The influence of aerosol particles on the melting behavior of ash deposits in biomass fired boilers

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CONCLUSIONS

- Alkali chloride in ash and deposits gives first melting temperature around 550^{o}C.
- Lead and zinc together with alkali chlorides decrease the first melting temperature further to around 200^{o}C.
- The amount of melt as a function of composition and temperature can be estimated using theoretical methods.

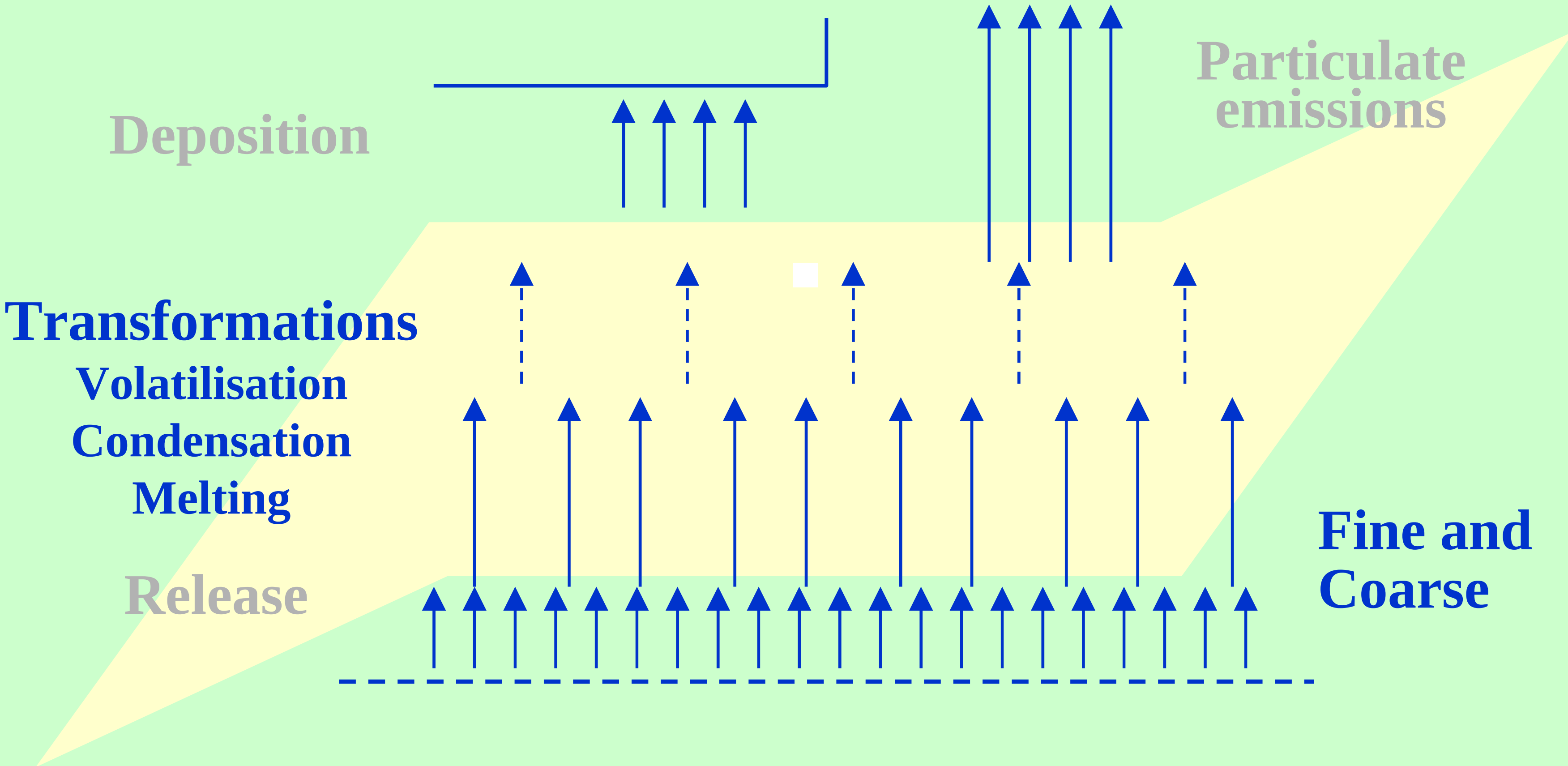
OUTLINE

- Background
- Melting properties of salt mixtures
- Estimation of ash fraction composition
- Melting of ash fractions
- Influence of lead and zinc on melting
- Conclusions

BACKGROUND

- Novel way of predicting ash behavior
- Advanced fuel analysis
- Basic chemistry knowledge
- Chemical thermodynamic modeling
- Submodels for other models

Ash reactions in boiler flue gases



MELTING OF SALT MIXTURES

- **Pure melting points**
- **Stepwise melting**
- **Characteristic temperatures**
- **Complex melting models**

Melting temperatures

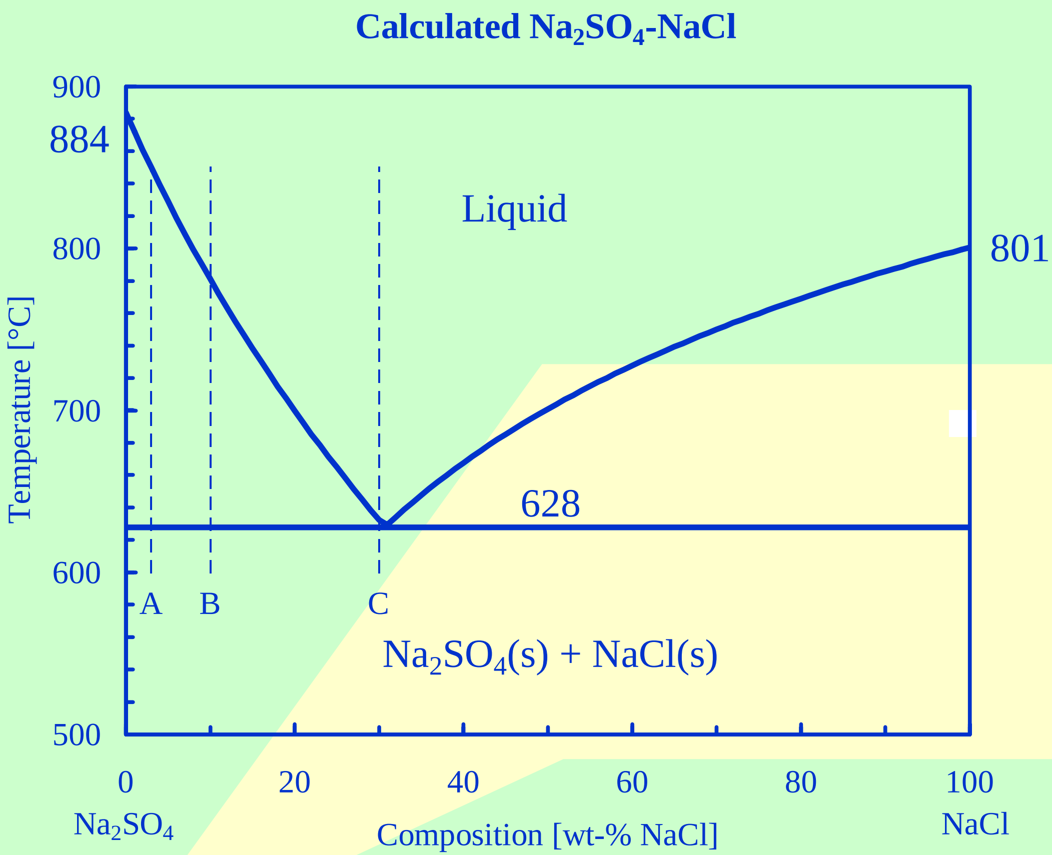
Pure compounds

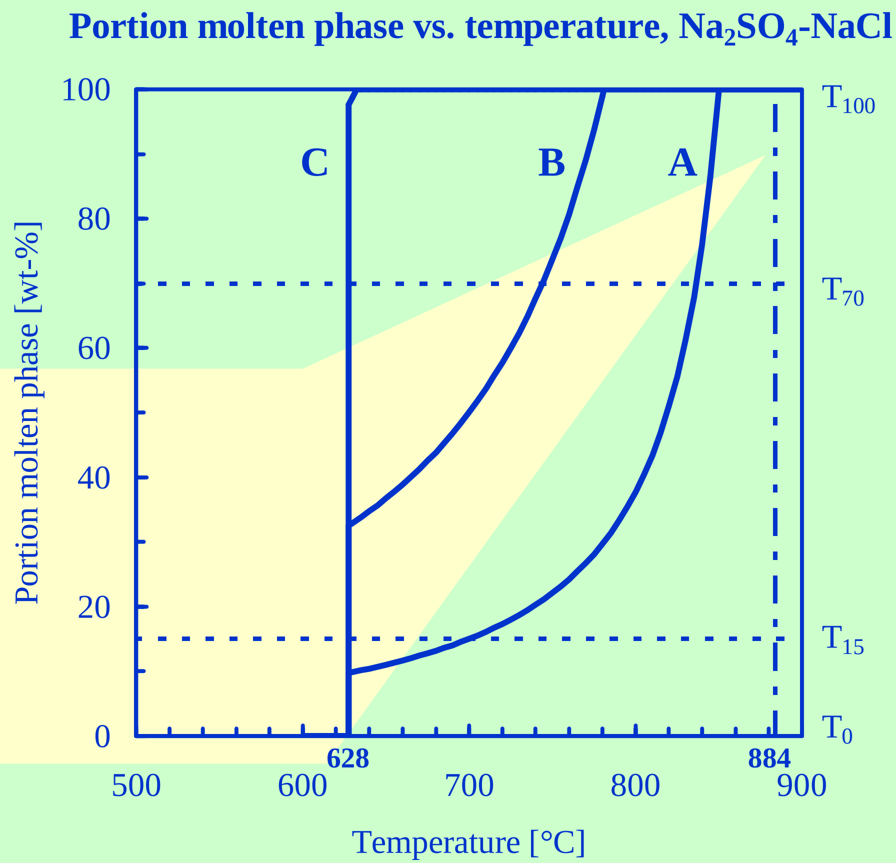
$PbSO_4$	1170^oC
K_2SO_4	1069
Na_2SO_4	884
NaCl	801
KCl	771
$ZnSO_4$	730
$PbCl_2$	501
$ZnCl_2$	318

Eutectics

$PbSO_4$-K_2SO_4	814^oC
$PbSO_4$-Na_2SO_4	719
$ZnSO_4$-K_2SO_4	566
$PbSO_4$-$ZnSO_4$	674
$ZnSO_4$-Na_2SO_4	485
$PbCl_2$-NaCl	444
$PbCl_2$-KCl	435
$ZnCl_2$-NaCl	294
$ZnCl_2$-KCl	288
$PbCl_2$-$ZnCl_2$	243

Stepwise melting – Melting curve





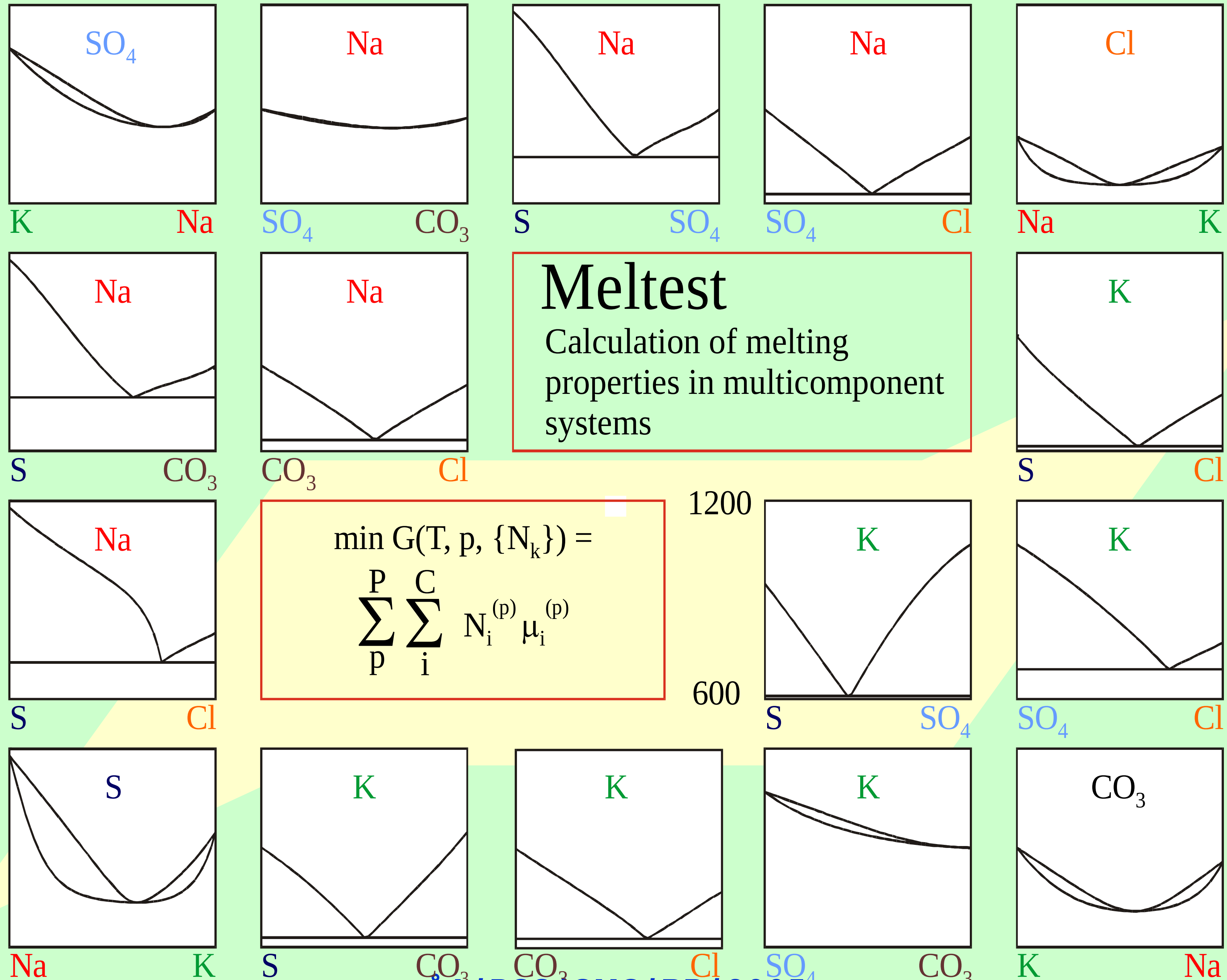
Characteristic temperatures

T_0	First melting temperature
T_{15}	Sticky temperature
T_{70}	Flow temperature
T_{100}	Final melting temperature

Meltest

Calculation of melting properties in multicomponent systems

$$\min G(T, p, \{N_k\}) = \sum_{p}^{P} \sum_{i}^{C} N_i^{(p)} \mu_i^{(p)}$$



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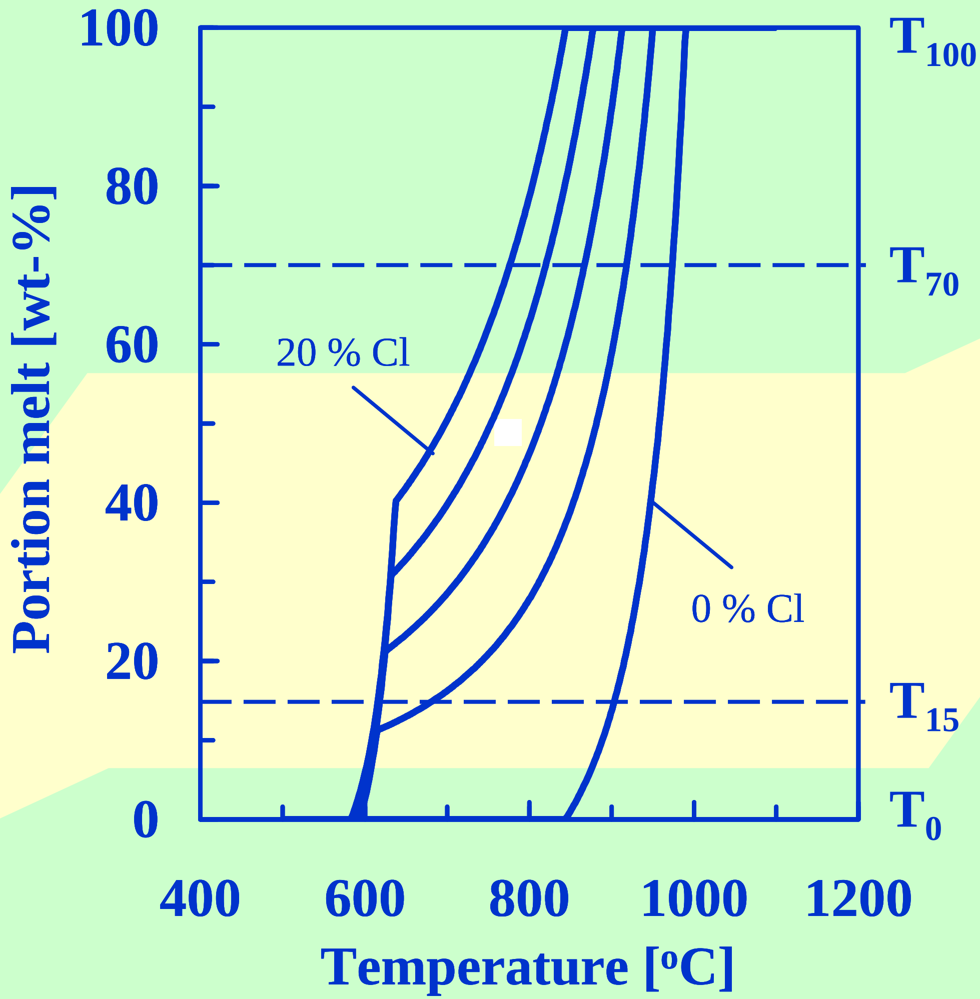
meltest.cdr

Melting curves for alkali ash

K/Na = 90/10, SO_4/CO_3 = 80/20



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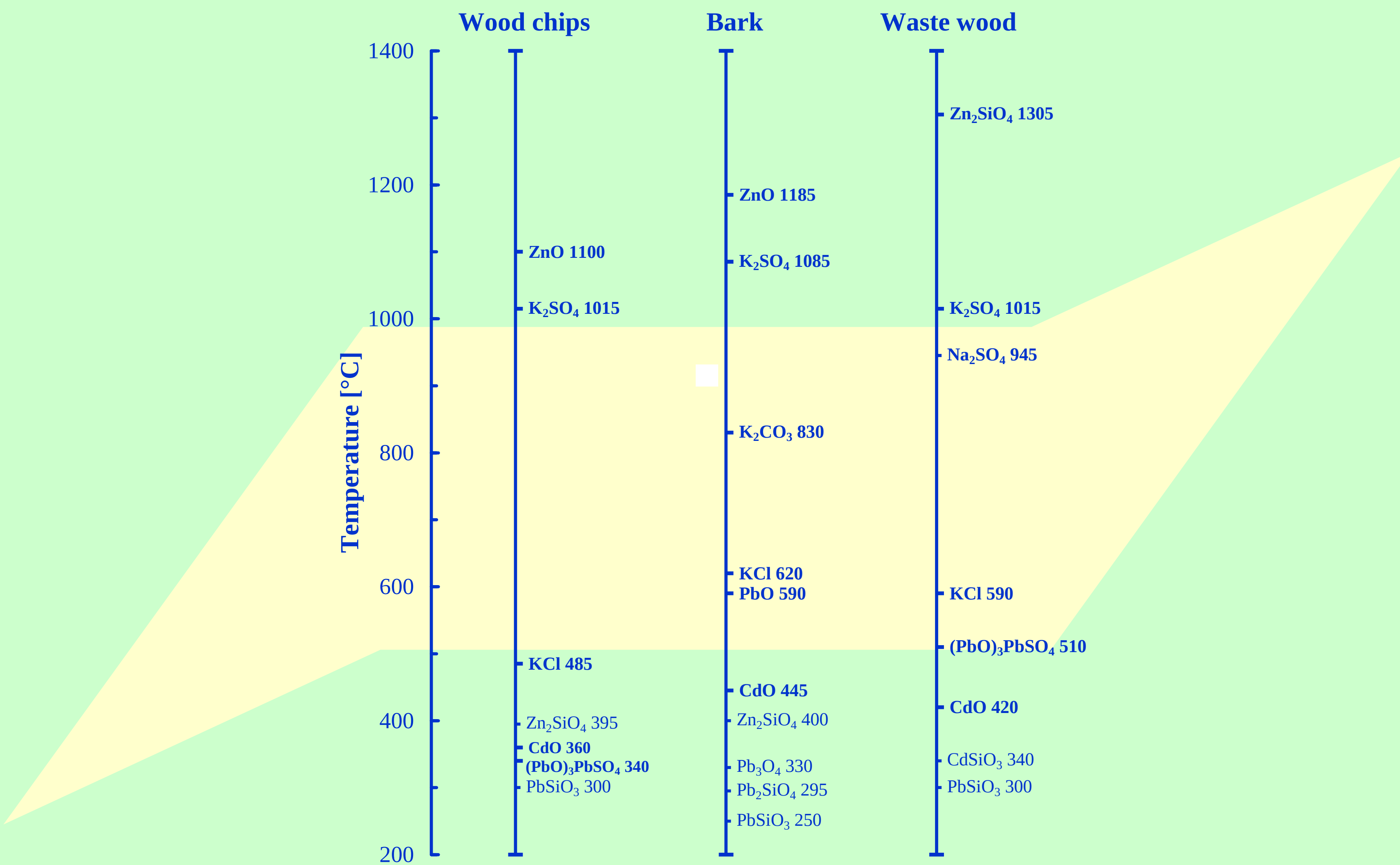
ESTIMATION OF COMPOSITION

- Prediction based on fuel composition
- Aerosol formation models
- Condensation chemistry
  - Influence of total alkali
  - Influence of Na, Cl, S

Condensation sequences at cooling

O_2 = 6 % in flue gases



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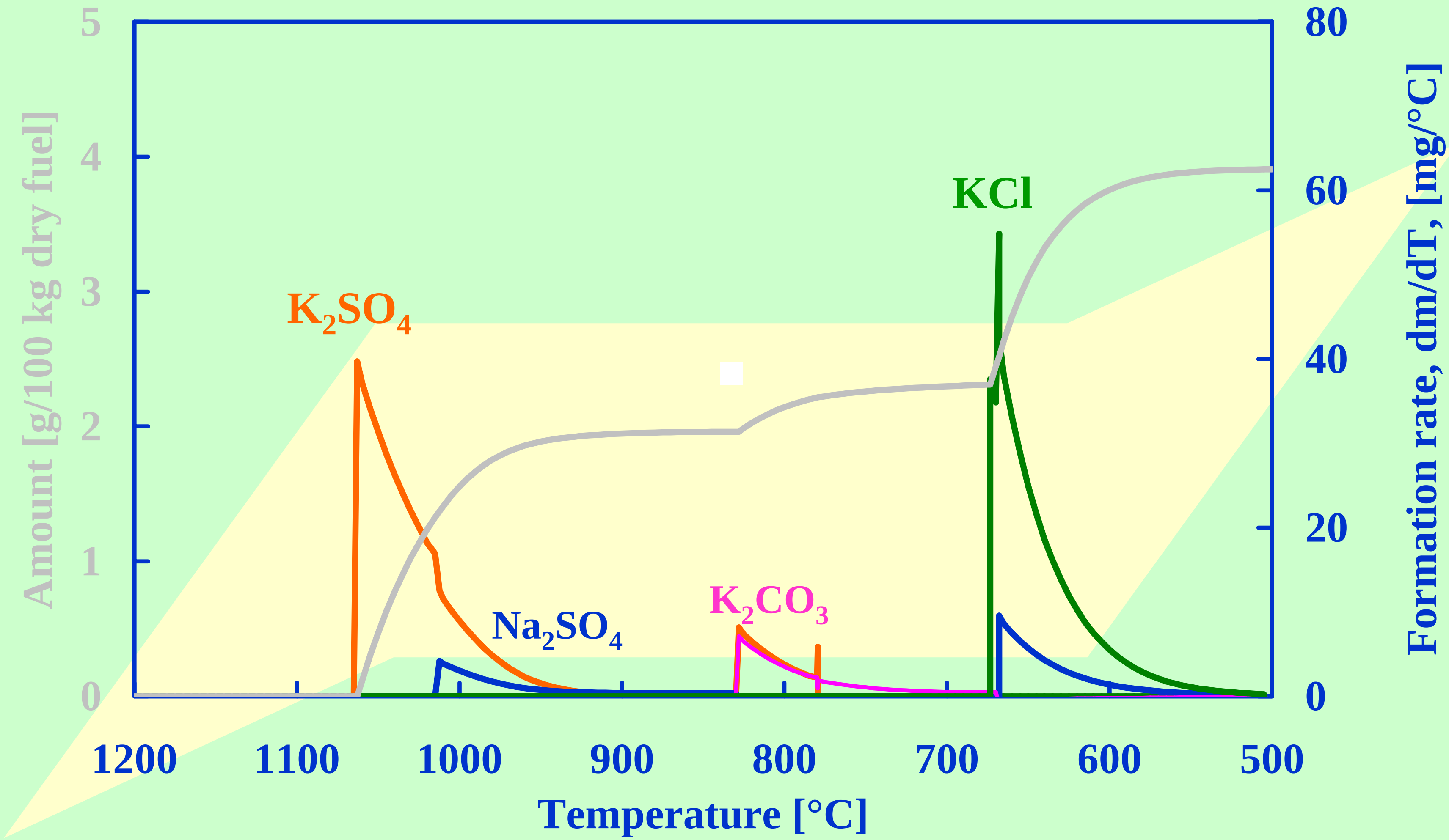
Alkali condensation – pure compounds

Na/(K+Na) = 0.2, Cl/(K+Na) = 0.45, S/(K_2+Na_2) = 0.45



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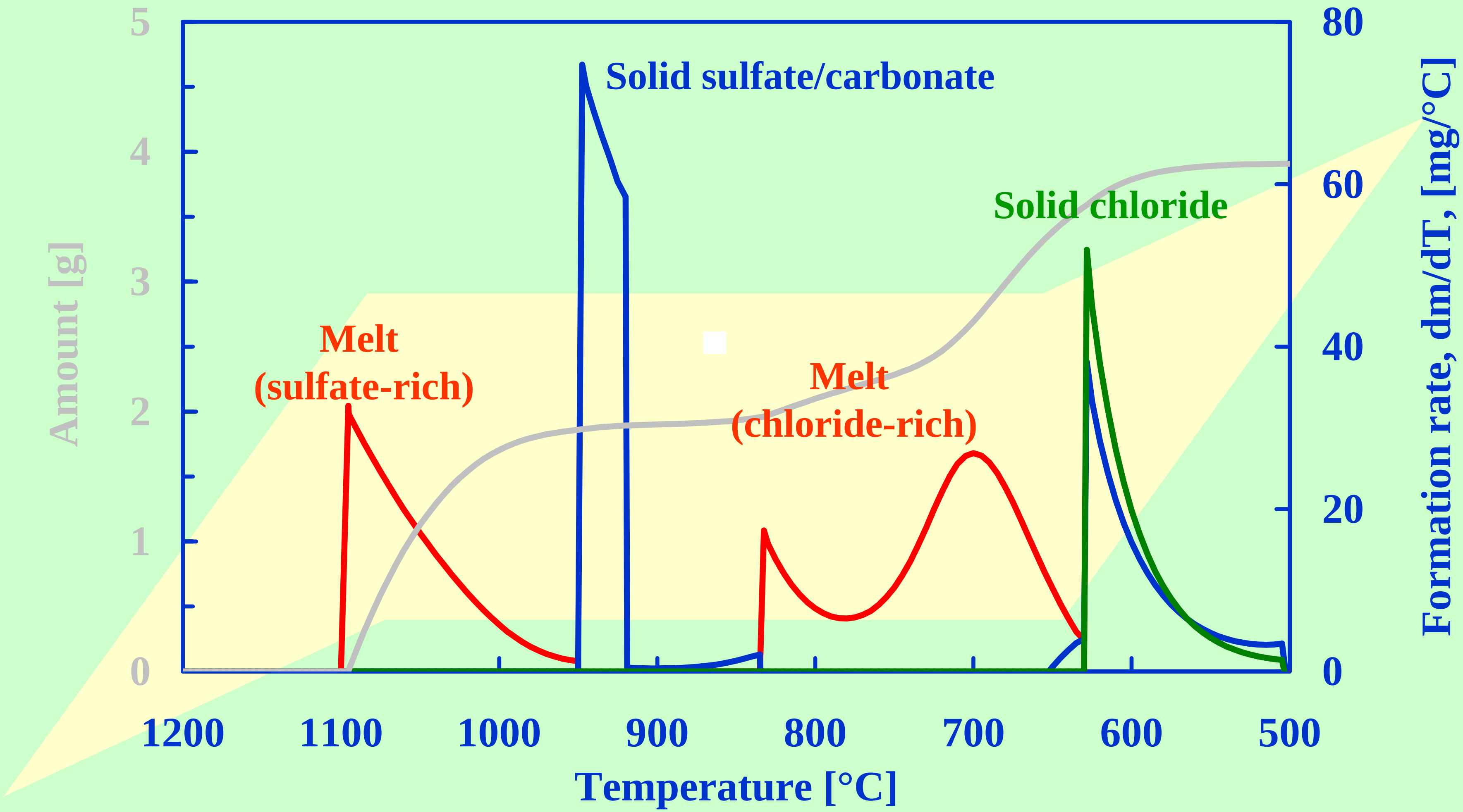
Alkali condensation – melt formation

Na/(K+Na) = 0.2, Cl/(K+Na) = 0.45, S/(K_2+Na_2) = 0.45



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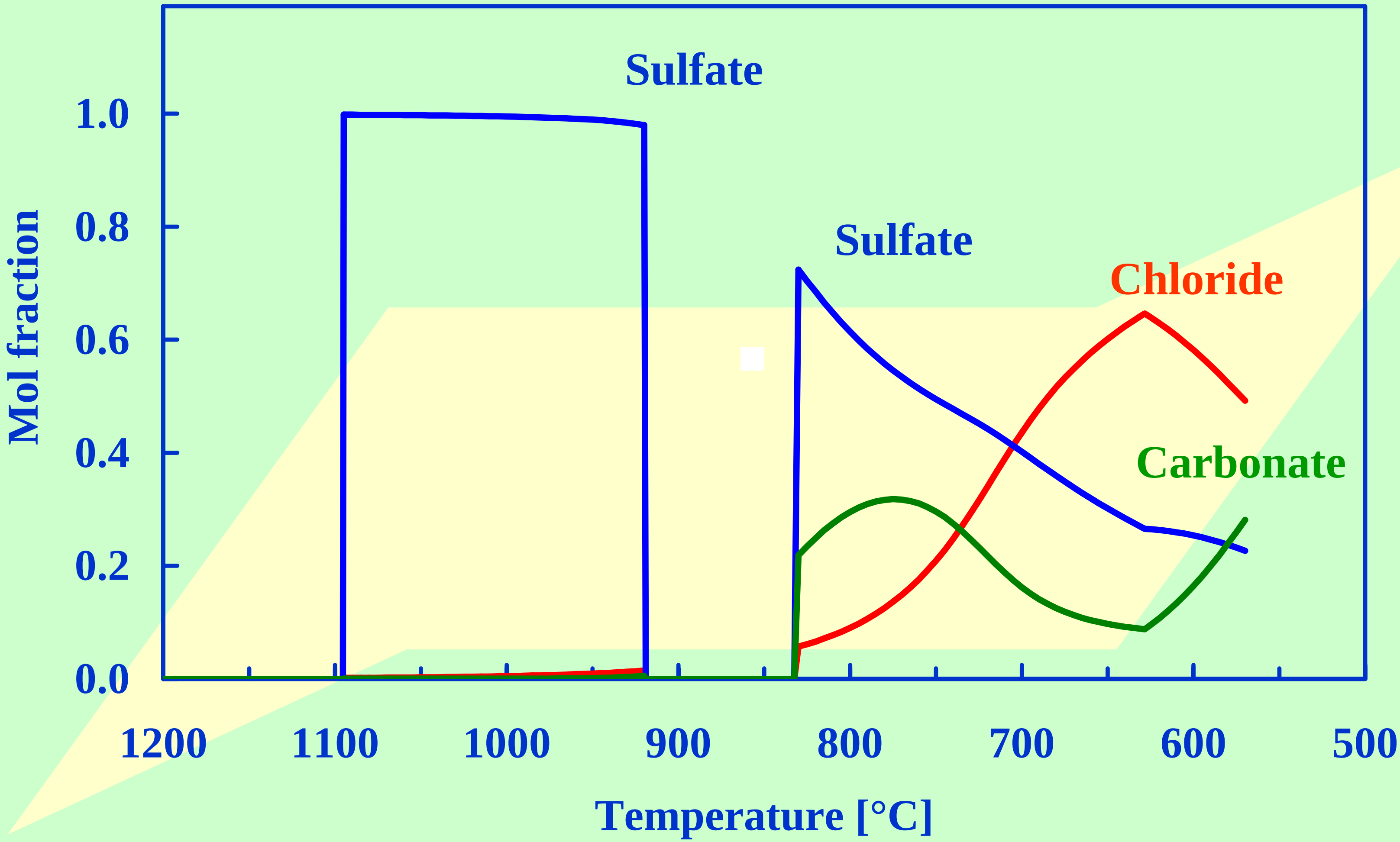
Alkali condensation – melt composition

Na/(K+Na) = 0.2, Cl/(K+Na) = 0.45, S/(K_2+Na_2) = 0.45



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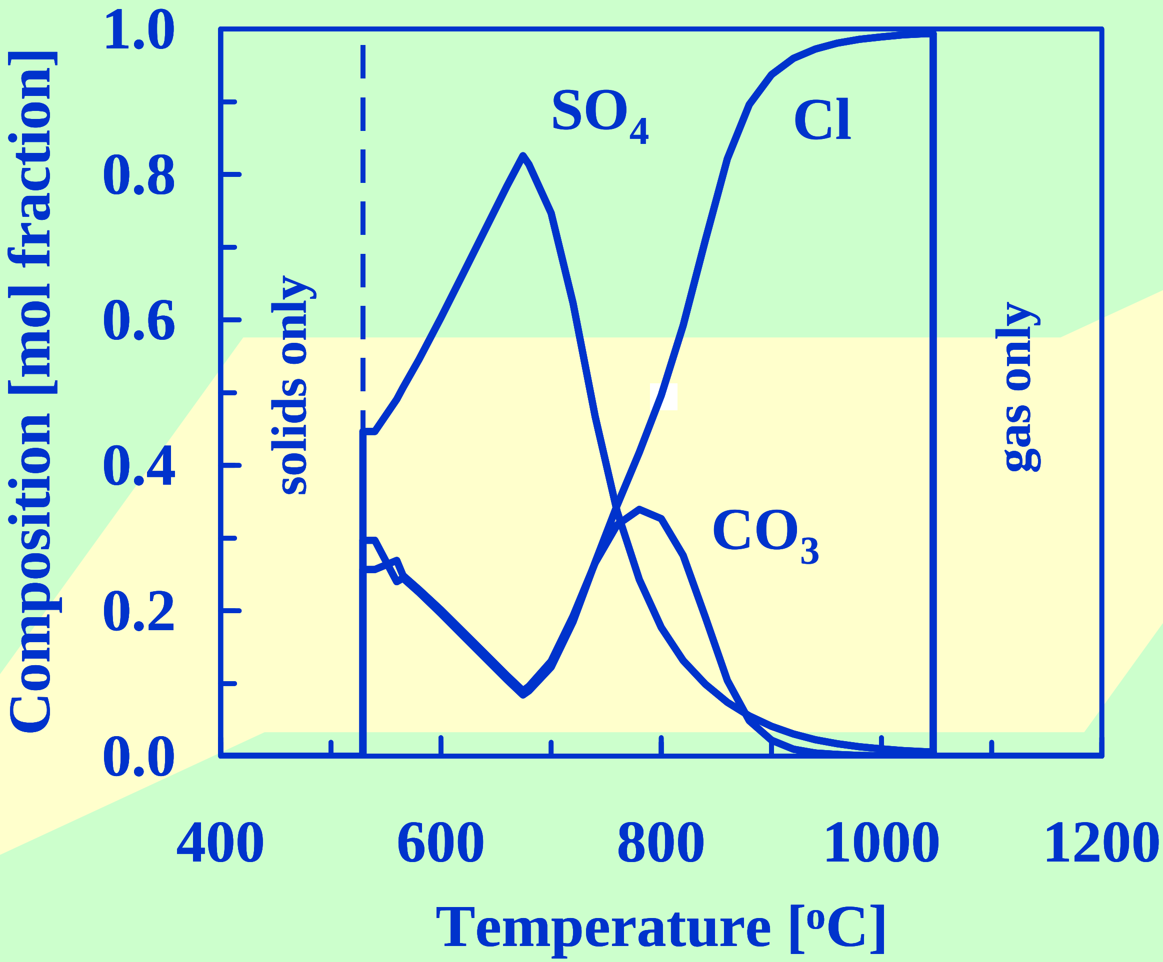
Melt composition

$Na/(K+Na) = 0.2$, $Cl/(K+Na) = 0.8$, $S/(K_2+Na_2) = 0.1$



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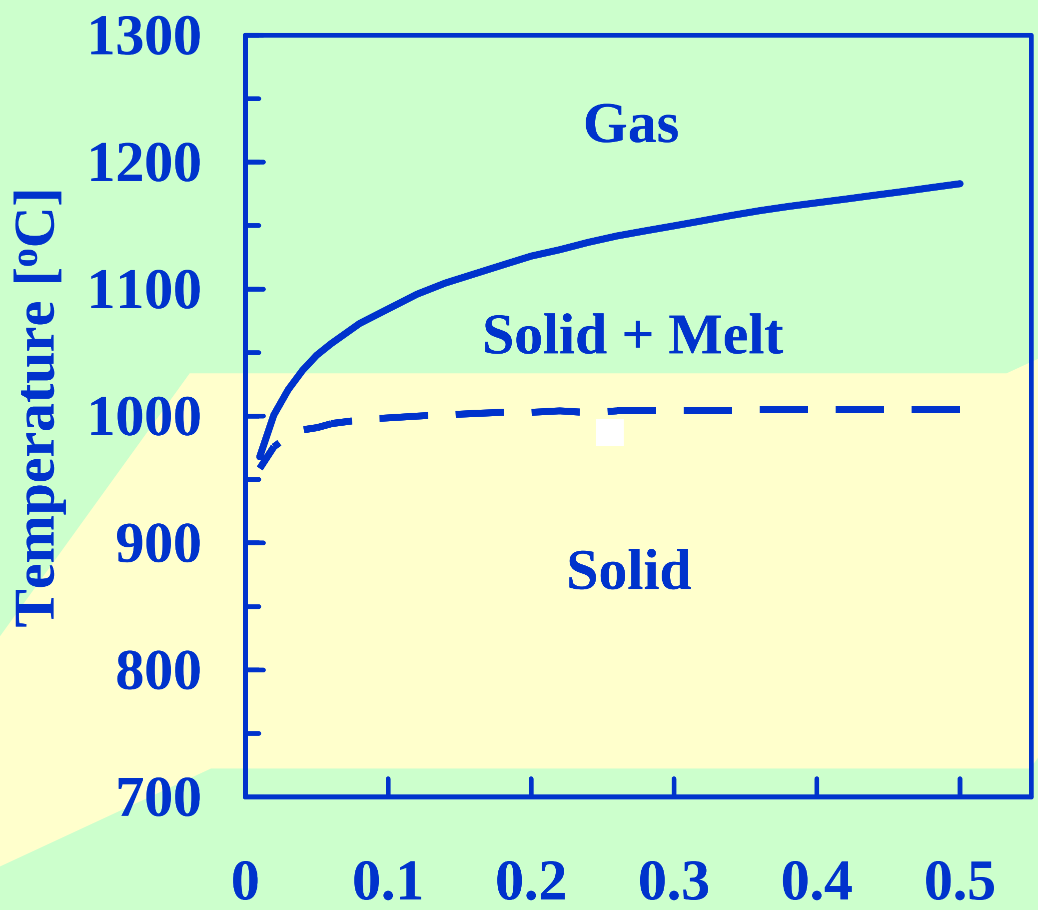
Influence of potassium

Na/(K+Na) = 0.1, Cl/(K+Na) = 0.05, S/(K_2+Na_2) = 0.95



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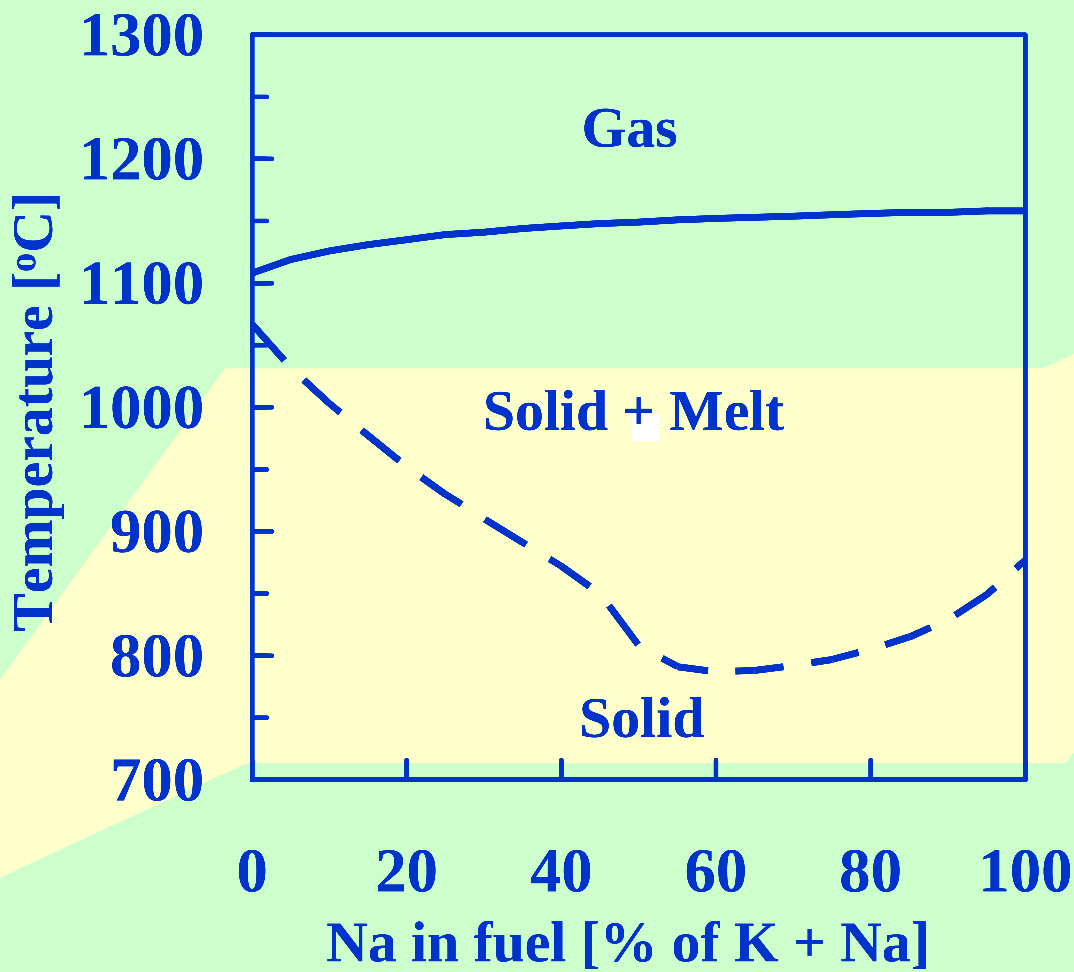
Influence of sodium

K in dry fuel = 0.2 %, Cl/(K+Na) = 0.05, S/(K_2+Na_2) = 0.95



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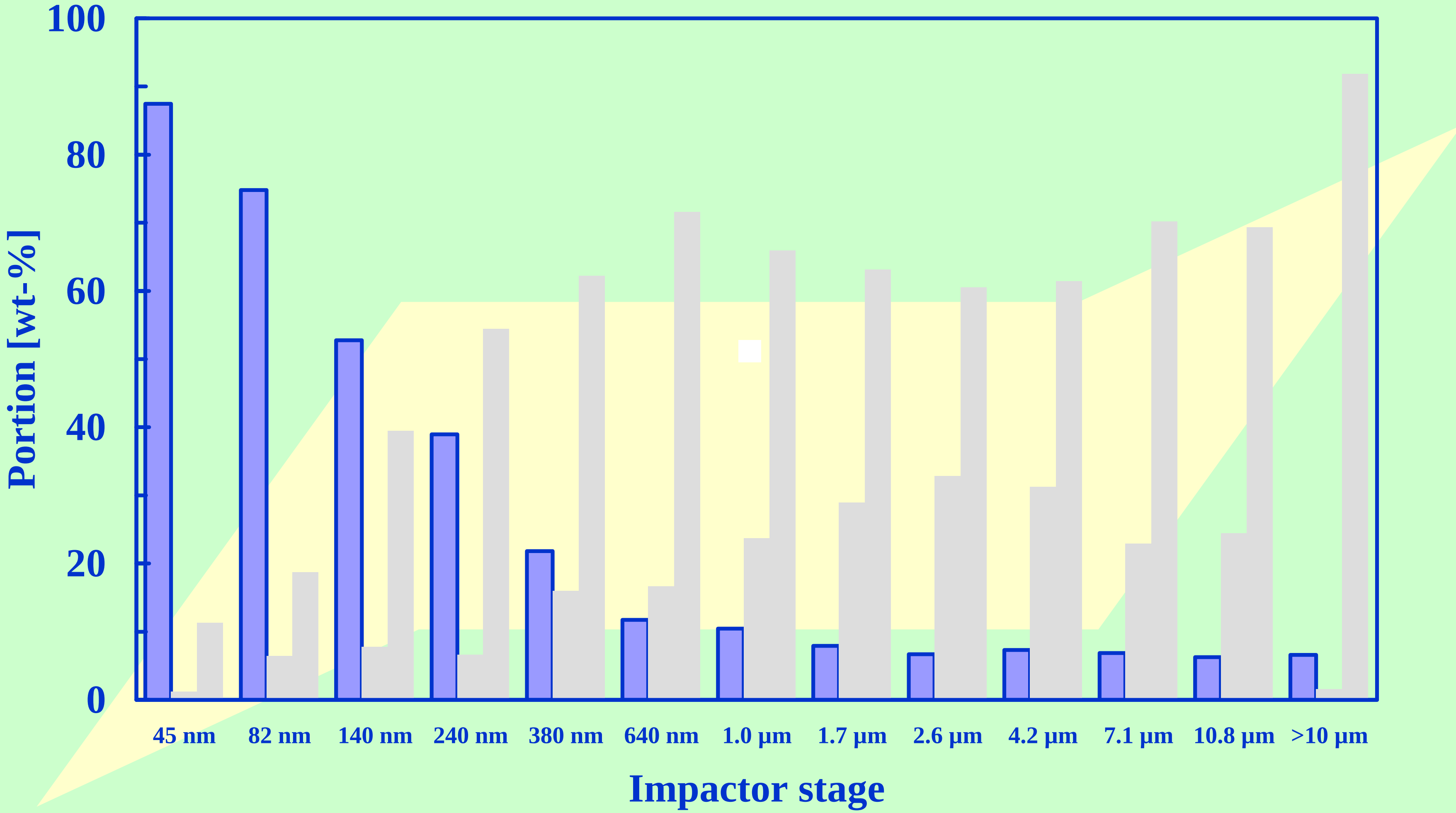
MELTING OF ASH FRACTIONS

- Impactor measurements
  - Biomass fired BFBC (105 MW)
  - Chemical composition by SEM/EDX
  - Al, Ca, Fe, K, Mg, Mn, Na, Si, Ti, Cl, S, P
  - Estimation of speciation (compounds)
  - Calculated melting curves
- Coarse ash fraction
  - Biomass grate firing

Alkali part (K, Na) of fine particles

Biomass combustion, BFBC



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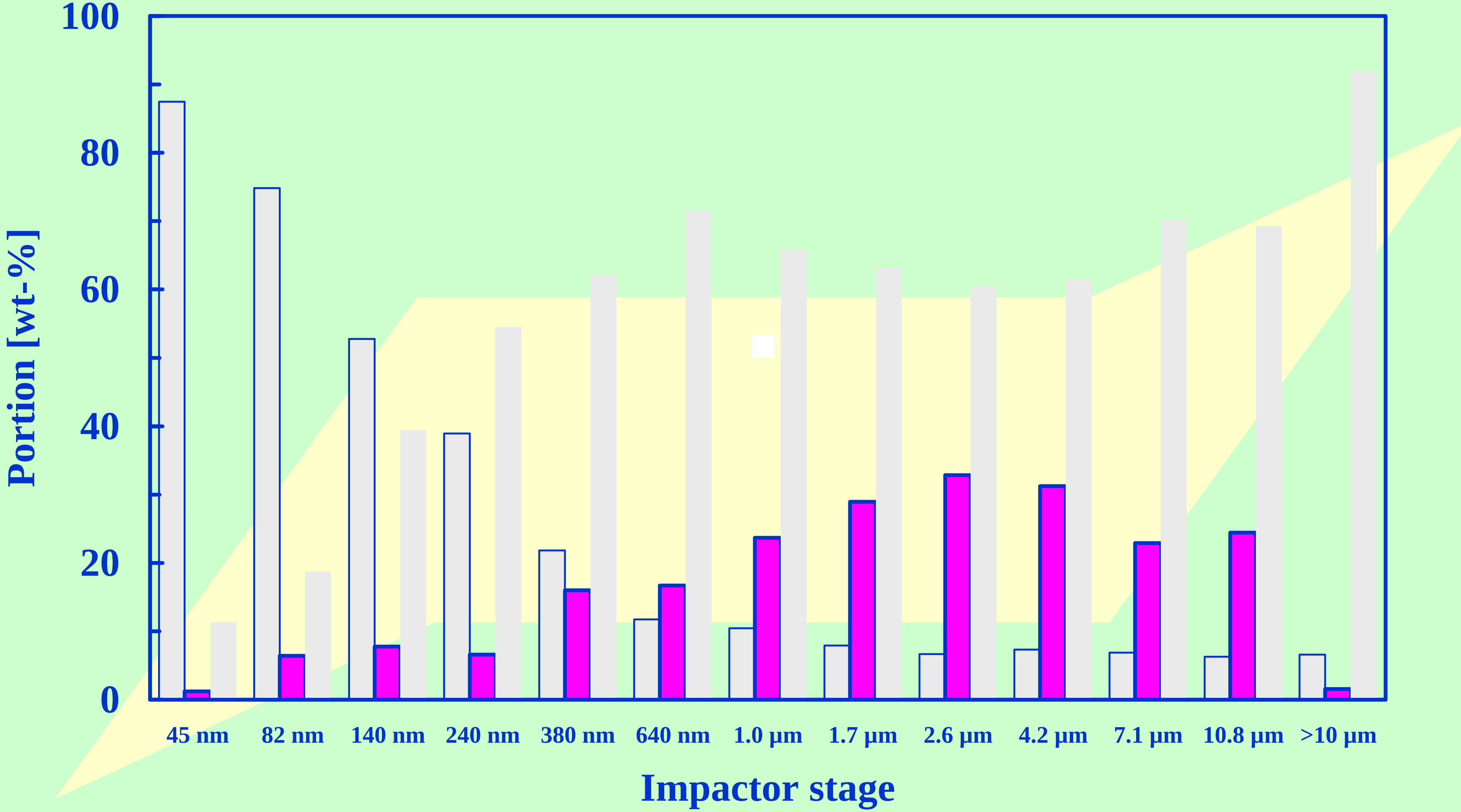
Calcium salt part (SO_4, CO_3) of fine particles

Biomass combustion, BFBC



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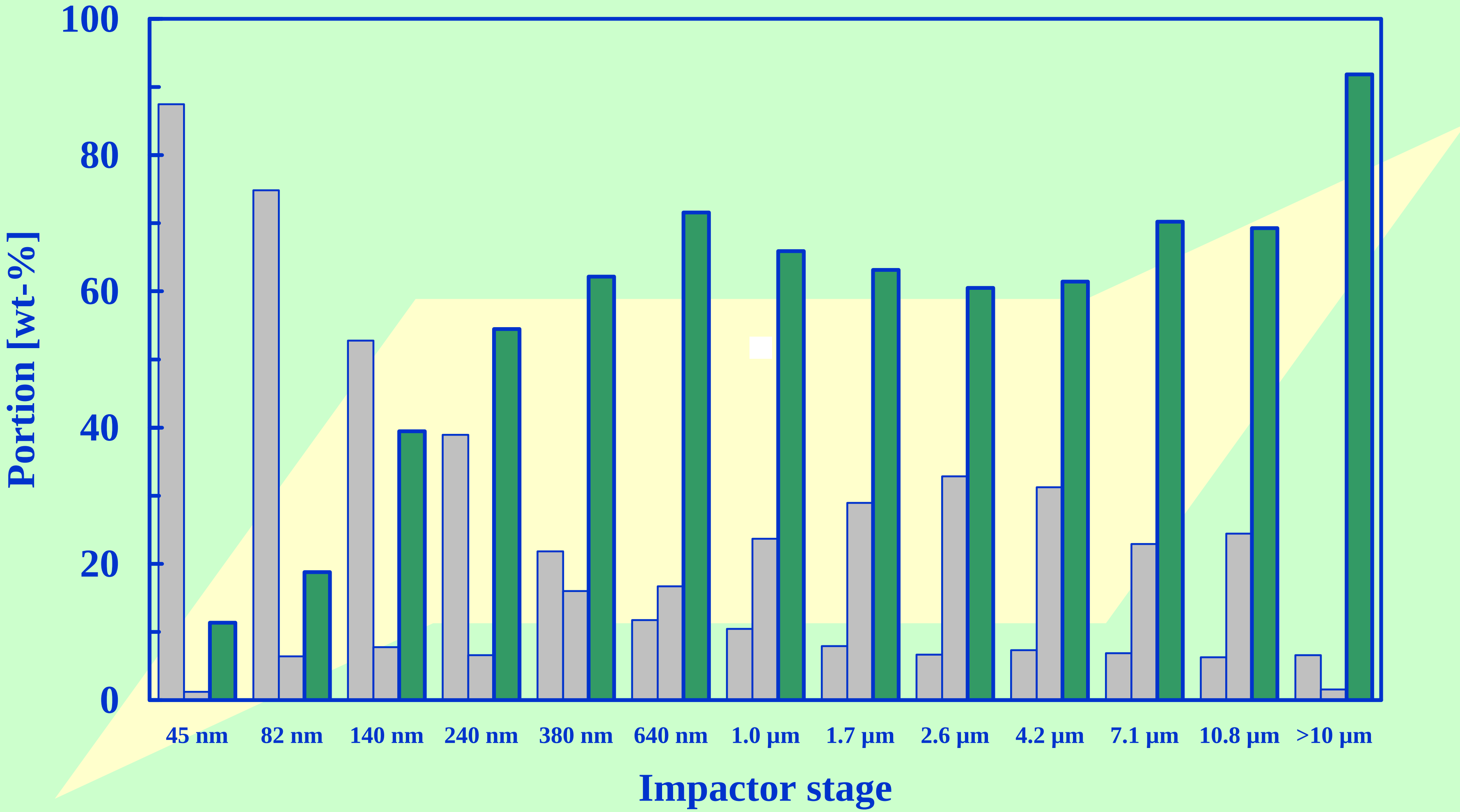
Inert part (oxides silicates) of fine particles

Biomass combustion, BFBC



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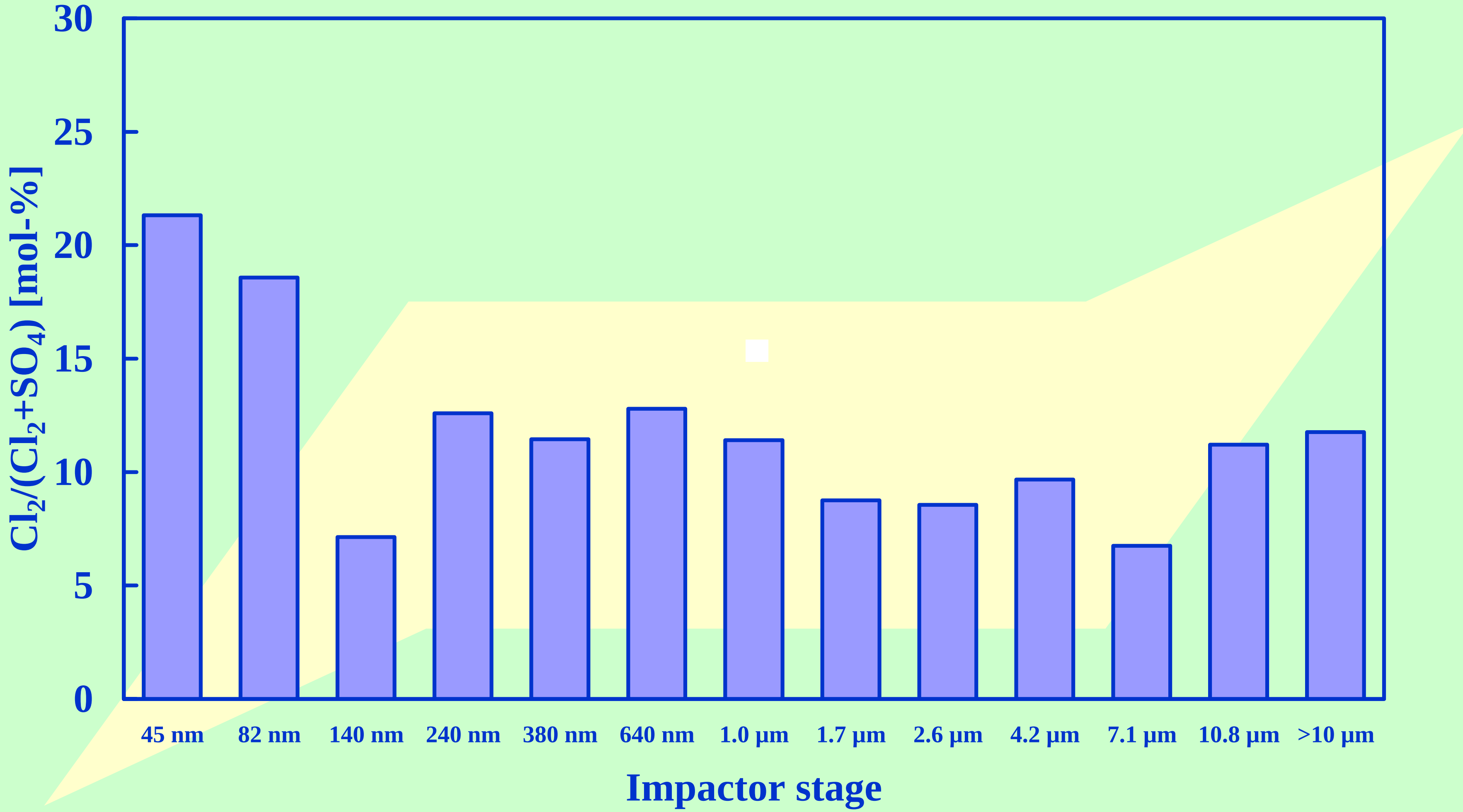
Chloride and sulfate of fine particles

Biomass combustion, BFBC



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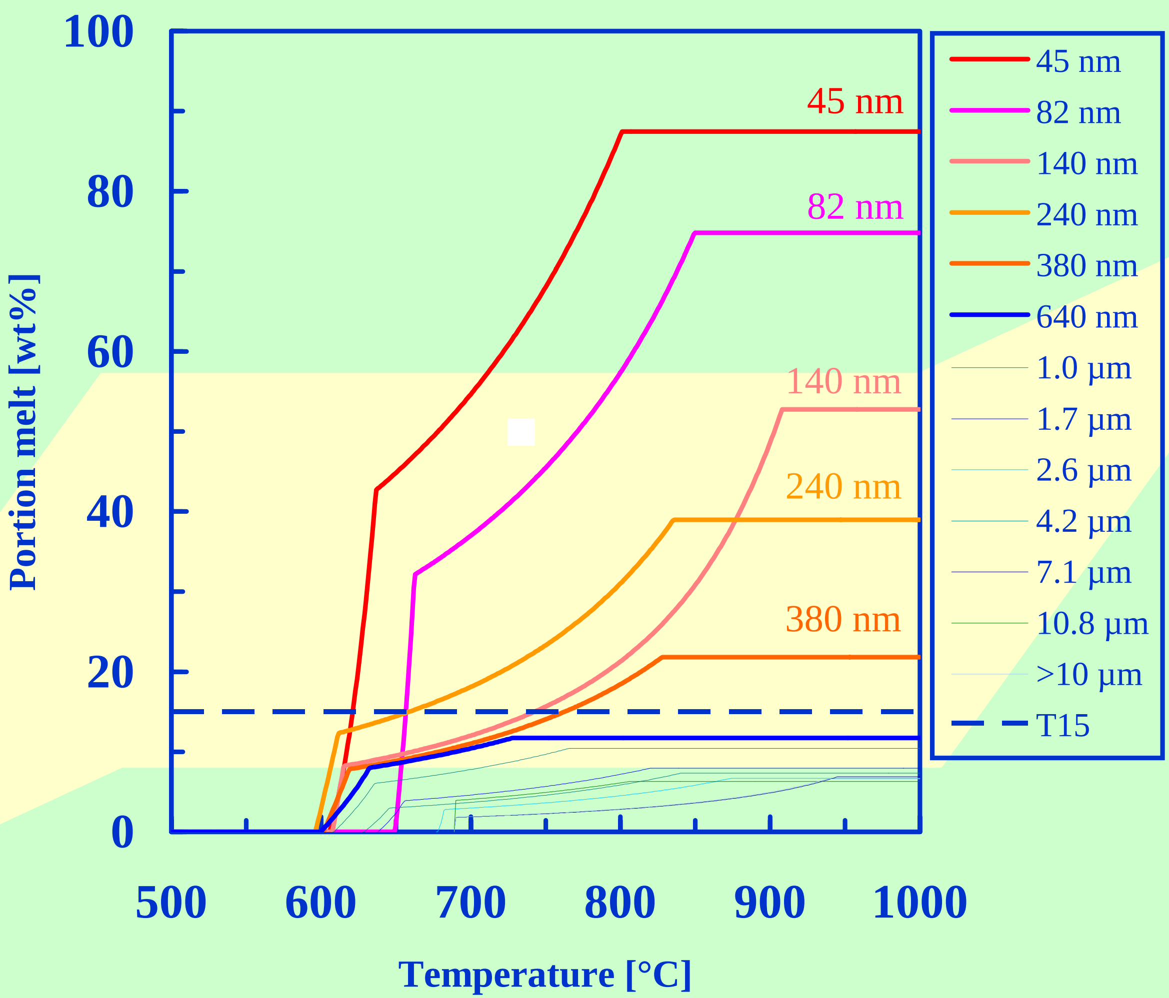
Melting curves of impactor samples

Biomass combustion, BFBC



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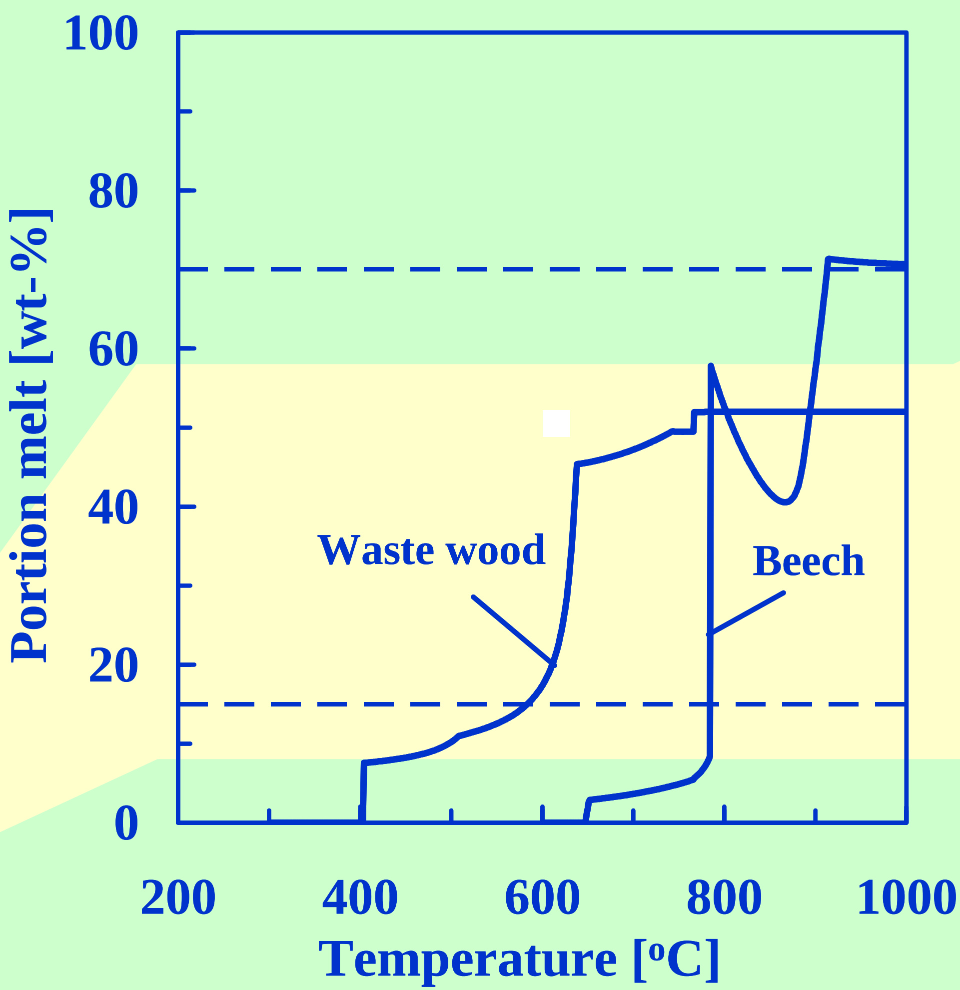
Melting curves of coarse ash

Grate biomass firing



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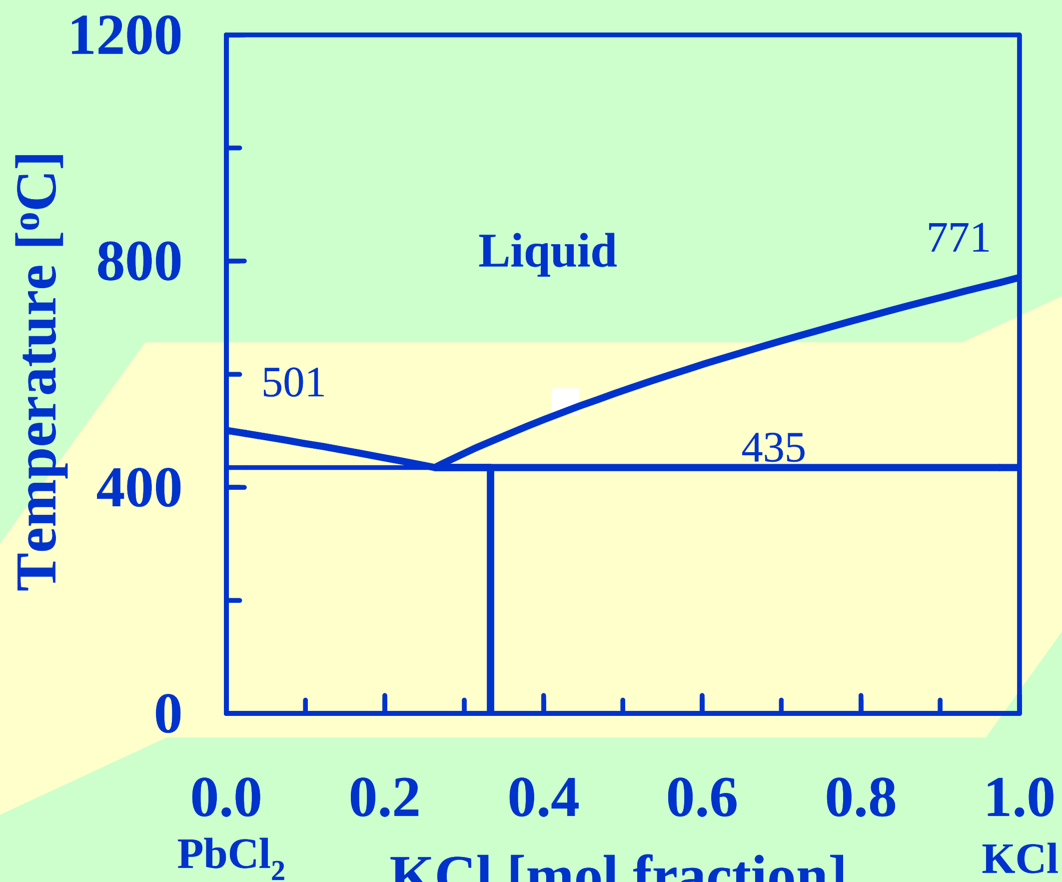
INFLUENCE OF LEAD AND ZINC

- **Alkali chlorides + Pb and Zn**
- **Biomass grate firing**
- **Calculated cases**

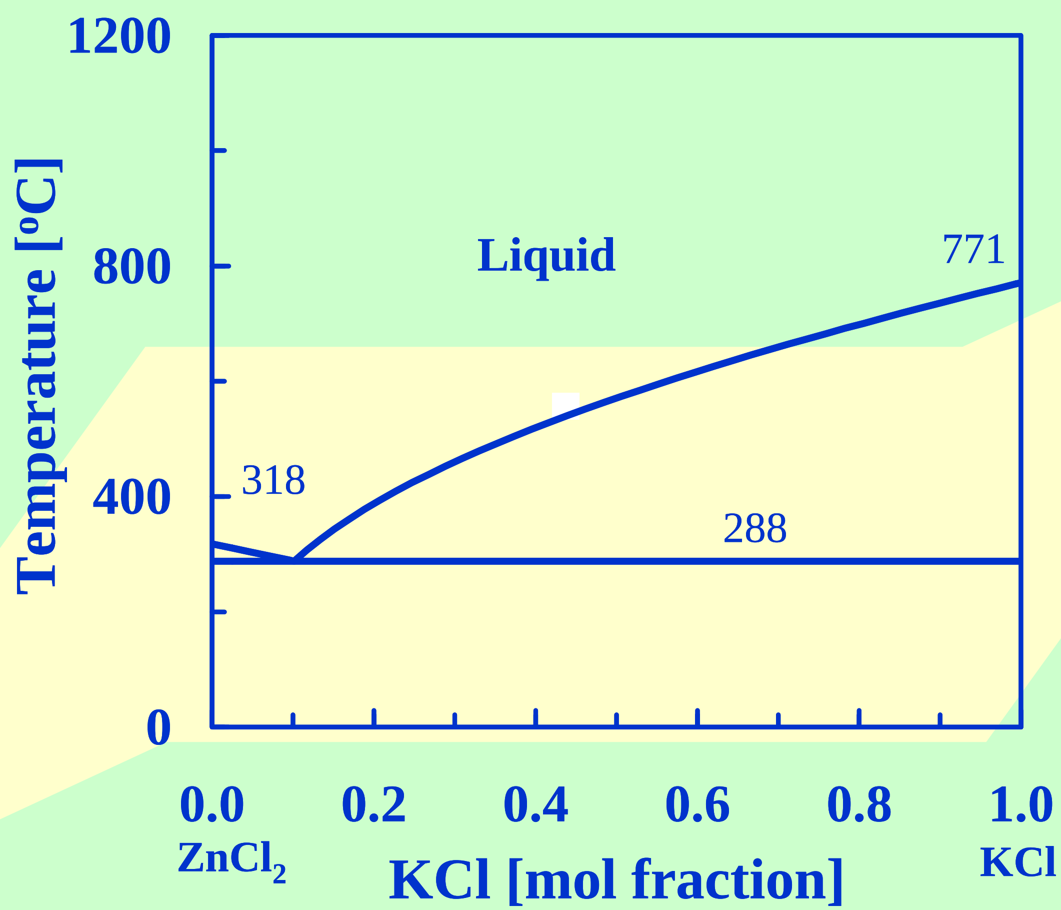
Calculated phase diagram KCl-$PbCl_2$

ÅAU-model



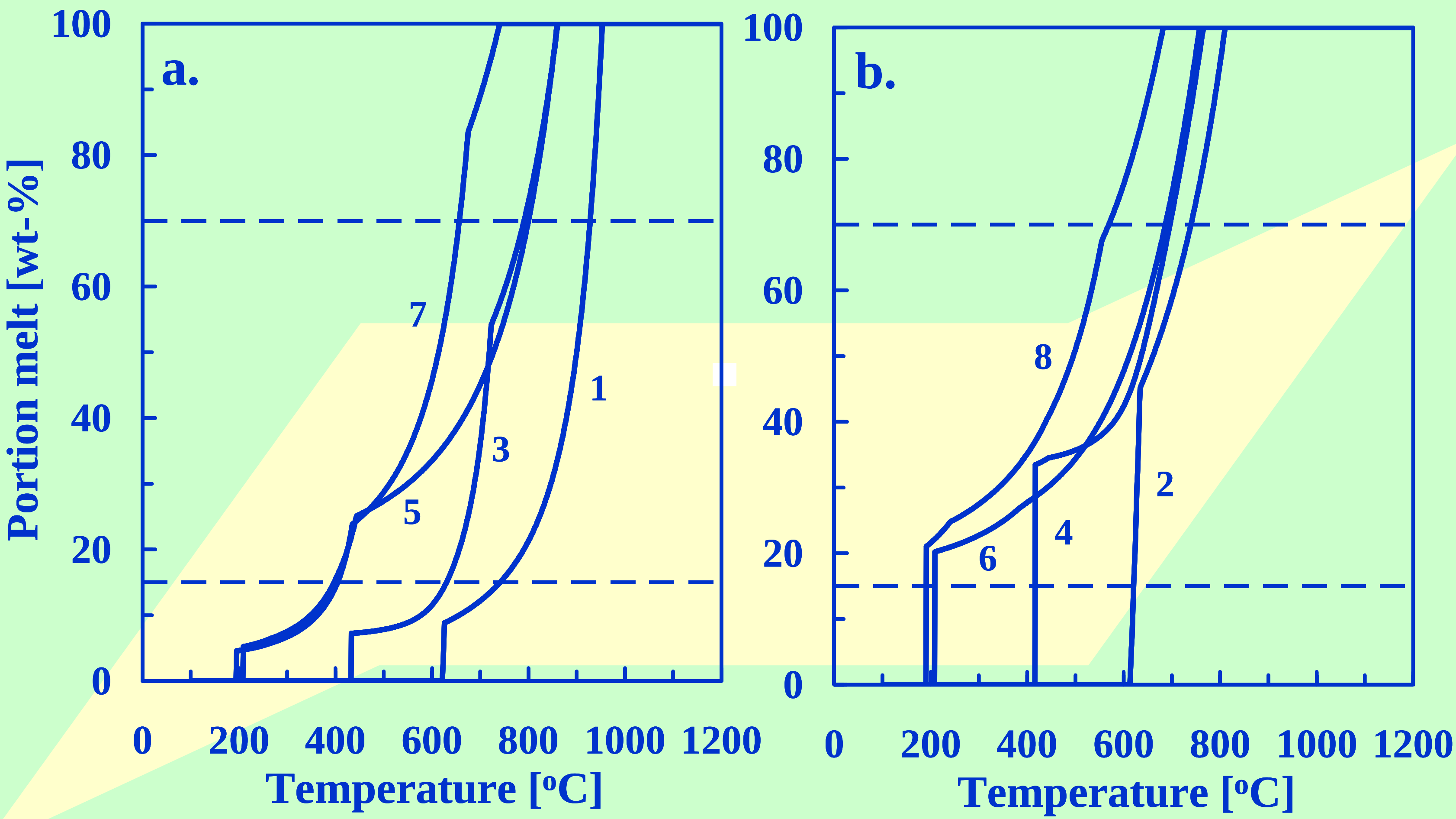
Calculated phase diagram KCl-$ZnCl_2$

ÅAU-model



Calculated melting curves for condensing fume

with Pb and Zn. a) low Cl, b) high Cl



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Calculated cases for condensing fume

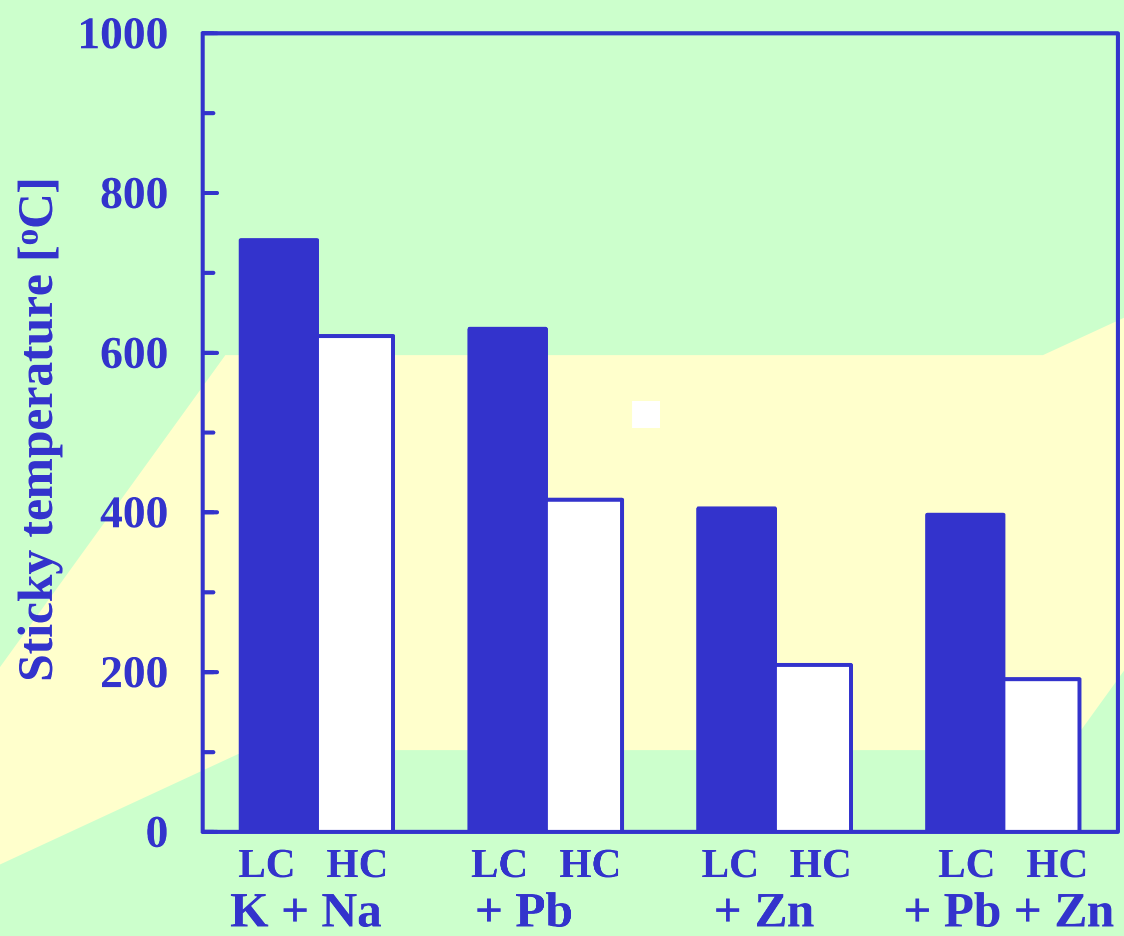
with Pb and Zn

Case #	Cl_2/A(* m/m	Na_2/A m/m	Pb/A m/m	Zn/A m/m
1	5	20	0	0
2	25	20	0	0
3	5	20	20	0
4	25	20	20	0
5	5	20	0	20
6	25	20	0	20
7	5	20	20	20
8	25	20	20	20

') A = K_2 + Na_2 + Pb + Zn = Cl_2 + SO_4 mol

Sticky temperature dependency of Pb and Zn

LC: low chloride, HC: high chloride



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CONCLUSIONS

- **Melting properties of ash fractions affect deposit formation and growth**
- **Melting properties can be estimated if chemical composition is known**
- **Composition can be estimated based on thermodynamic considerations**
- **Stickiness strongly dependent of composition**
- **Ratio Cl/S critical for alkali fume melting $\longrightarrow$ $T_0 \approx 550^{o}C$**
- **Presence of lead and zinc in alkali fume can decrease T_0 to $200^{o}C$**

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