function of furnace load or liquor HV/"quality"

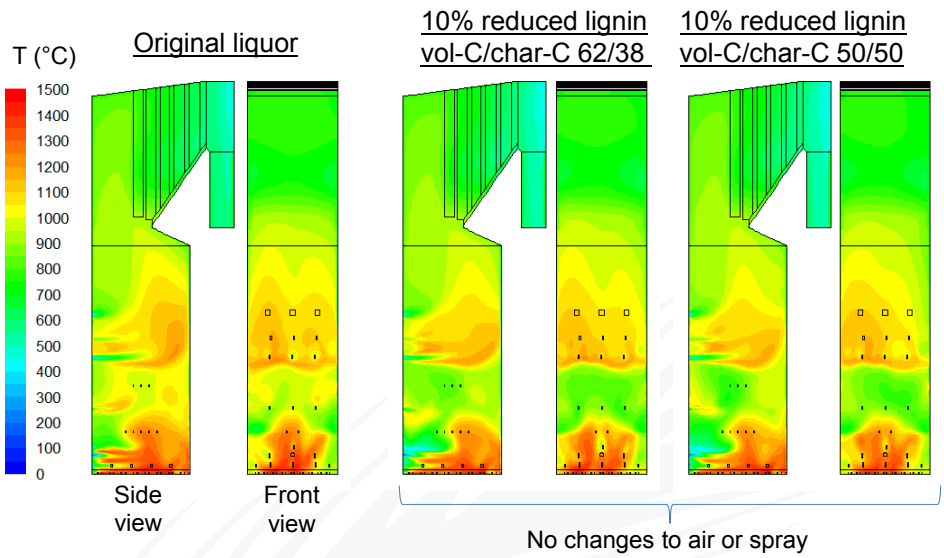
Conclusions

- Less char-C with lignin removal
  - Less C to the lower furnace with lignin removal if drop size stays the same
  - Changes to operation needed to compensate
- For up to 20% lignin removal
  - With air distribution unchanged (p22%/s43%/t35%) decrease in liquor temperature by approximately 1 °C
  - Combined change in air+spray (p28%/s40%/t32%) decrease in liquor temperature by approximately 3.6 °C

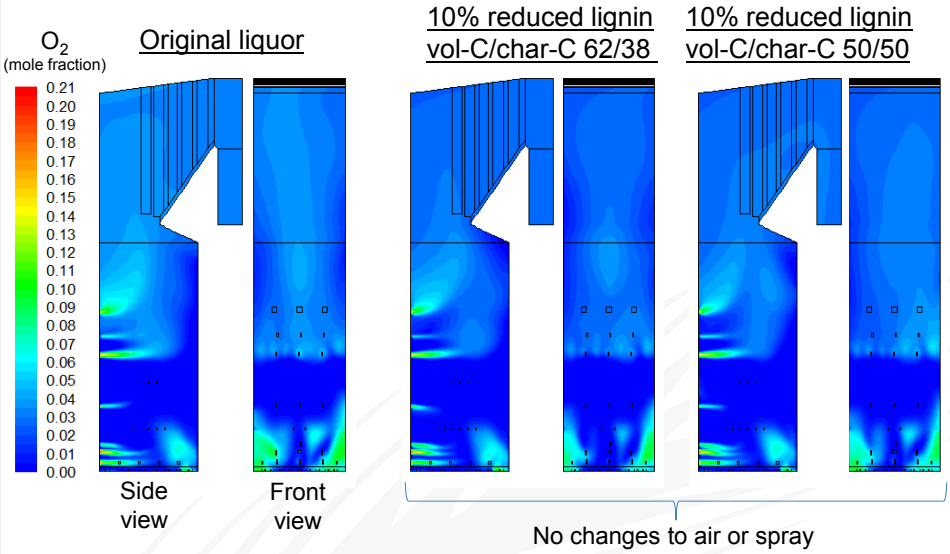
CFD results

- **Run 1:** Wisa Base Case, 100% MCR, flue gas O_2 3% (wet)
- **Runs 8-15:** using vol-C / char-C based on experimental data
  - **Runs 8 and 9:** 10% (97% MCR) and 20% (94% MCR) lignin removed, total air adjusted for flue gas O_2 3% (wet), other variables unchanged (similar to Phase 1 runs 2&3) (results in carbon balance ≠ 0)
  - **Runs 10 and 11:** 10% (97% MCR) & 20% (94% MCR) lignin removed, modifications to air distribution **and** liquor spraying for carbon balance = 0
  - **Runs 12 and 13:** same as runs 10&11 but with 100% MCR
  - **Runs 14 and 15:** 10% (97% MCR) & 20% (94% MCR) lignin removed, modifications to liquor spraying for carbon balance = 0 (similar to Phase 1 runs 6&7)

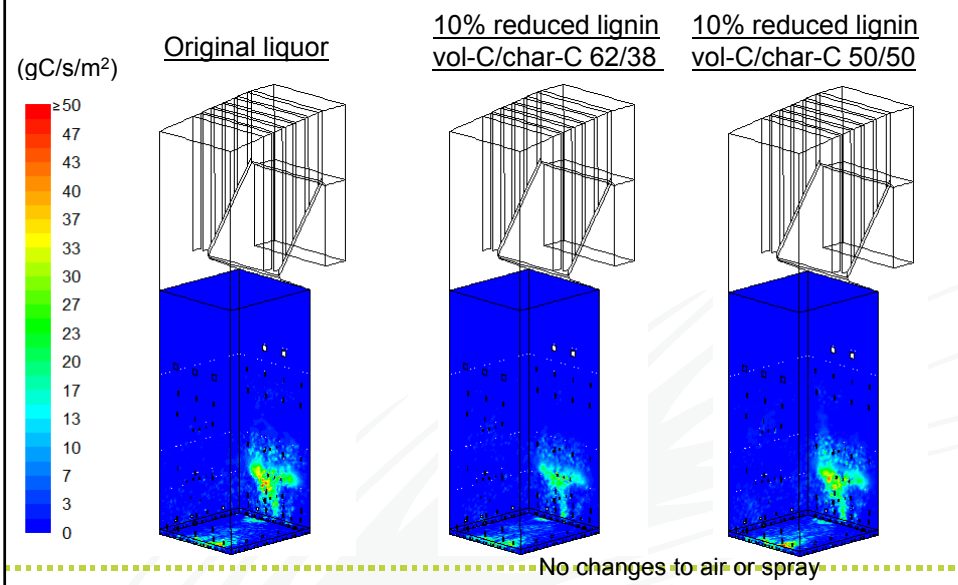
Temperature



O_2 concentration

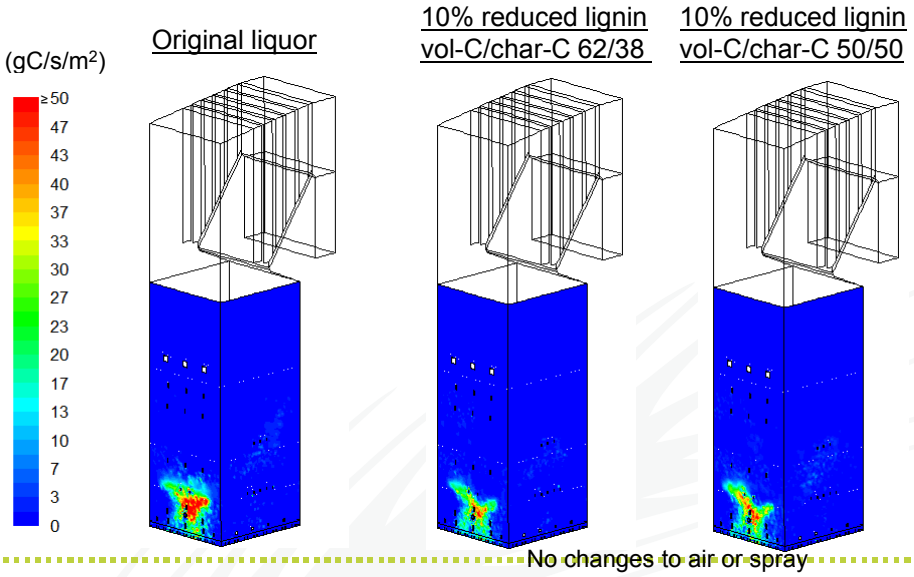


Carbon to walls/bed



Left wall, back wall, and char bed

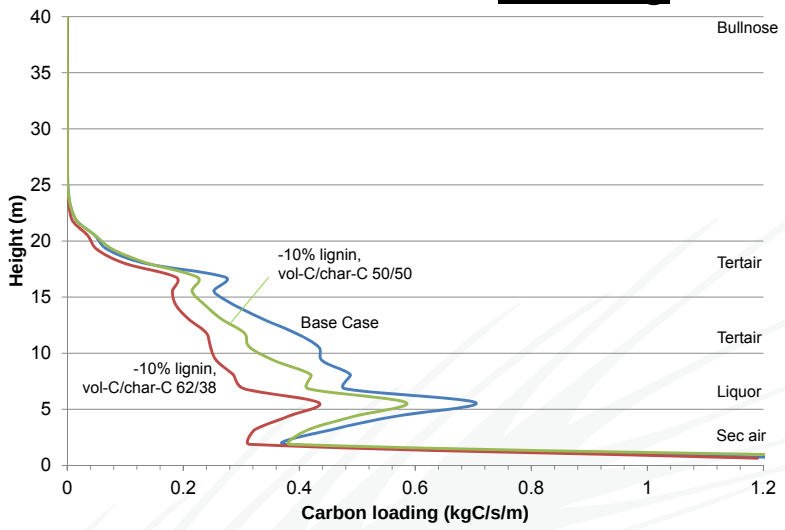
Carbon to walls/bed



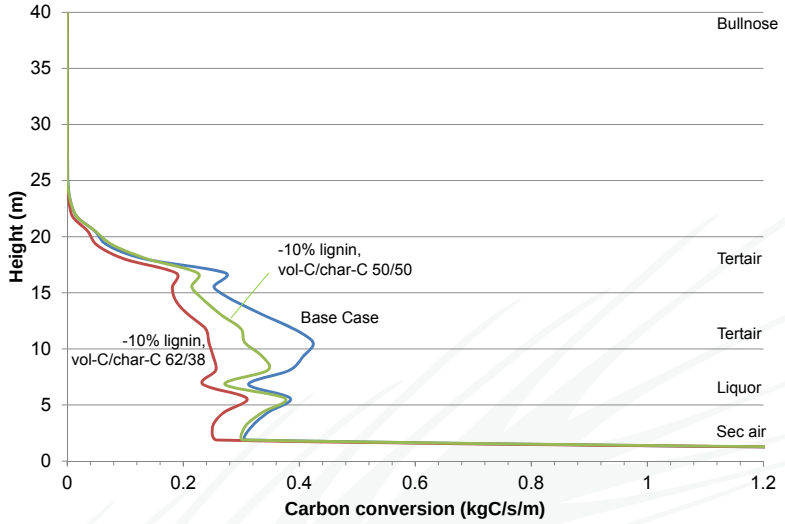
No changes to air or spray

Right wall and front wall

Furnace carbon loading



Furnace carbon conversion



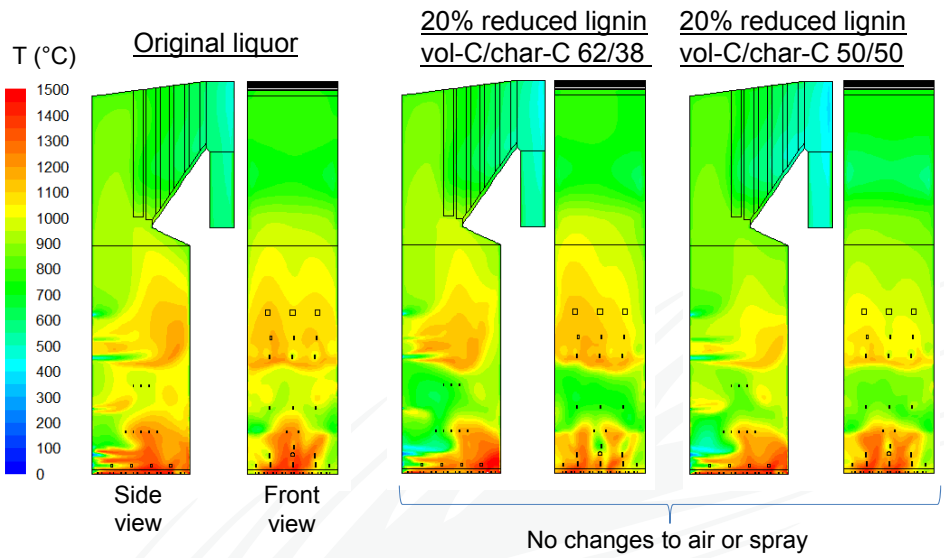
Fate of char carbon

(kg/s)	Base Case	10% reduced lignin, vol-C/char-C 62/38	10% reduced lignin, vol-C/char-C 50/50
In liquor feed	8.81	6.19	8.12
in-flight conversion	3.90	2.60	3.39
to bed/walls	4.91	3.59	4.74
conversion on bed/walls	4.70	4.37	4.95
carbon accumulation	0.21	-0.78	-0.21

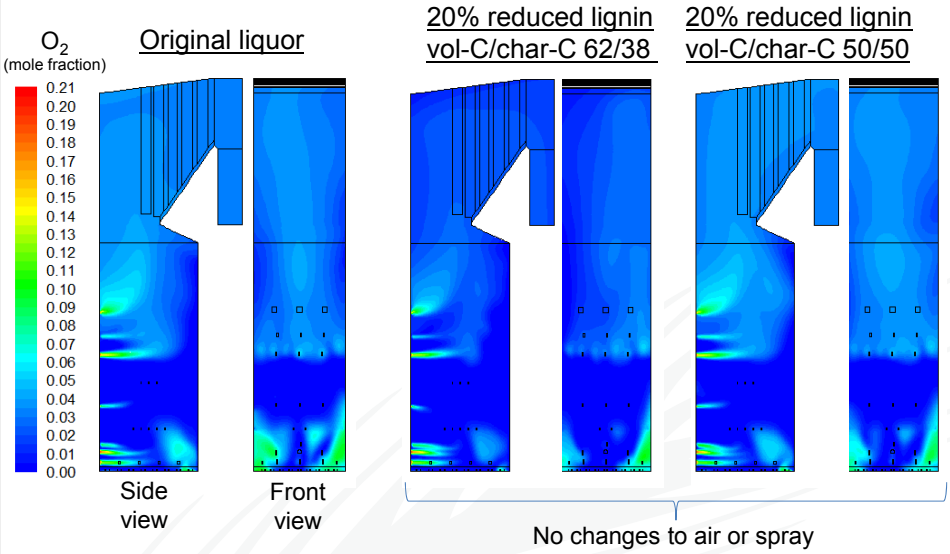
Fate of char carbon

(%)	Base Case	10% reduced lignin, vol-C/char-C 62/38	10% reduced lignin, vol-C/char-C 50/50
In liquor feed	100.0	100.0	100.0
in-flight conversion	44.3	42.0	41.7
to bed/walls	55.7	58.0	58.3
conversion on bed/walls	53.4	70.5	61.0
carbon accumulation	2.3	-12.5	-2.6

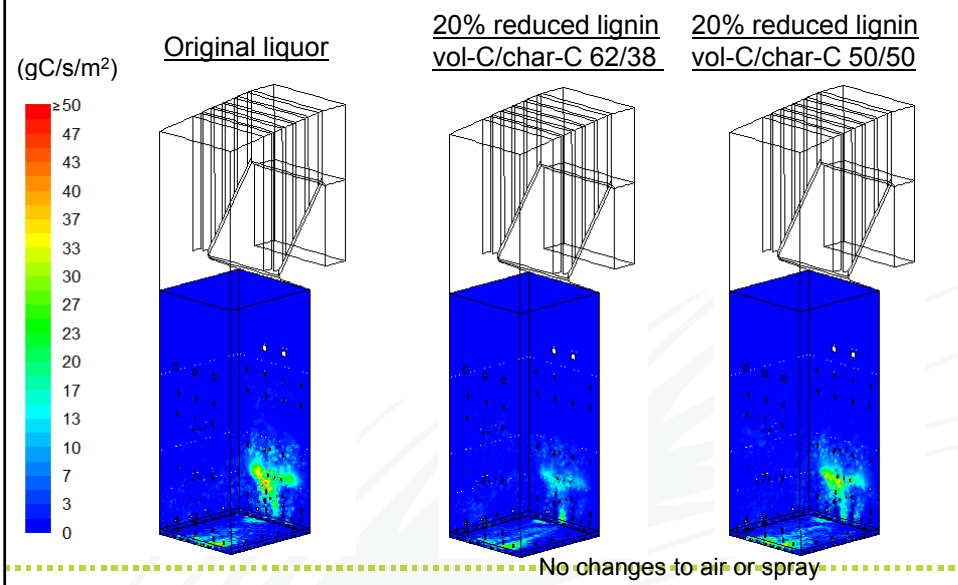
Temperature



O_2 concentration

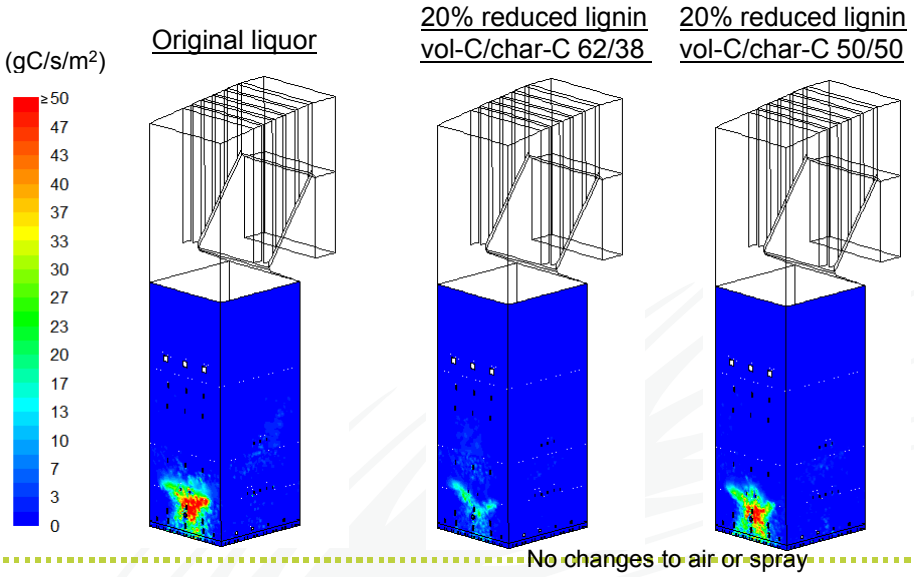


Carbon to walls/bed



Left wall, back wall, and char bed

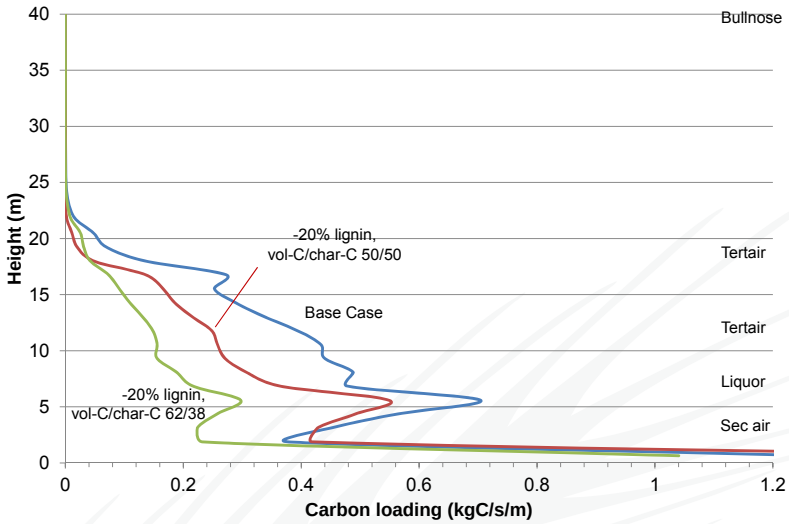
Carbon to walls/bed



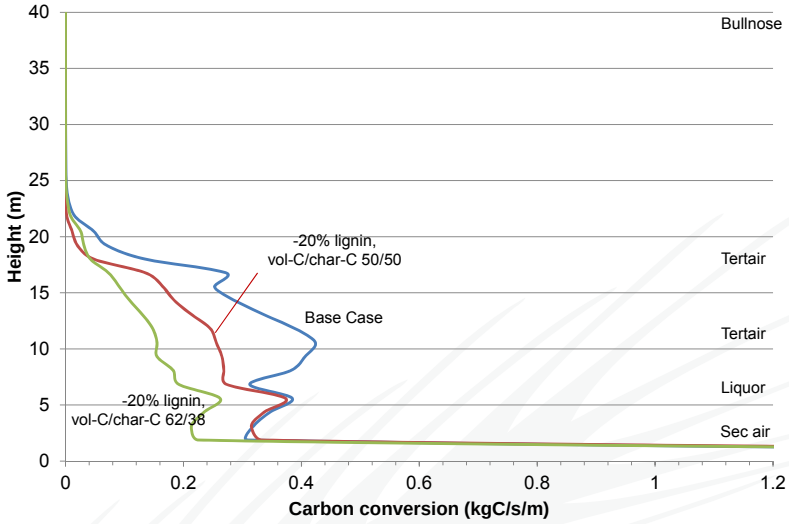
No changes to air or spray

Right wall and front wall

Furnace carbon loading



Furnace carbon conversion



Fate of char carbon

(kg/s)	Base Case	20% reduced lignin, vol-C/char-C 62/38	20% reduced lignin, vol-C/char-C 50/50
In liquor feed	8.81	4.30	7.25
in-flight conversion	3.90	1.79	2.80
to bed/walls	4.91	2.51	4.45
conversion on bed/walls	4.70	4.10	4.84
carbon accumulation	0.21	-1.59	-0.39

Fate of char carbon

(%)	Base Case	20% reduced lignin, vol-C/char-C 62/38	20% reduced lignin, vol-C/char-C 50/50
In liquor feed	100.0	100.0	100.0
in-flight conversion	44.3	41.6	38.6
to bed/walls	55.7	58.4	61.4
conversion on bed/walls	53.4	95.5	66.8
carbon accumulation	2.3	-37.1	-5.4

CFD results

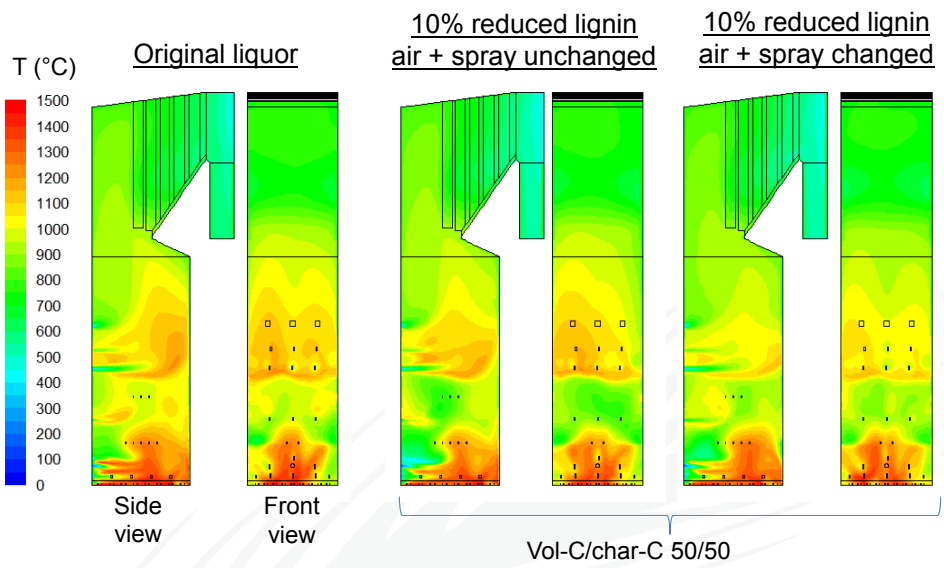
- **Run 1:** Wisa Base Case, 100% MCR, flue gas O_2 3% (wet)
- **Runs 8-15:** using vol-C / char-C based on experimental data
  - **Runs 8 and 9:** 10% (97% MCR) and 20% (94% MCR) lignin removed, total air adjusted for flue gas O_2 3% (wet), other variables unchanged (similar to Phase 1 runs 2&3) (results in carbon balance ≠ 0)
  - **Runs 10 and 11:** 10% (97% MCR) & 20% (94% MCR) lignin removed, modifications to air distribution **and** liquor spraying for carbon balance = 0
  - **Runs 12 and 13:** same as runs 10&11 but with 100% MCR
  - **Runs 14 and 15:** 10% (97% MCR) & 20% (94% MCR) lignin removed, modifications to liquor spraying for carbon balance = 0 (similar to Phase 1 runs 6&7)

Liquor feed and combustion air (Runs 1 and 10 & 11)

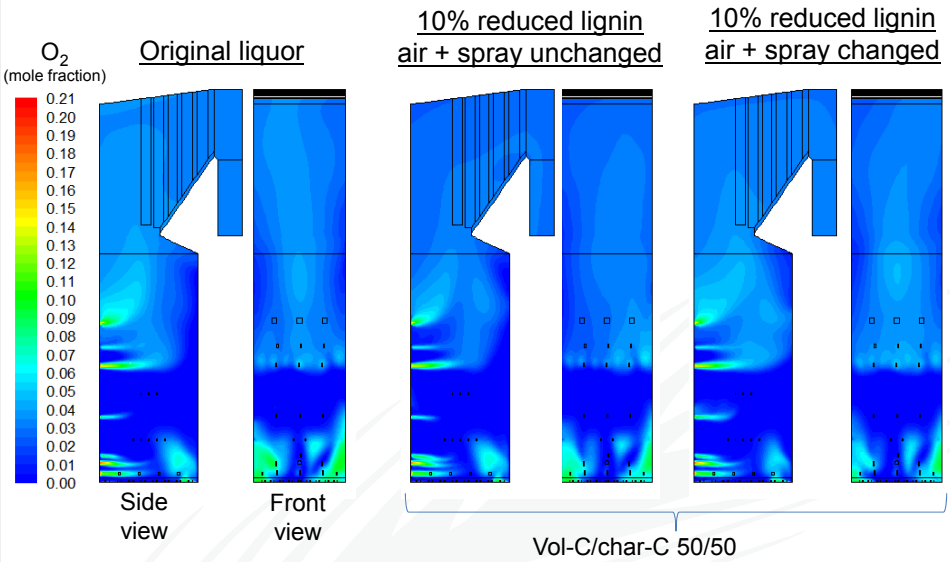
	Original Black Liquor	10% lower lignin Run 10	20% lower ligning Run 11
Liquor feed (tds/d)	5320	5160	5000
Of MCR (%)	100	97	94
Air (kg/s)	272	256	232
Air (Nm3/s)	211	199	180
Primary	22%	25% *	28% *
Secondary	43%	40%	40%
Tertiary	35%	35%	32%
Target flue gas O_2 (% wet)	3.0	3.0	3.0
Dp average (mm)	5.7	6.5	11
ΔT spray (°C)	0	-0.6	-3.6

Air distribution changed after which average droplet size "optimized" for carbon balanced situation.
Air change based on discussion with industry: "with a lower HV/quality liquor, more of the combustion (air+liquor) to lower furnace".
*) these percentages give ~same mass flow (kg/s) primary

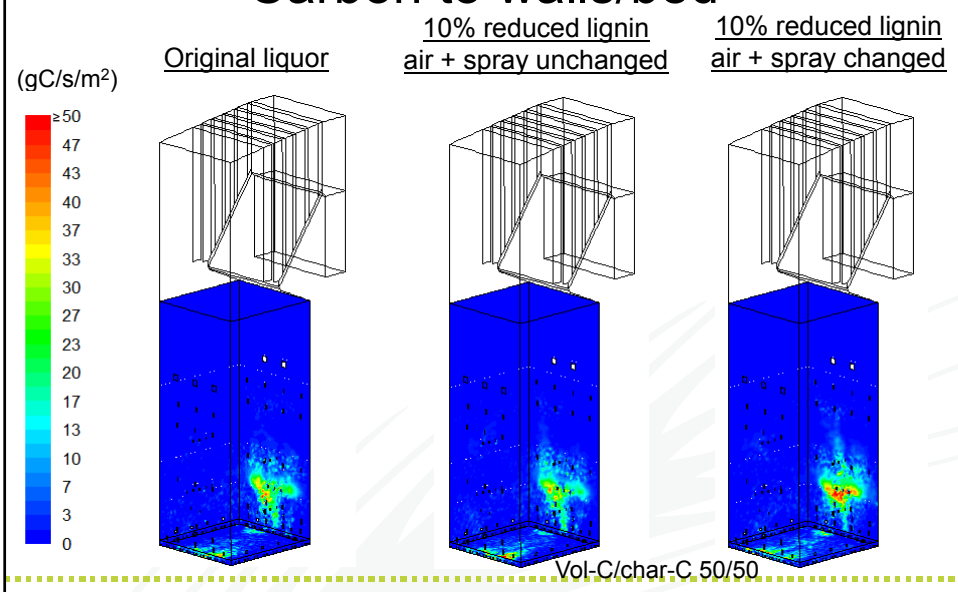
Temperature



O_2 concentration

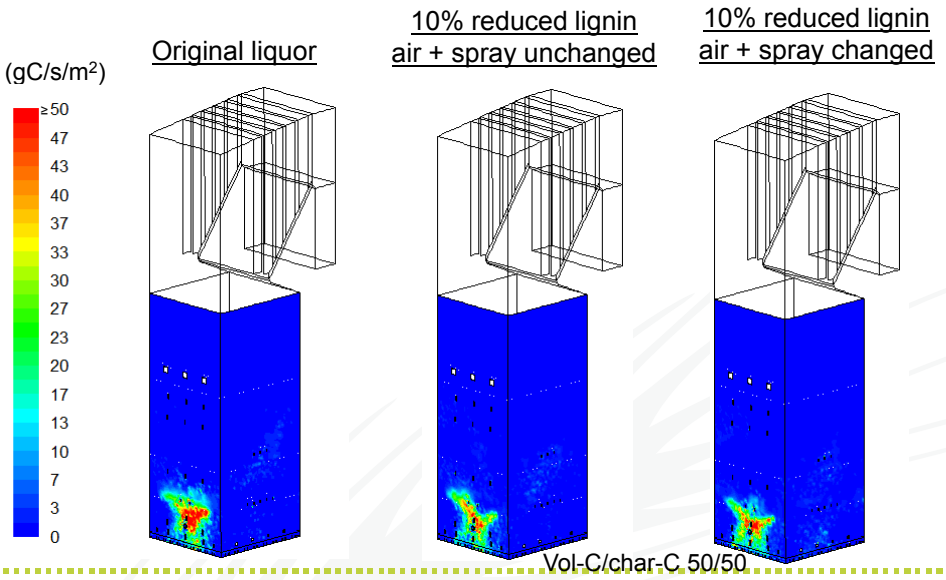


Carbon to walls/bed



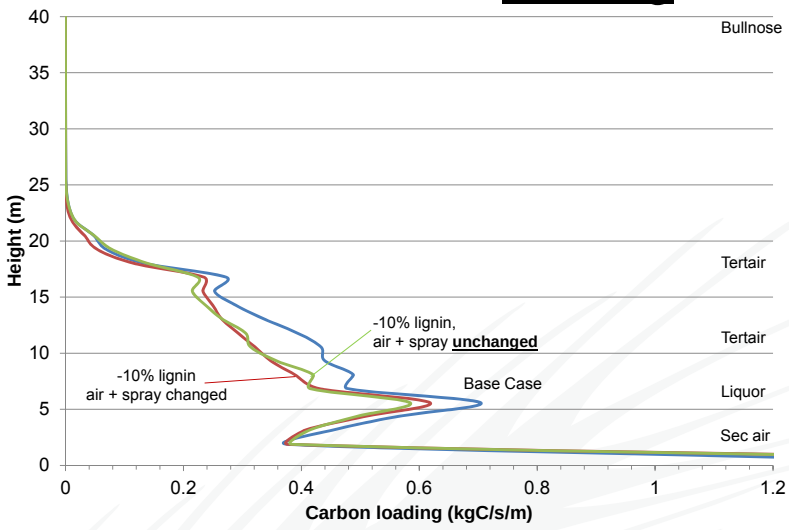
Left wall, back wall, and char bed

Carbon to walls/bed

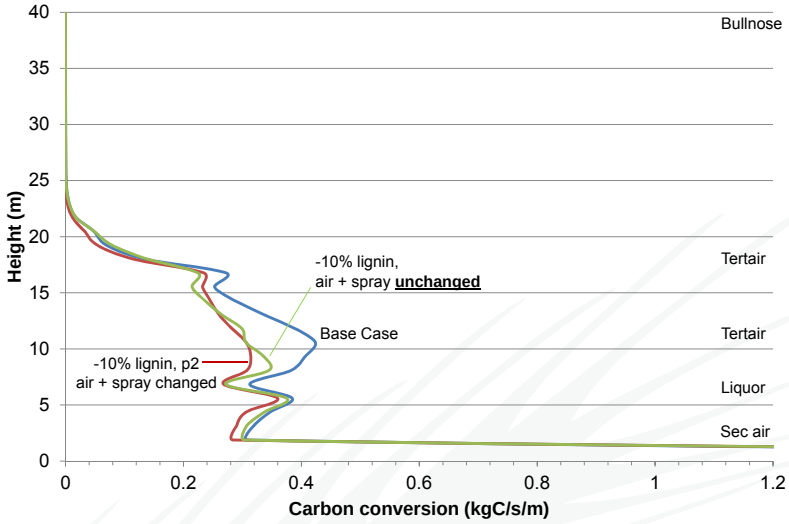


Right wall and front wall

Furnace carbon loading



Furnace carbon conversion



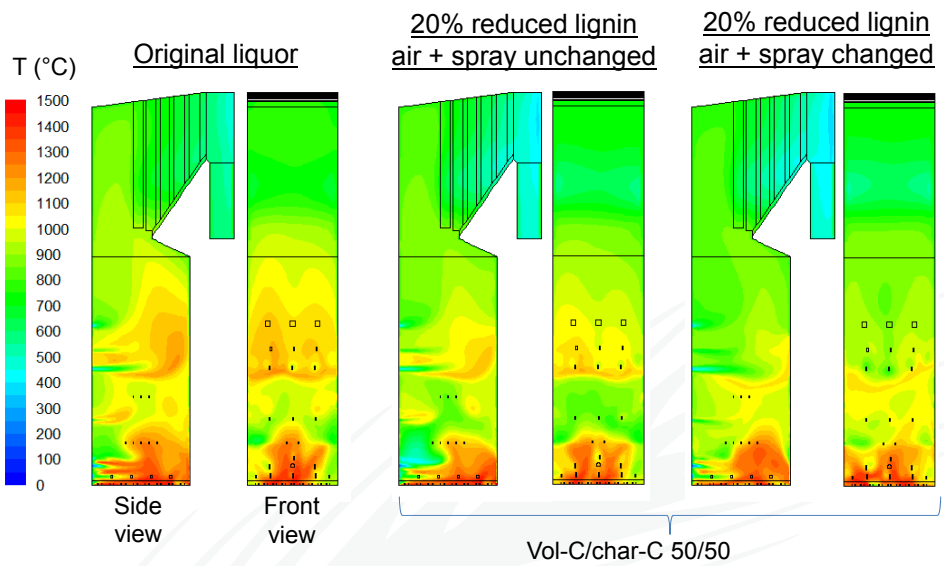
Fate of char carbon

(kg/s)	Base Case	10% reduced lignin, air + spray unchanged	10% reduced lignin, air + spray changed
In liquor feed	8.81	8.12	8.12
in-flight conversion	3.90	3.39	2.94
to bed/walls	4.91	4.74	5.19
conversion on bed/walls	4.70	4.95	5.20
carbon accumulation	0.21	-0.21	-0.01

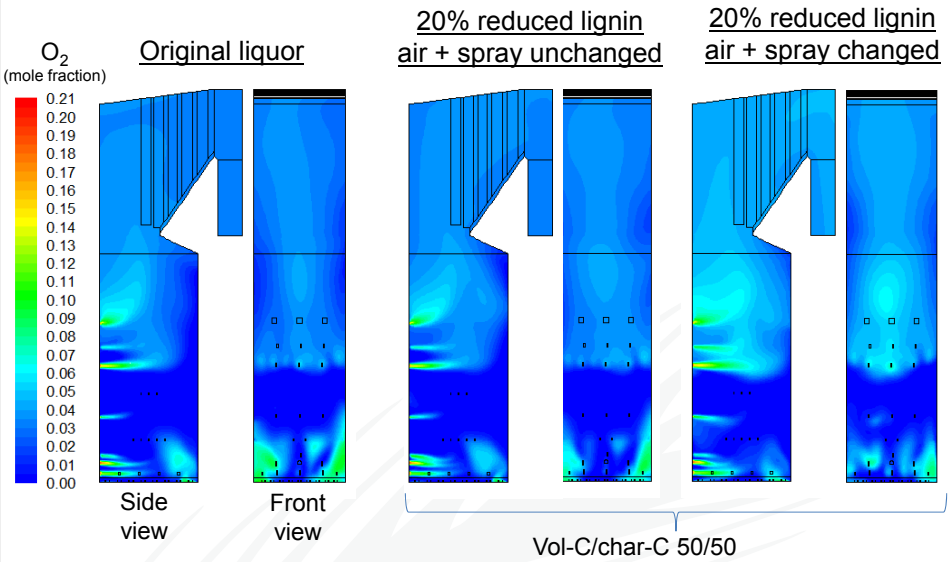
Fate of char carbon

(%)	Base Case	10% reduced lignin, air + spray unchanged	10% reduced lignin, air + spray changed
In liquor feed	100.0	100.0	100.0
in-flight conversion	44.3	41.7	36.2
to bed/walls	55.7	58.3	63.8
conversion on bed/walls	53.4	61.0	64.0
carbon accumulation	2.3	-2.6	-0.2

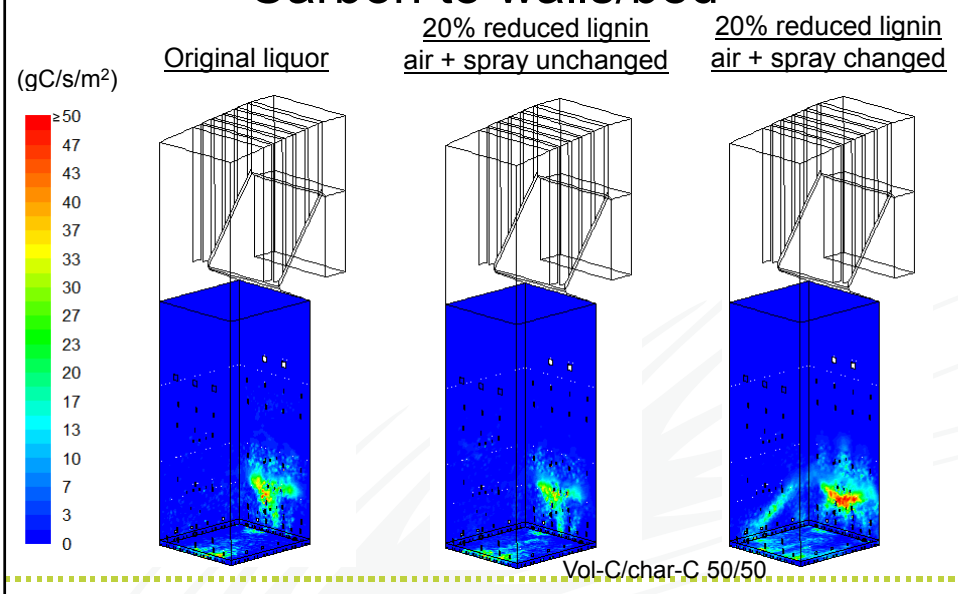
Temperature



O_2 concentration

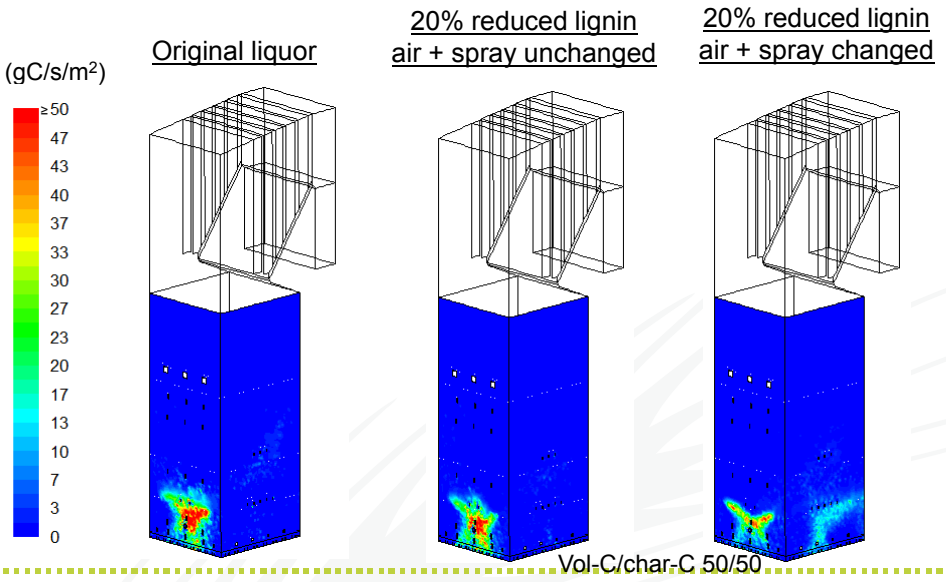


Carbon to walls/bed



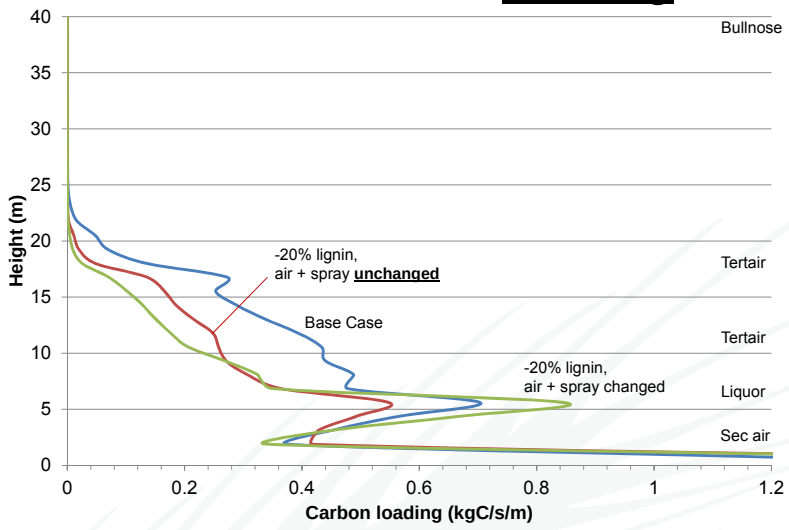
Left wall, back wall, and char bed

Carbon to walls/bed

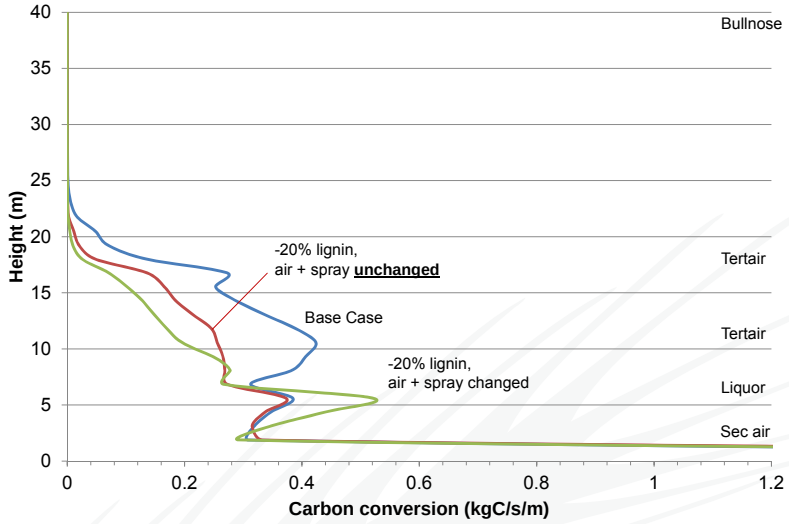


Right wall and front wall

Furnace carbon loading



Furnace carbon conversion



Fate of char carbon

(kg/s)	Base Case	20% reduced lignin, air + spray unchanged	20% reduced lignin, air + spray changed
In liquor feed	8.81	7.25	7.25
in-flight conversion	3.90	2.80	1.42
to bed/walls	4.91	4.45	5.83
conversion on bed/walls	4.70	4.84	5.74
carbon accumulation	0.21	-0.39	0.09

Fate of char carbon

(%)	Base Case	20% reduced lignin, air + spray unchanged	20% reduced lignin, air + spray changed
In liquor feed	100.0	100.0	100.0
in-flight conversion	44.3	38.6	19.6
to bed/walls	55.7	61.4	80.4
conversion on bed/walls	53.4	66.8	79.2
carbon accumulation	2.3	-5.4	1.2

CFD results

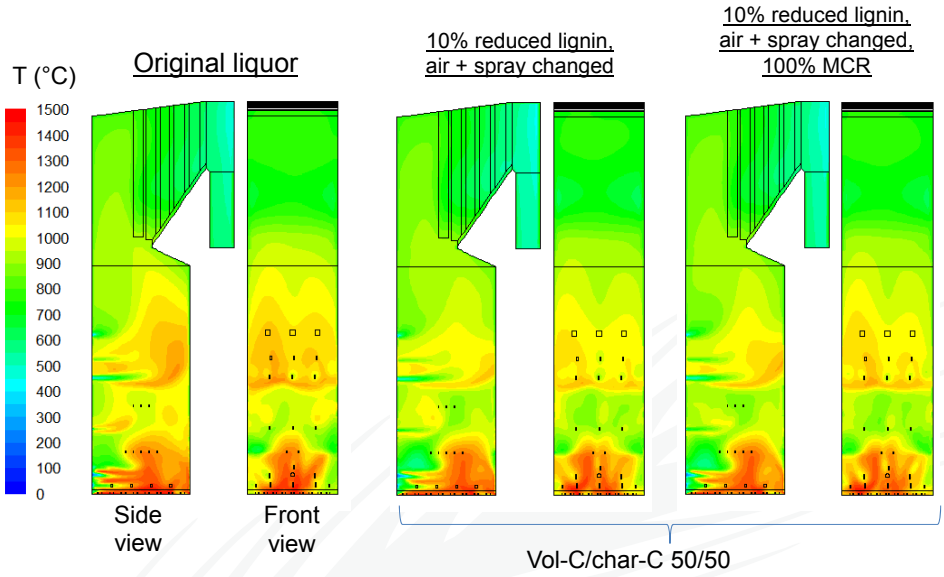
- **Run 1:** Wisa Base Case, 100% MCR, flue gas O_2 3% (wet)
- **Runs 8-15:** using vol-C / char-C based on experimental data
  - **Runs 8 and 9:** 10% (97% MCR) and 20% (94% MCR) lignin removed, total air adjusted for flue gas O_2 3% (wet), other variables unchanged (similar to Phase 1 runs 2&3) (results in carbon balance ≠ 0)
  - **Runs 10 and 11:** 10% (97% MCR) & 20% (94% MCR) lignin removed, modifications to air distribution **and** liquor spraying for carbon balance = 0
  - **Runs 12 and 13:** same as runs 10&11 but with 100% MCR
  - **Runs 14 and 15:** 10% (97% MCR) & 20% (94% MCR) lignin removed, modifications to liquor spraying for carbon balance = 0 (similar to Phase 1 runs 6&7)

Liquor feed and combustion air (Runs 1 and 10-13)

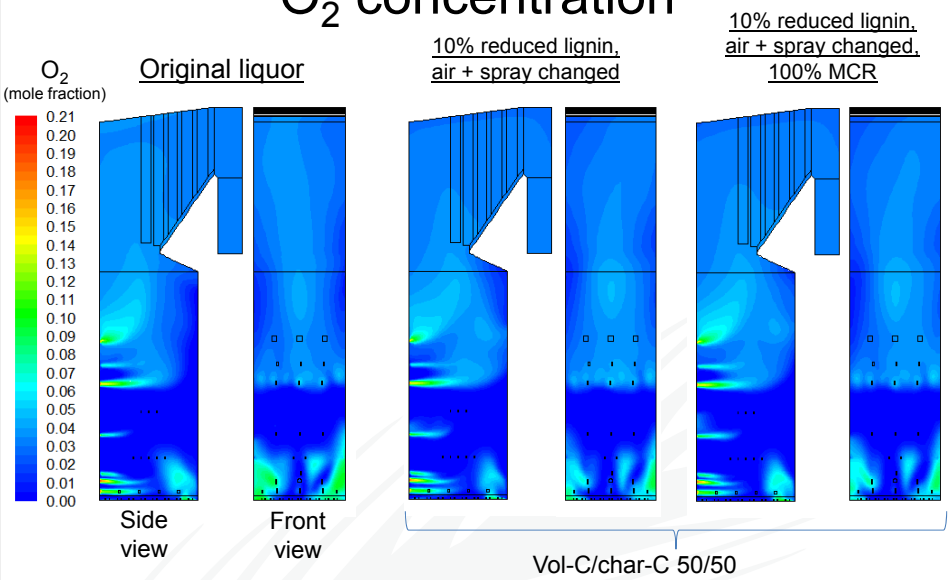
	Original Black Liquor	10% lower lignin Run 10	20% lower ligning Run 11	10% lower lignin Run 12	20% lower ligning Run 13
Liquor feed (tds/d)	5320	5160	5000	5320	5320
Of MCR (%)	100	97	94	100	100
Air (kg/s)	272	256	232	264	247
Air (Nm3/s)	211	199	180	205	191
Primary	22%	25% *	28% *	24% *	26% *
Secondary	43%	40%	40%	40%	40%
Tertiary	35%	35%	32%	36%	34%
Target flue gas O_2 (% wet)	3.0	3.0	3.0	3.0	3.0
Dp average (mm)	5.7	6.5	11	6.0	9.3
ΔT spray (°C)	0	-0.6	-3.6	-0.2	-2.5

Air distribution changed after which average droplet size "optimized" for carbon balanced situation.
Air change based on discussion with industry: "with a lower HV/quality liquor, more of the combustion (air+liquor) to lower furnace".
*) these percentages give ~same mass flow (kg/s) primary

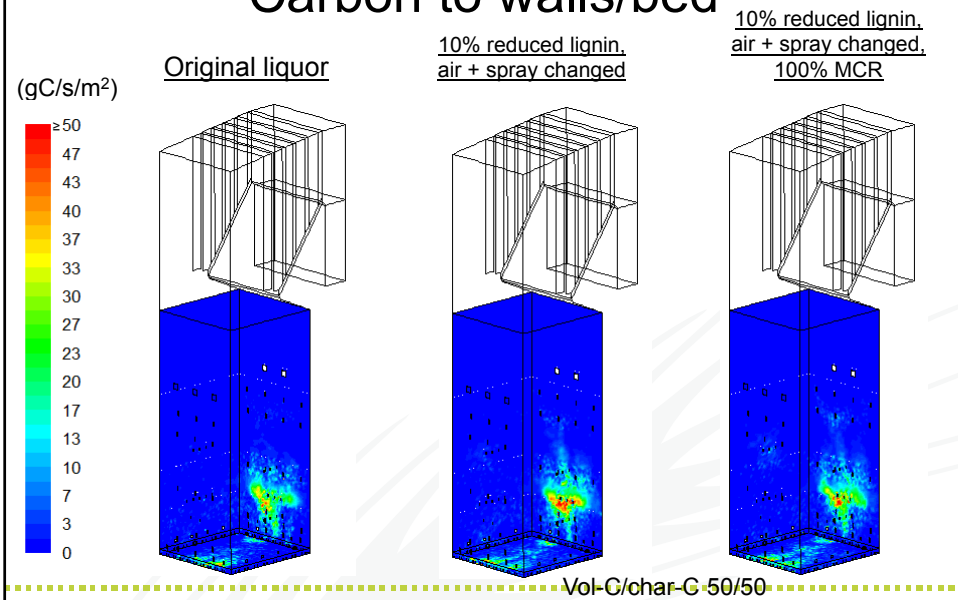
Temperature



O_2 concentration

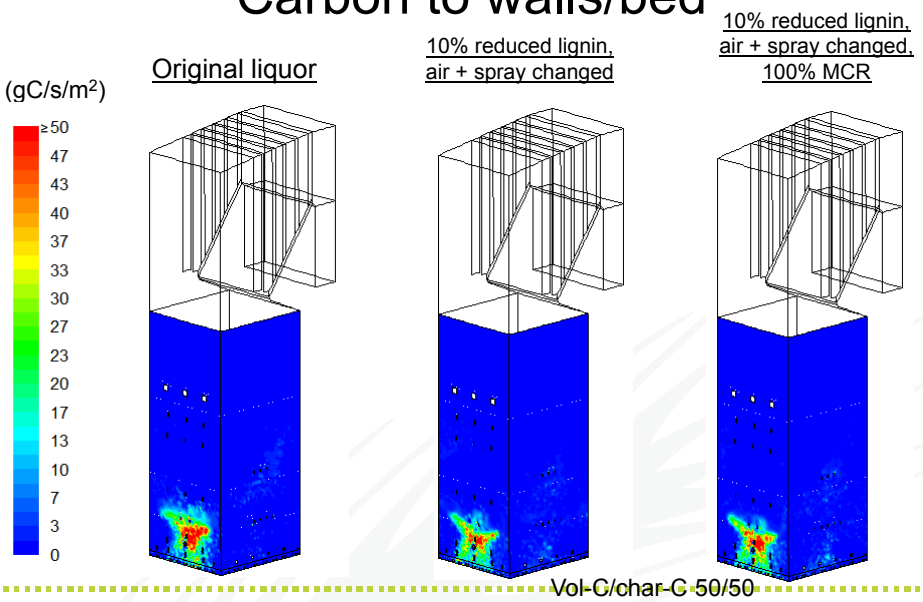


Carbon to walls/bed



Left wall, back wall, and char bed

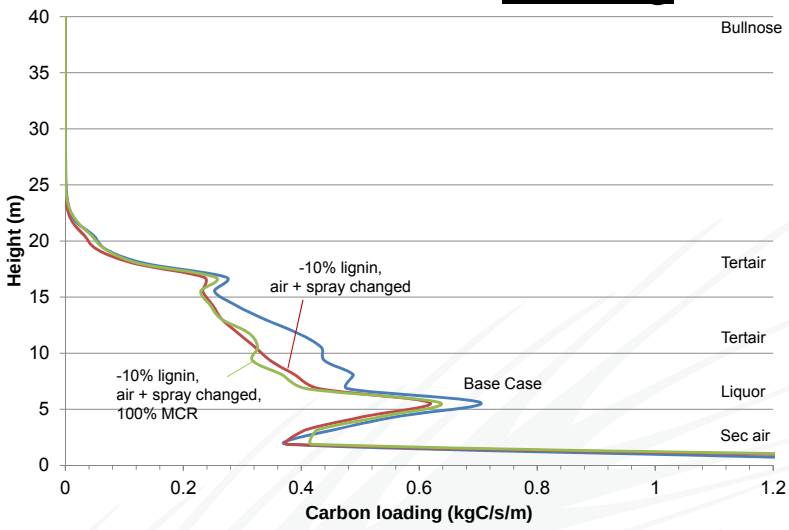
Carbon to walls/bed



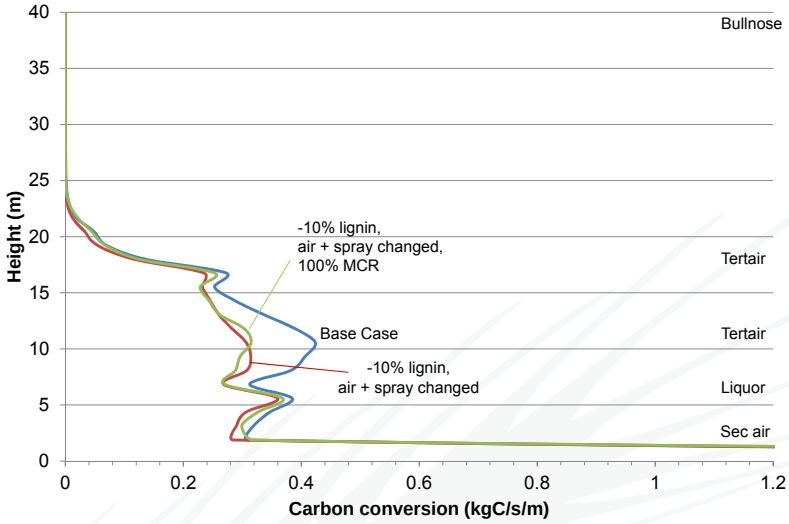
Vol-C/char-C 50/50

Right wall and front wall

Furnace carbon loading



Furnace carbon conversion



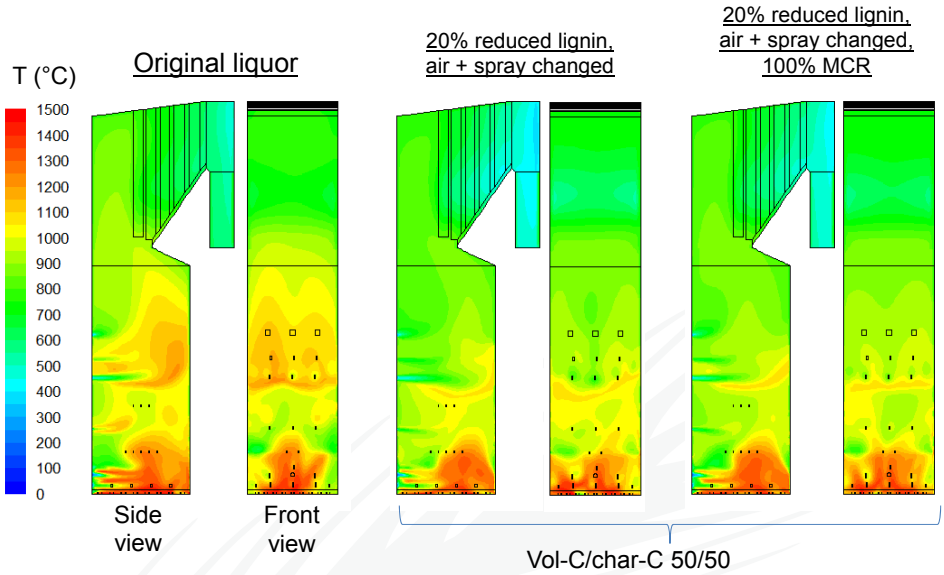
Fate of char carbon

(kg/s)	Base Case	10% reduced lignin, air + spray changed	10% reduced lignin, p2, air + spray changed 100% MCR
In liquor feed	8.81	8.12	8.37
in-flight conversion	3.90	2.94	3.18
to bed/walls	4.91	5.19	5.20
conversion on bed/walls	4.70	5.20	5.13
carbon accumulation	0.21	-0.01	0.06

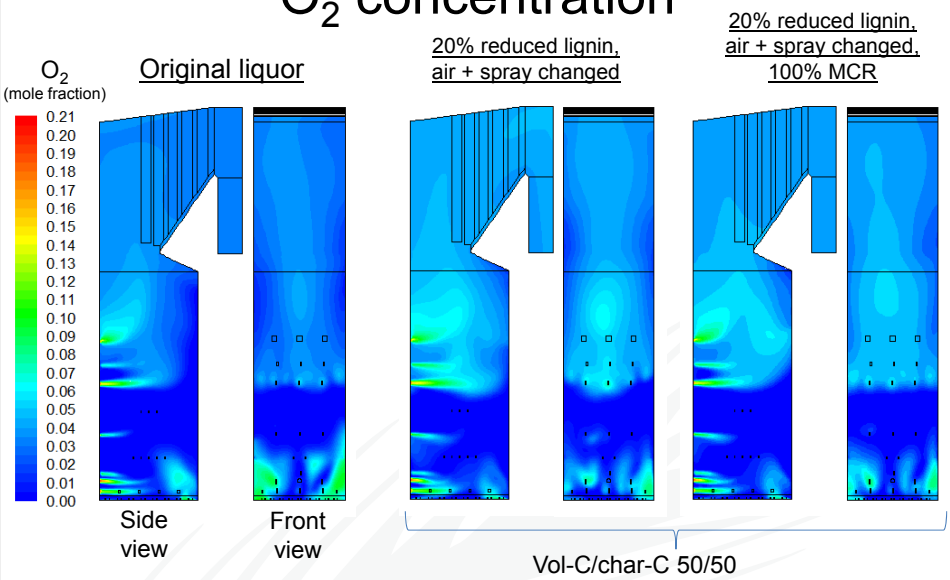
Fate of char carbon

(%)	Base Case	10% reduced lignin, air + spray changed	10% reduced lignin, p2, air + spray changed 100% MCR
In liquor feed	100.0	100.0	100.0
in-flight conversion	44.3	36.2	37.9
to bed/walls	55.7	63.8	62.1
conversion on bed/walls	53.4	64.0	61.3
carbon accumulation	2.3	-0.2	0.7

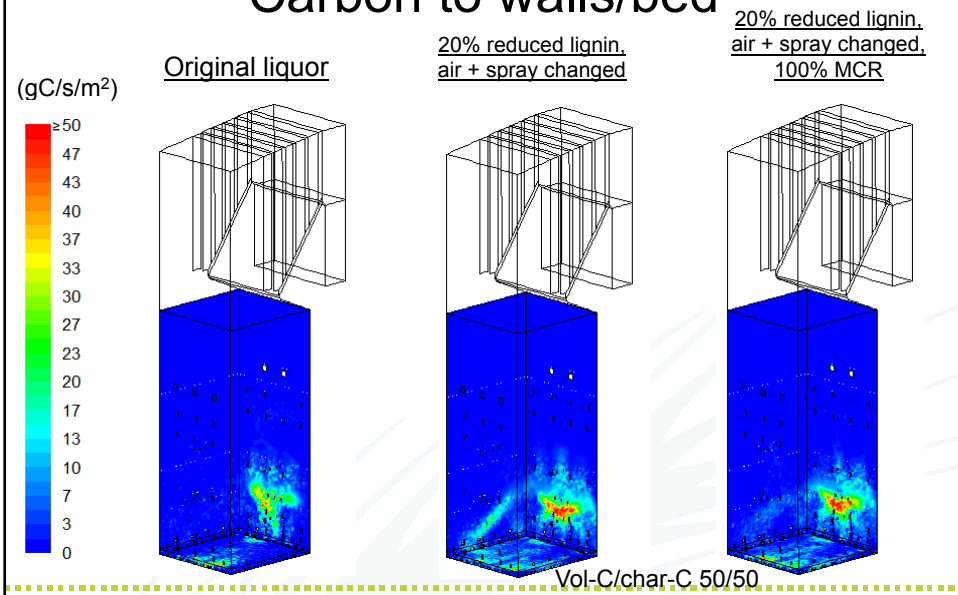
Temperature



O_2 concentration

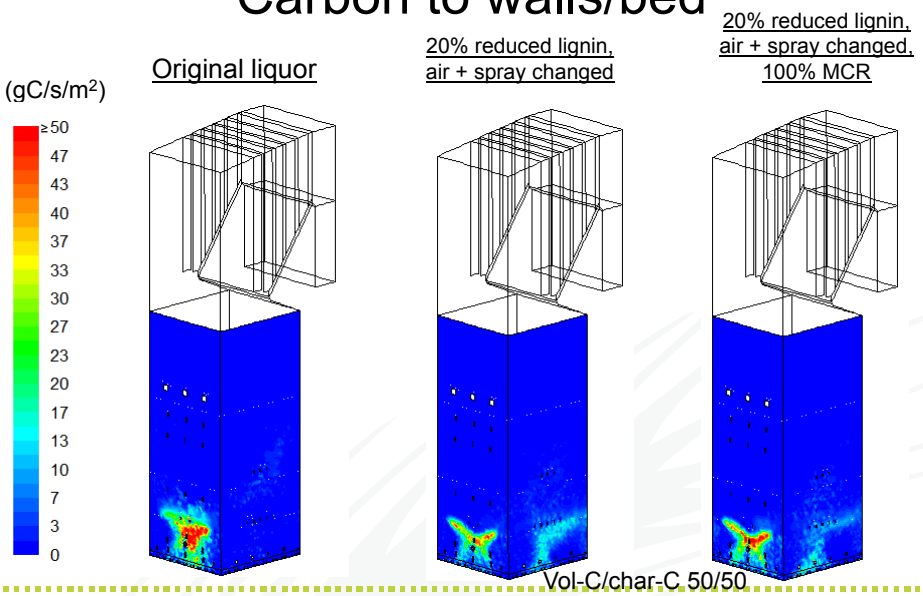


Carbon to walls/bed



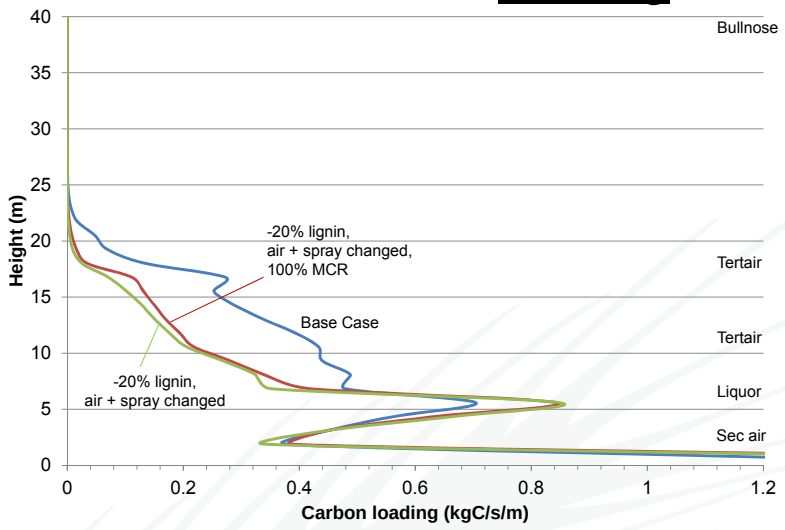
Left wall, back wall, and char bed

Carbon to walls/bed

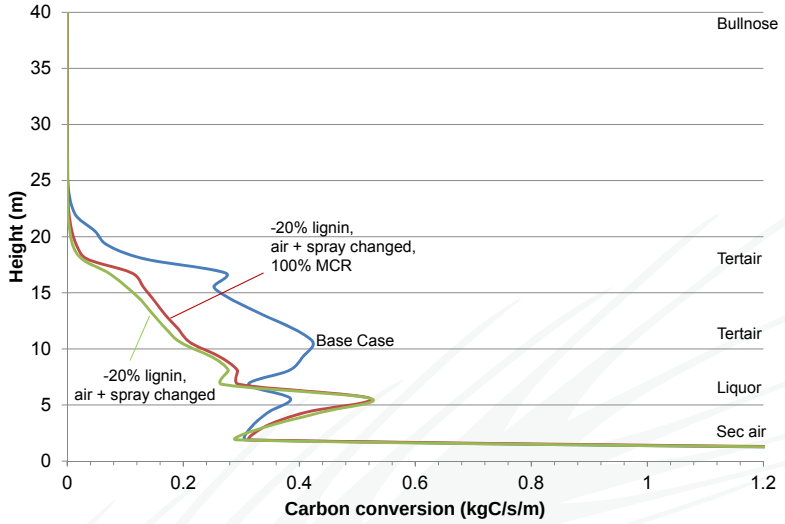


Right wall and front wall

Furnace carbon loading



Furnace carbon conversion



Fate of char carbon

(kg/s)	Base Case	20% reduced lignin, air + spray changed	20% reduced lignin, p2, air + spray changed 100% MCR
In liquor feed	8.81	7.25	7.71
in-flight conversion	3.90	1.42	1.84
to bed/walls	4.91	5.83	5.86
conversion on bed/walls	4.70	5.74	5.82
carbon accumulation	0.21	0.09	0.04

Fate of char carbon

(%)	Base Case	20% reduced lignin, air + spray changed	20% reduced lignin, p2, air + spray changed 100% MCR
In liquor feed	100.0	100.0	100.0
in-flight conversion	44.3	19.6	23.9
to bed/walls	55.7	80.4	76.1
conversion on bed/walls	53.4	79.2	75.6
carbon accumulation	2.3	1.2	0.5

CFD results

- **Run 1:** Wisa Base Case, 100% MCR, flue gas O_2 3% (wet)
- **Runs 8-15:** using vol-C / char-C based on experimental data
  - **Runs 8 and 9:** 10% (97% MCR) and 20% (94% MCR) lignin removed, total air adjusted for flue gas O_2 3% (wet), other variables unchanged (similar to Phase 1 runs 2&3) (results in carbon balance ≠ 0)
  - **Runs 10 and 11:** 10% (97% MCR) & 20% (94% MCR) lignin removed, modifications to air distribution **and** liquor spraying for carbon balance = 0
  - **Runs 12 and 13:** same as runs 10&11 but with 100% MCR
  - **Runs 14 and 15:** 10% (97% MCR) & 20% (94% MCR) lignin removed, modifications to liquor spraying for carbon balance = 0 (similar to Phase 1 runs 6&7)

Liquor feed and combustion air (Runs 1, 6&7, 10&11, 14&15)

	Original Black Liquor	10% lower lignin Run 6	20% lower ligning Run 7	10% lower lignin Run 10	20% lower ligning Run 11	10% lower lignin Run 14	20% lower ligning Run 15
Liquor feed (tds/d)	5320	5160	5000	5160	5000	5160	5000
Of MCR (%)	100	97	94	97	94	97	94
Air (kg/s)	272	256	232	256	232	256	232
Air (Nm3/s)	211	199	180	199	180	199	180
Primary	22%	22%	22%	25% *	28% *	22%	22%
Secondary	43%	43%	43%	40%	40%	43%	43%
Tertiary	35%	35%	35%	35%	32%	35%	35%
Target flue gas O_2 (% wet)	3.0	3.0	3.0	3.0	3.0	3.0	3.0
	Phase 1	Phase 1	Phase 1	Phase 2	Phase 2	Phase 2	Phase 2
Vol-C/char-C	**50/50**	**62/38**	**70/30**	**50/50**	**50/50**	**50/50**	**50/50**
Dp average (mm)	**5.7**	**12.5**	**23.0**	**6.5**	**11**	**6.3**	**7.2**
ΔT spray (°C)	**0**	**-4.7**	**-11.9**	**-0.6**	**-3.6**	**-0.4**	**-1.0**

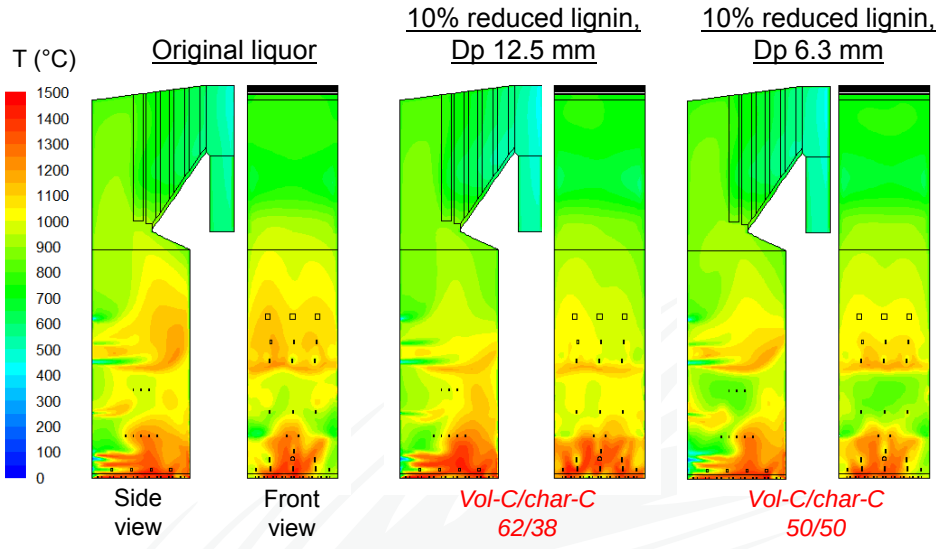
Air distribution changed after which average droplet size "optimized" for carbon balanced situation.
Air change based on discussion with industry: "with a lower HV/quality liquor, more of the combustion (air+liquor) to lower furnace".
*) these percentages give ~same mass flow (kg/s) primary

Liquor feed and combustion air (Runs 1, 6&7, 10&11, 14&15)

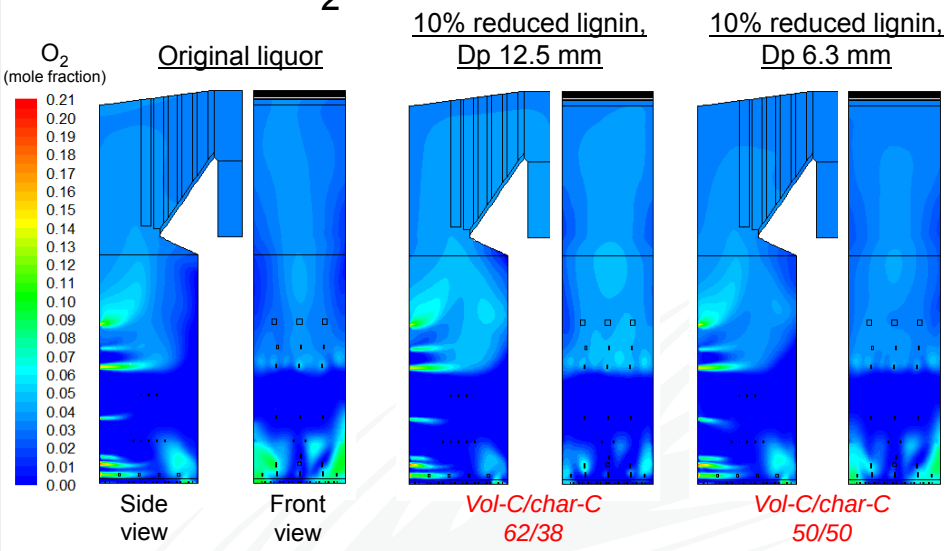
	Original Black Liquor	10% lower lignin Run 6	20% lower ligning Run 7	10% lower lignin Run 10	20% lower ligning Run 11	10% lower lignin Run 14	20% lower ligning Run 15
Liquor feed (tds/d)	5320	5160	5000	5160	5000	5160	5000
Of MCR (%)	100	97	94	97	94	97	94
Air (kg/s)	272	256	232	256	232	256	232
Air (Nm3/s)	211	199	180	199	180	199	180
Primary	22%	22%	22%	25% *	28% *	22%	22%
Secondary	43%	43%	43%	40%	40%	43%	43%
Tertiary	35%	35%	35%	35%	32%	35%	35%
Target flue gas O_2 (% wet)	3.0	3.0	3.0	3.0	3.0	3.0	3.0
	Phase 1	Phase 1	Phase 1	Phase 2	Phase 2	Phase 2	Phase 2
Vol-C/char-C	**50/50**	**62/38**	**70/30**	**50/50**	**50/50**	**50/50**	**50/50**
Dp average (mm)	**5.7**	**12.5**	**23.0**	**6.5**	**11**	**6.3**	**7.2**
ΔT spray (°C)	**0**	**-4.7**	**-11.9**	**-0.6**	**-3.6**	**-0.4**	**-1.0**

Air distribution changed after which average droplet size "optimized" for carbon balanced situation.
Air change based on discussion with industry: "with a lower HV/quality liquor, more of the combustion (air+liquor) to lower furnace".
*) these percentages give ~same mass flow (kg/s) primary

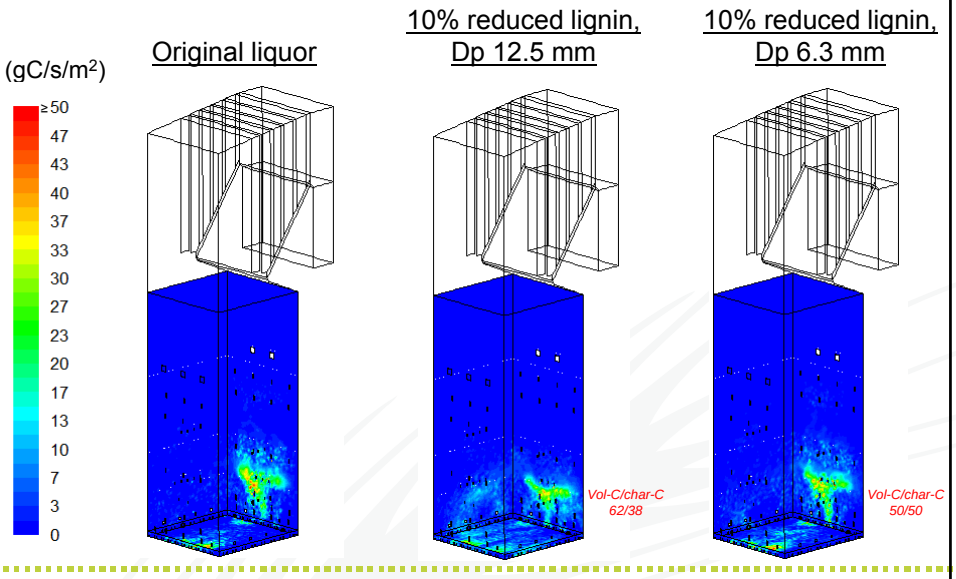
Temperature



O_2 concentration

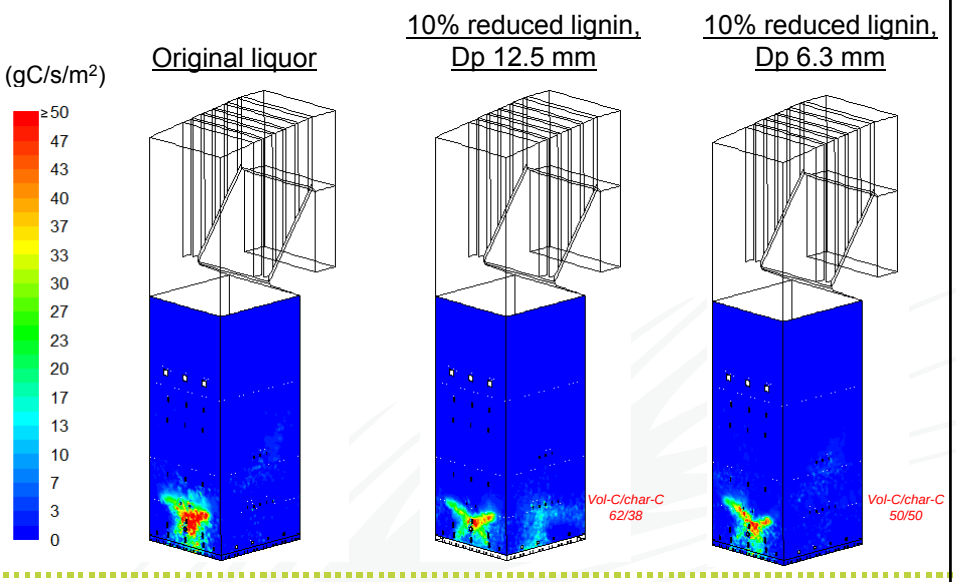


Carbon to walls/bed



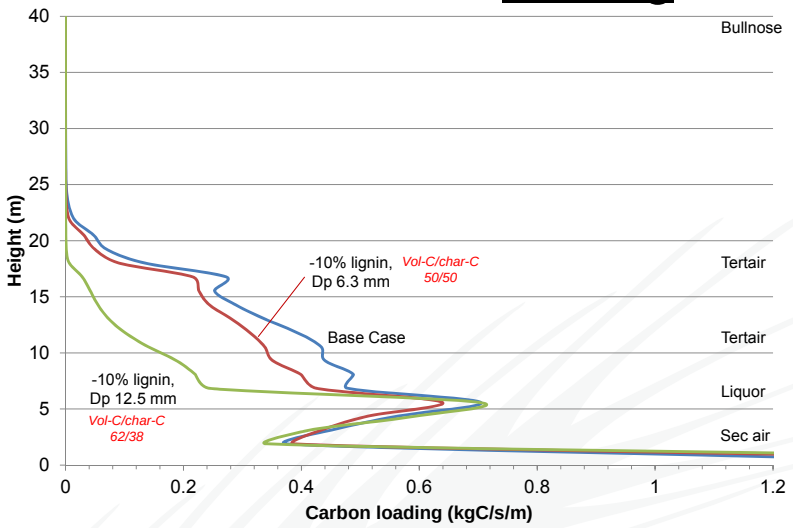
Left wall, back wall, and char bed

Carbon to walls/bed

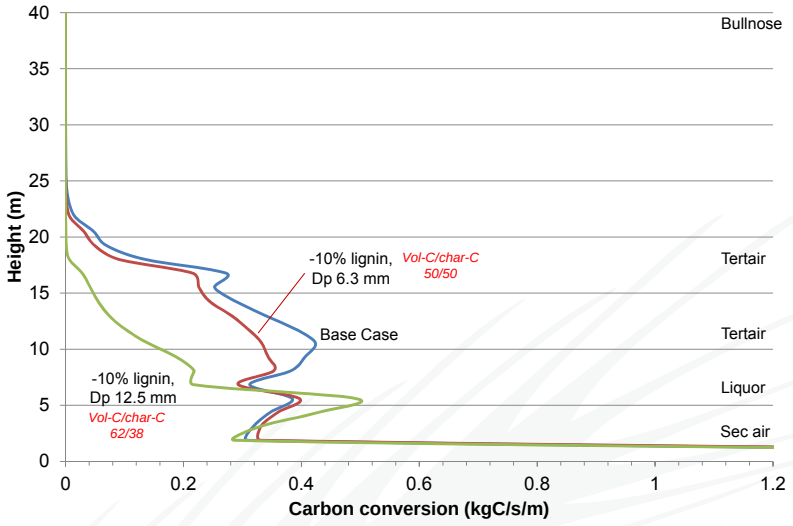


Right wall and front wall

Furnace carbon loading



Furnace carbon conversion



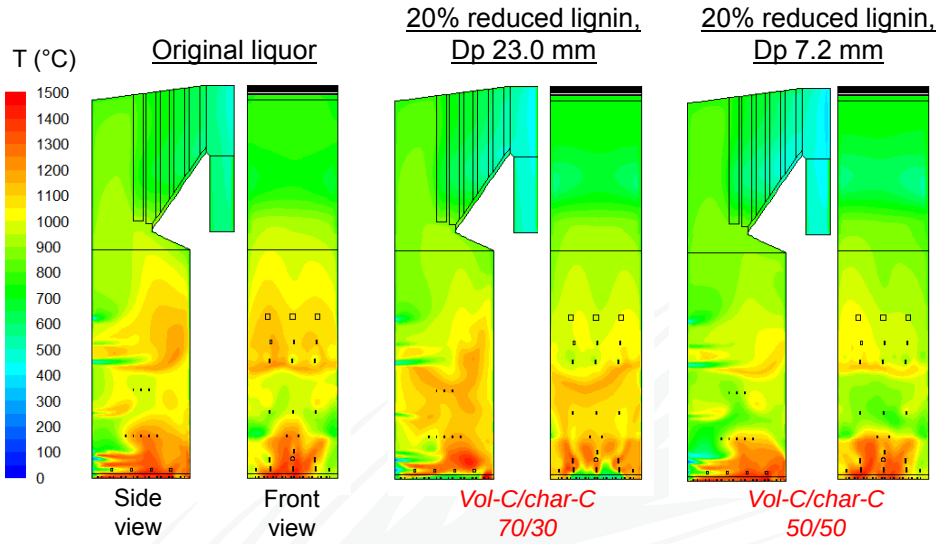
Fate of char carbon

(kg/s)	Base Case	10% reduced lignin, Dp 12.5 mm	10% reduced lignin, Dp 6.3 mm
In liquor feed	8.81	6.19	8.12
in-flight conversion	3.90	1.01	3.08
to bed/walls	4.91	5.18	5.04
conversion on bed/walls	4.70	5.16	5.01
carbon accumulation	0.21	0.02	0.03
		Vol-C/char-C 62/38	*Vol-C/char-C 50/50*

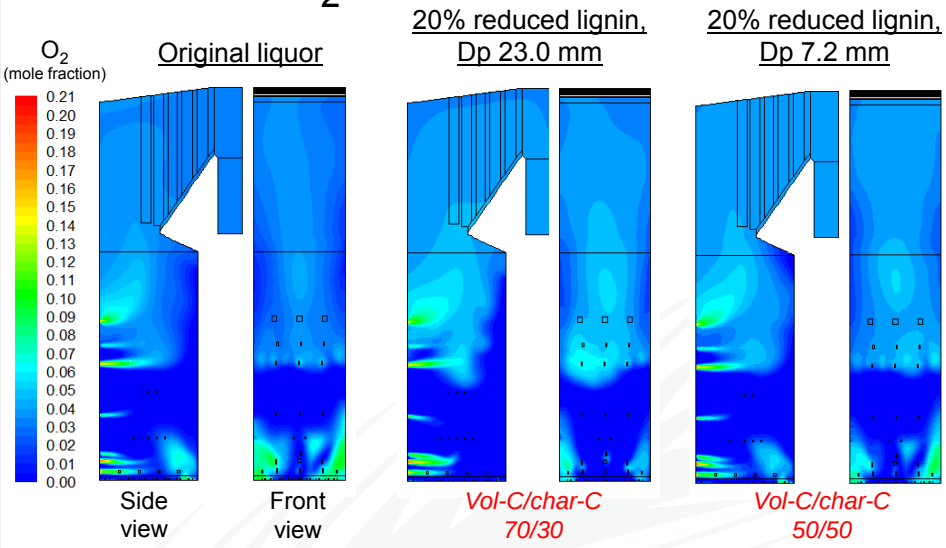
Fate of char carbon

(%)	Base Case	10% reduced lignin, Dp 12.5 mm	10% reduced lignin, Dp 6.3 mm
In liquor feed	100.0	100.0	100.0
in-flight conversion	44.3	16.3	38.0
to bed/walls	55.7	83.7	62.0
conversion on bed/walls	53.4	83.4	61.7
carbon accumulation	2.3	0.3	0.3
		Vol-C/char-C 62/38	*Vol-C/char-C 50/50*

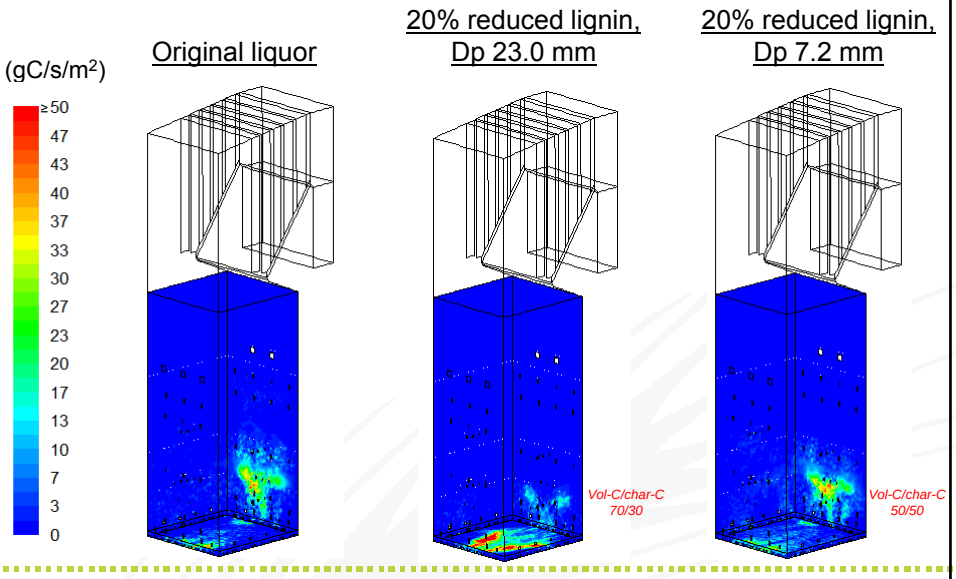
Temperature



O_2 concentration

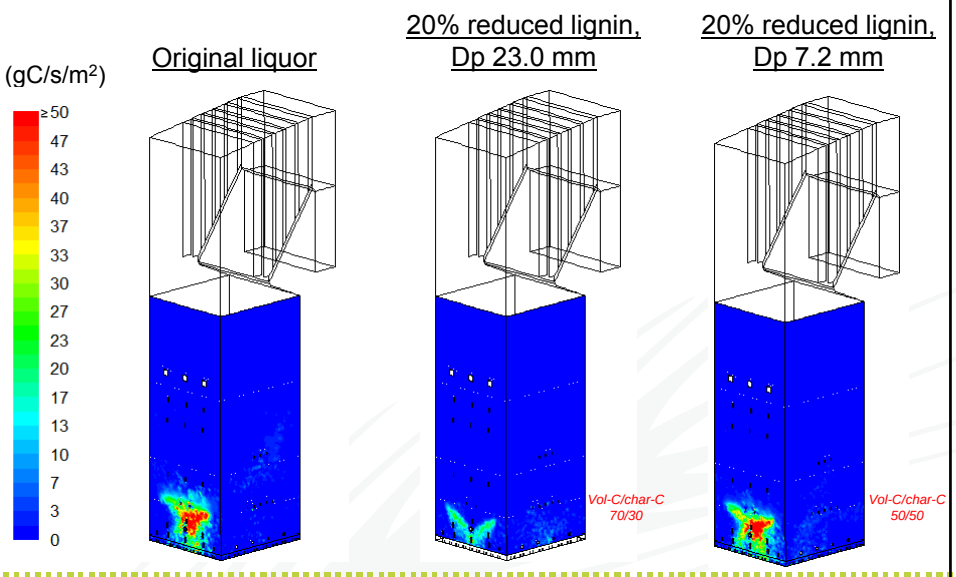


Carbon to walls/bed



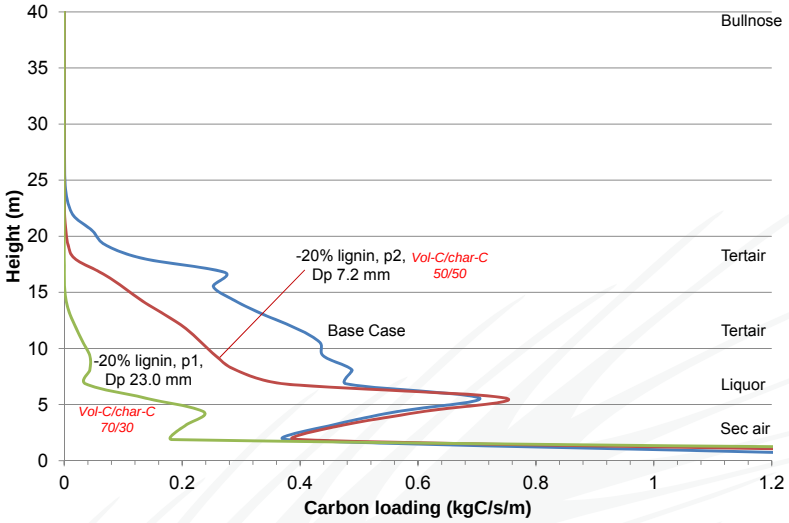
Left wall, back wall, and char bed

Carbon to walls/bed

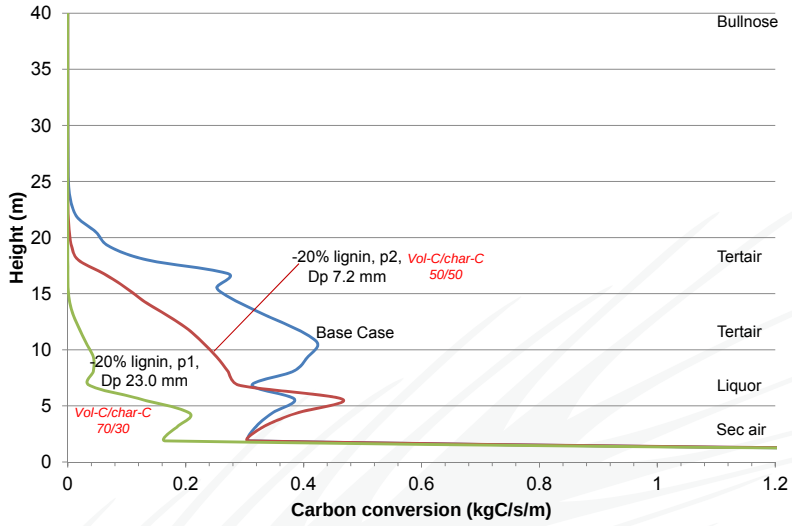


Right wall and front wall

Furnace carbon loading



Furnace carbon conversion



Fate of char carbon

(kg/s)	Base Case	20% reduced lignin, Dp 23.0 mm	20% reduced lignin, Dp 7.2 mm
In liquor feed	8.81	4.30	7.25
in-flight conversion	3.90	0.24	2.07
to bed/walls	4.91	4.05	5.18
conversion on bed/walls	4.70	4.02	5.15
carbon accumulation	0.21	0.03	0.03
		Vol-C/char-C 70/30	*Vol-C/char-C 50/50*

Fate of char carbon

(%)	Base Case	20% reduced lignin, Dp 23.0 mm	20% reduced lignin, Dp 7.2 mm
In liquor feed	100.0	100.0	100.0
in-flight conversion	44.3	5.7	28.5
to bed/walls	55.7	94.3	71.5
conversion on bed/walls	53.4	93.6	71.0
carbon accumulation	2.3	0.7	0.4
		Vol-C/char-C 70/30	*Vol-C/char-C 50/50*

Conclusions

- Less char-C with lignin removal
  - Less C to the lower furnace with lignin removal if drop size stays the same
  - Changes to operation needed to compensate
- For up to 20% lignin removal
  - With air distribution unchanged (p22%/s43%/t35%) decrease in liquor temperature by approximately 1 °C
  - Combined change in air+spray (p28%/s40%/t32%) decrease in liquor temperature by approximately 3.6 °C

SUOMEN SOODAKATTILAYHDISTYS RY
RAPORTTISARJA

1/2015 Suomen Soodakattilayhdistys ry
Konemestaripäivä 29.1.2015, esitelmät
Hotelli Cumulus, Rauma, Metsä Fibre Oy, Rauman tehdas
(16A0913-E0154) 29.1.2015

2/2015 Suomen Soodakattilayhdistys ry
Aktiivihiilen mitoituksen varmistus ja optimointi sekä TOC-reduktion varmistaminen
(16A0913-E0155) 29.1.2015

3/2015 Suomen Soodakattilayhdistys ry
Soodakattilan käynnistys-, pysäytys- ja häiriöjaksojen määrittely
(16A0913-E0156) 14.4.2015

4/2015 Suomen Soodakattilayhdistys ry
CFD Modeling of Reduced Lignin Black Liquor Combustion
Markus Engblom ja Nikolai DeMartini, Åbo Akademi
(16A0913-E0157) 14.4.2015

5/2015 Suomen Soodakattilayhdistys ry
Understanding Low Temperature Corrosion in Black Liquor Combustion
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