RecoPhos

Thermodynamics of phosphorus recovery

GTT Workshop 2015

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www.RecoPhos.org

InsPyro

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InsPyro – inspiring metallurgy

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KU Leuven spin-off (2009)
Founded and run by PhD's
B2B consultancy company

- Process development and improvement through:
  - Modelling and literature
  - Experiments
  - Characterization
  - Industrial experience
- Industries:
  - recycling incl. batteries and residues
  - non-ferrous metallurgy (lead-zinc)
  - steel, cast iron and ferro-alloys
- www.inspyro.be

InduCarb "thin film" reactor

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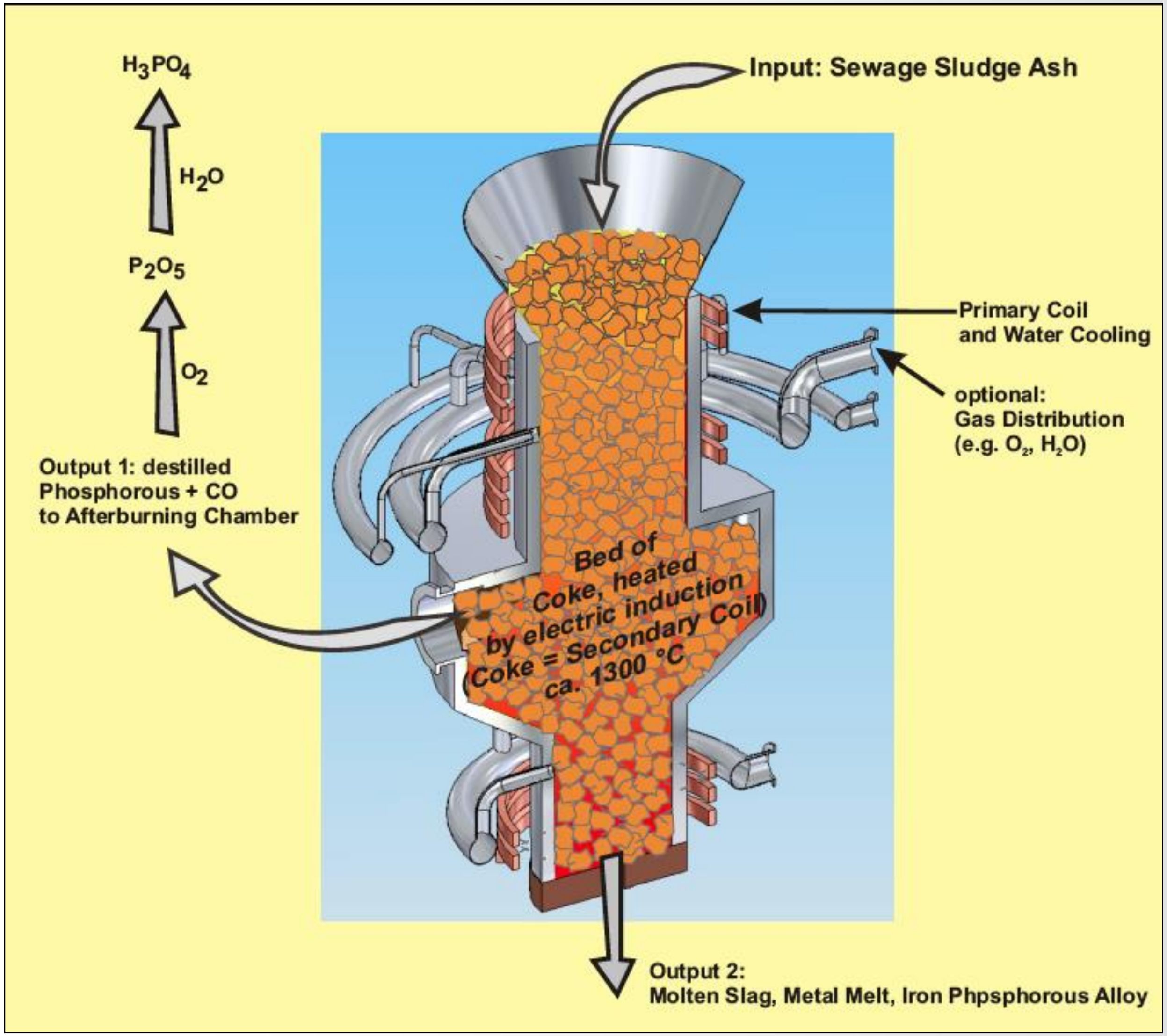

Demo reactor

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Phosphorus thermodynamics

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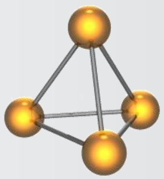
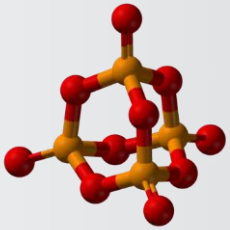
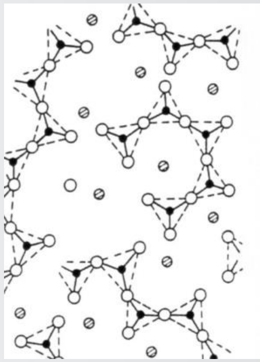
To understand the RecoPhos process, we need to know the behaviour of P in all phases:

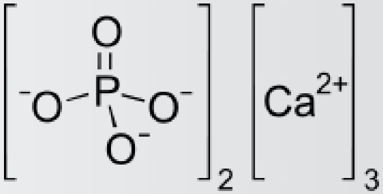
- Gas
  - $P_{4\ (g)}$, but also $P_{2\ (g)}$, P_4O_{10}, PO_2…
- Metal
  - Fe-P-Si-… liquid, Fe_3P upon cooling
- Slag
  - A network former like SiO_2
  - Strong interactions in phosphate stoichiometry e.g. $Ca_3(PO_4)_2$

The formed equilibrium is a result of activities of P compounds in all 3 phases.









Model for phosphorus in slag

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- State-of-the-art thermodynamic descriptions:
  - Most gas components available
  - Liquid metal phase and intermetallics OK
  - Slag with high P **not available**
- System P_2O_5-CaO-SiO_2-Al_2O_3-FeO-Fe_2O_3 as basic scope
- Need for full model of systems with P_2O_5

Binary interactions and solids

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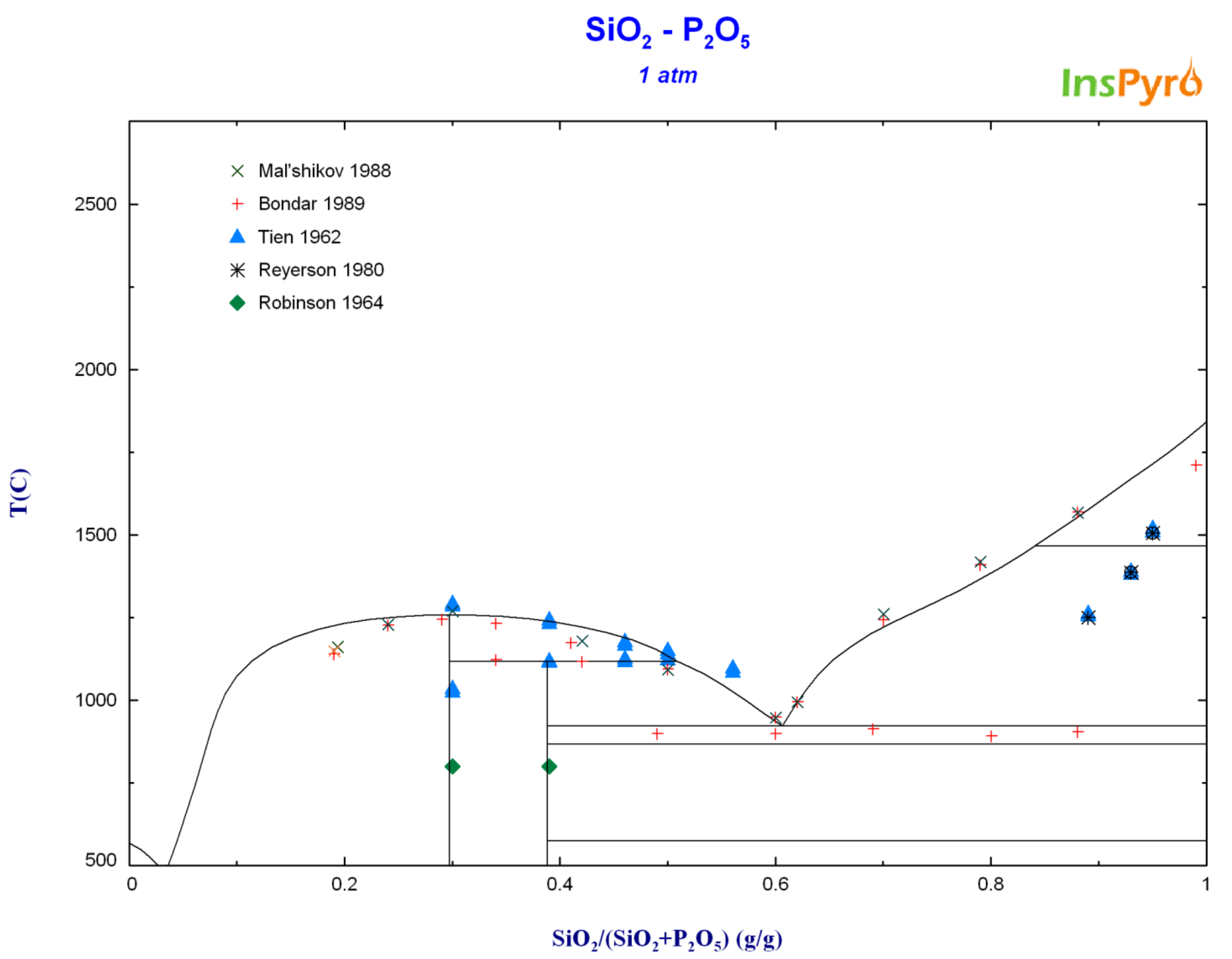
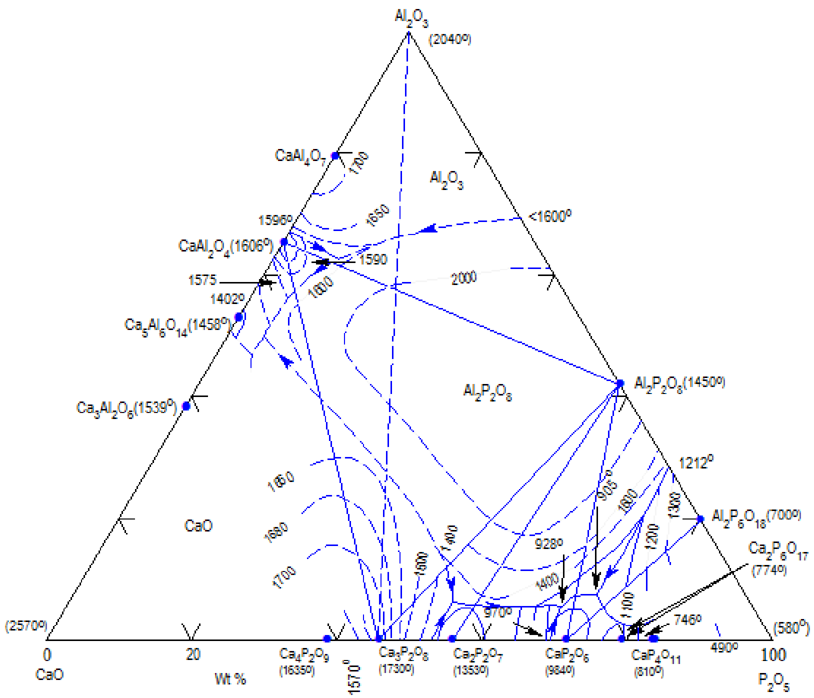
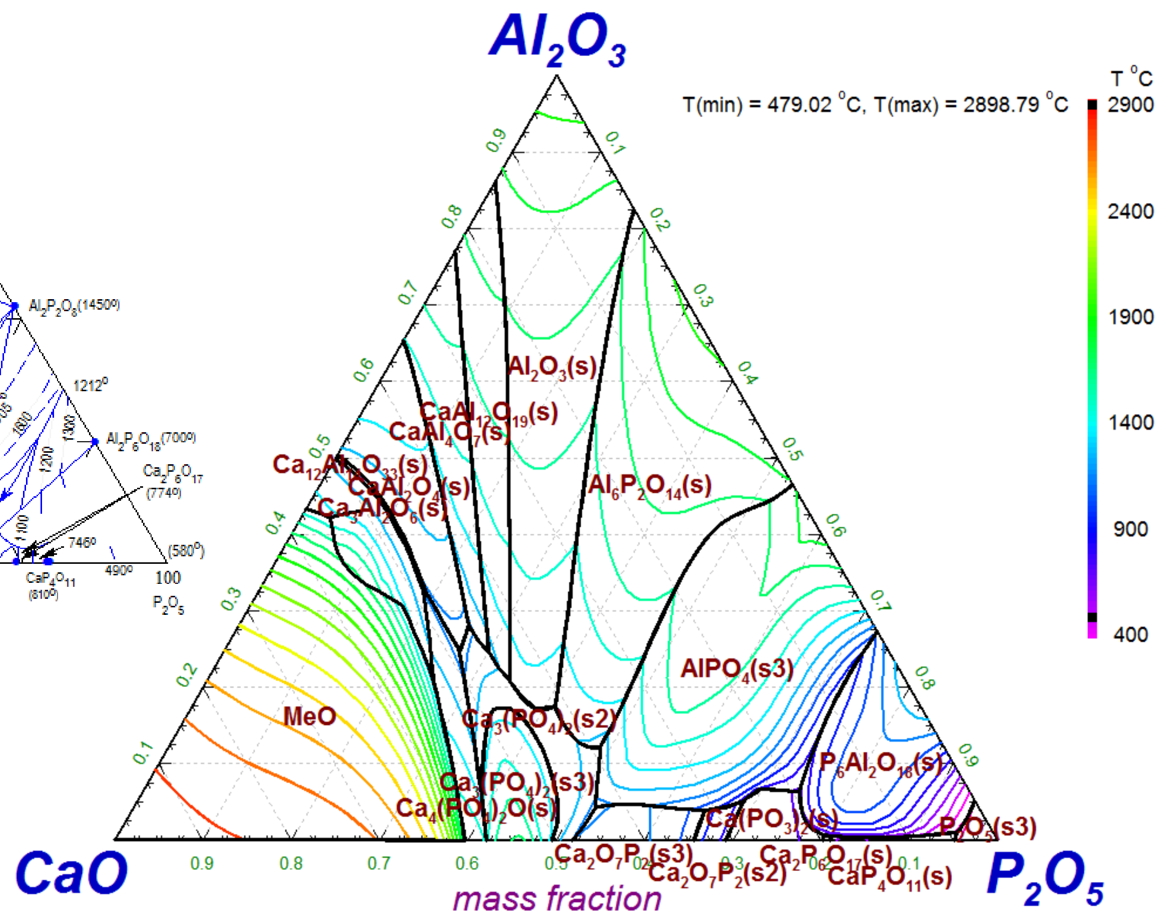


Ternary solution interactions





Equilibrium experiments

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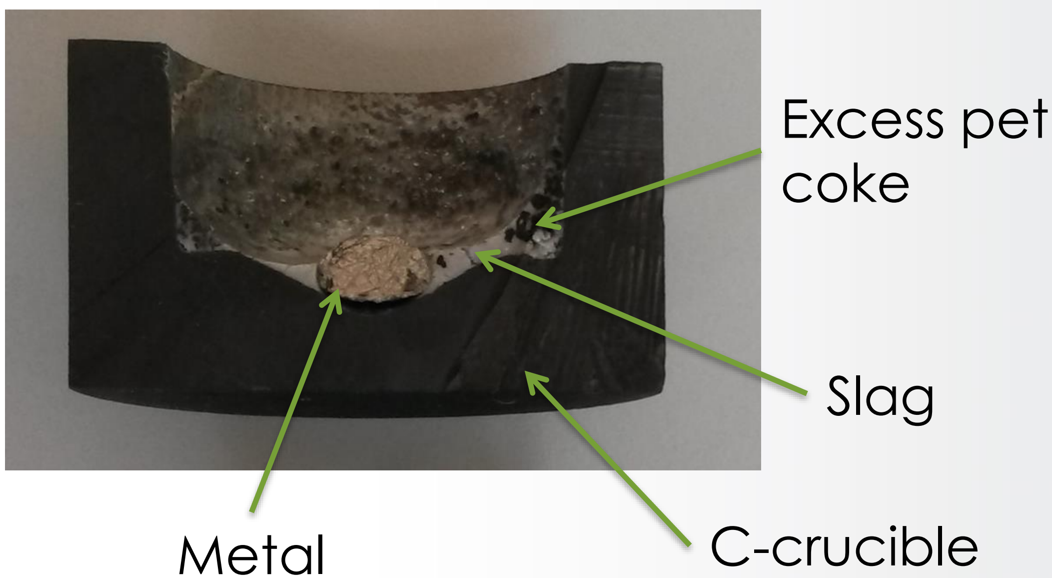
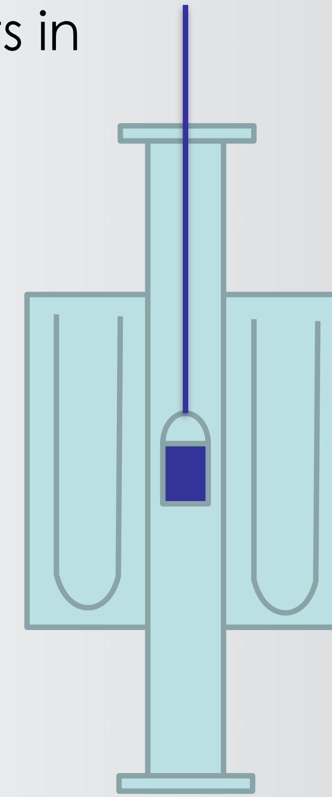
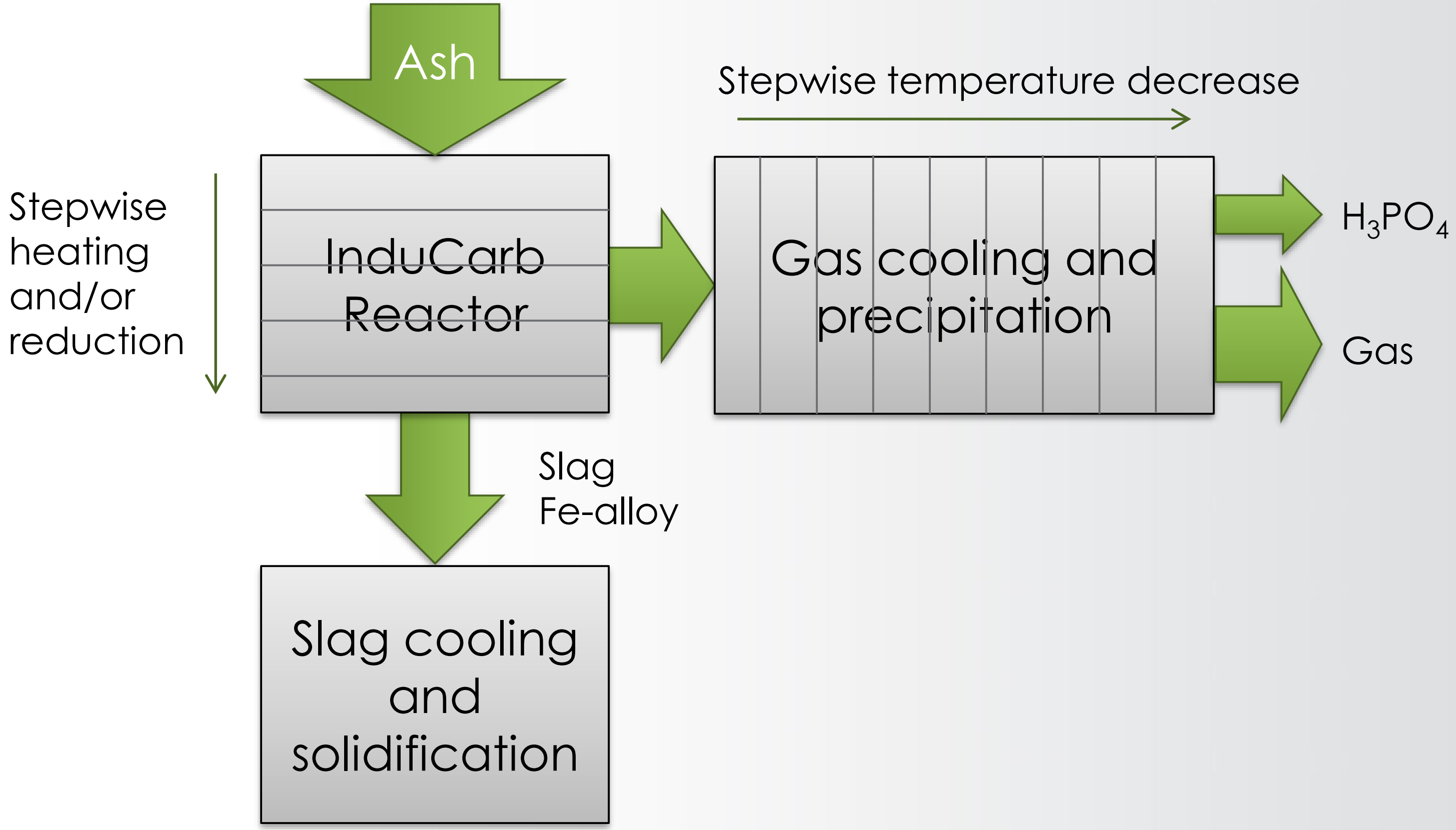
- Goal: provide model validation points in controlled equilibrium stat
- Conditions: Ar, 1400-1600°C, 4h
- Fluxing with SiO_2 and CaO
- Carbon saturation





Process modelling overview

- Macroscopic process model
- Different equilibrium steps



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InduCarb fuming model

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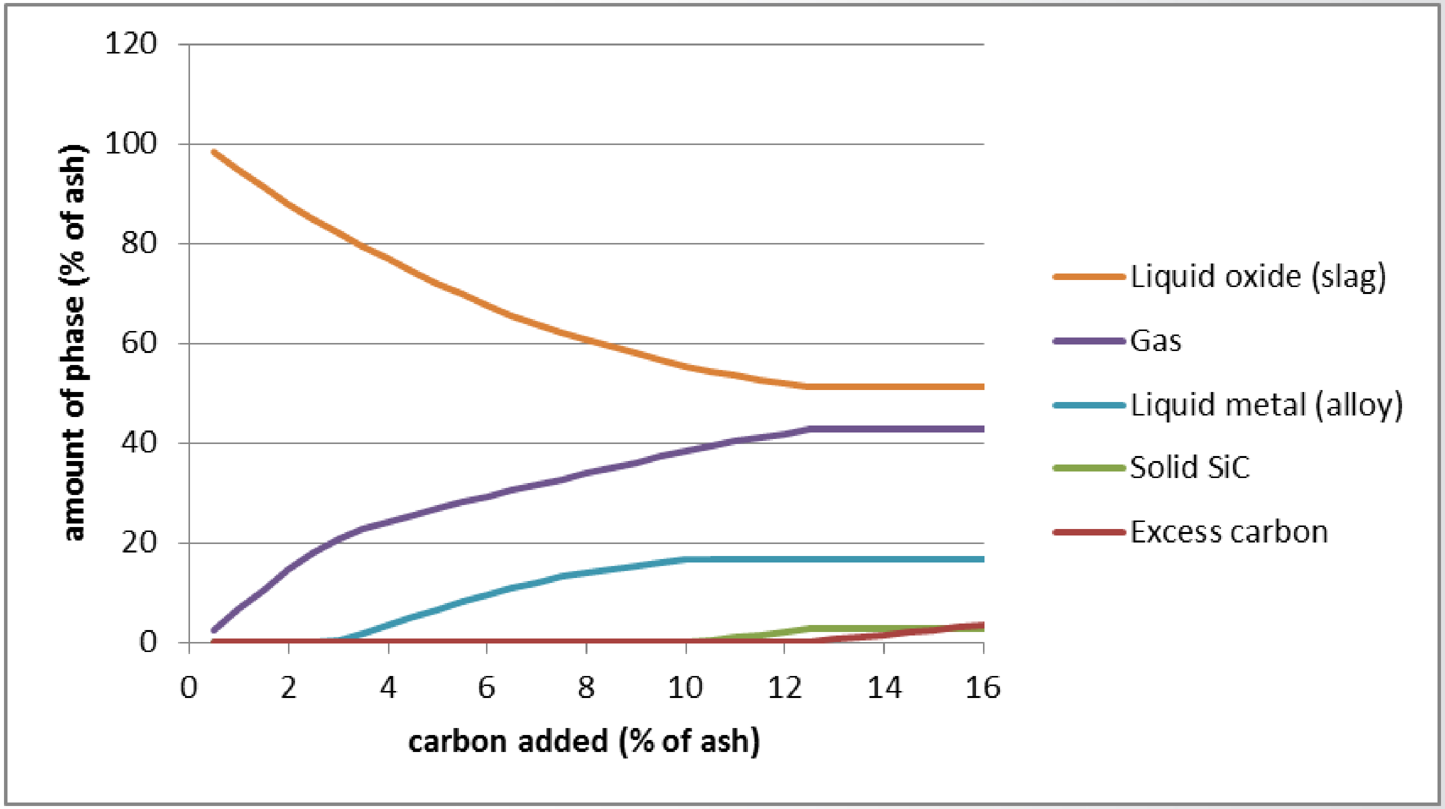
- Fuming model predicts phases and compositions as a function of reduction



Open system model

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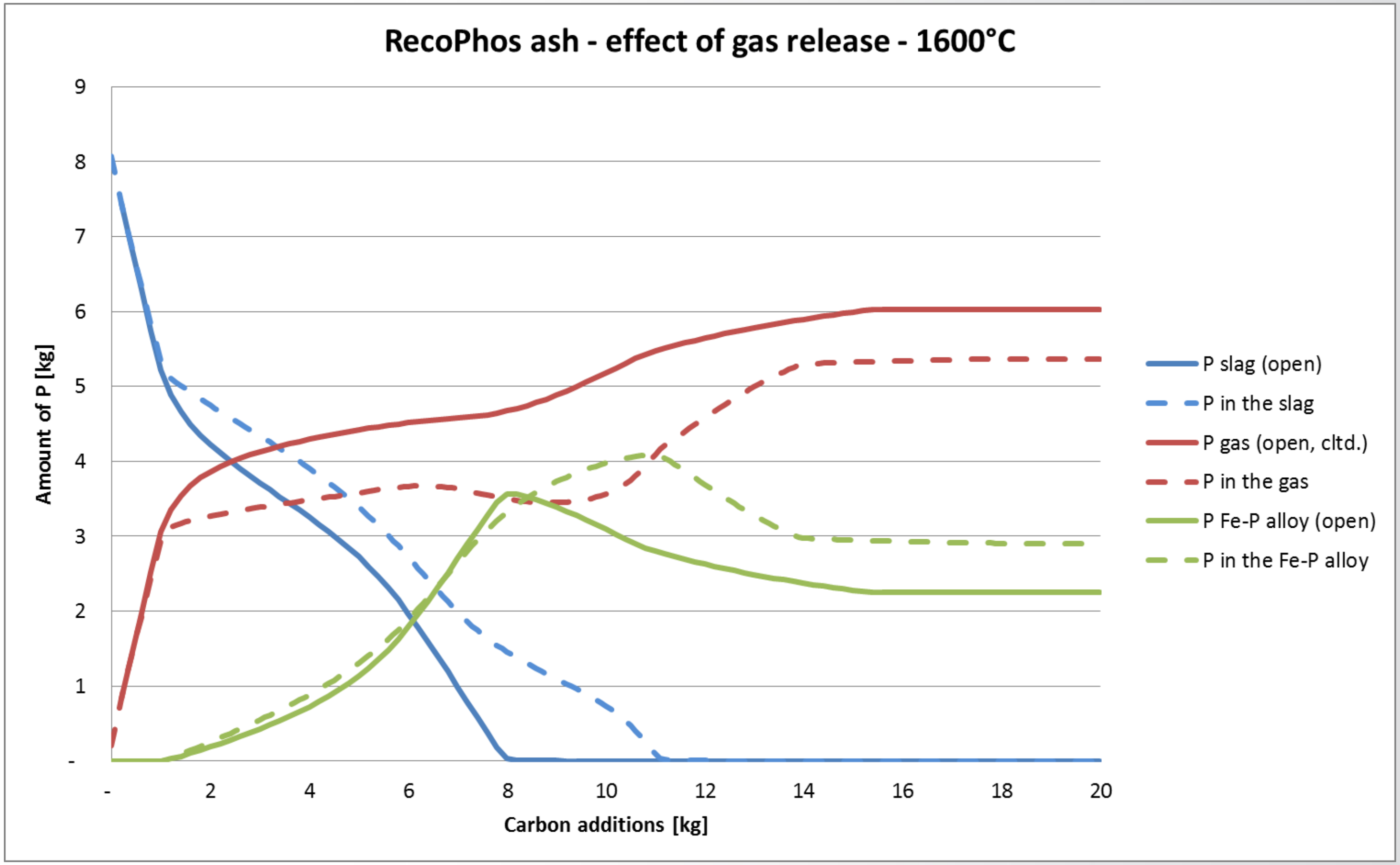
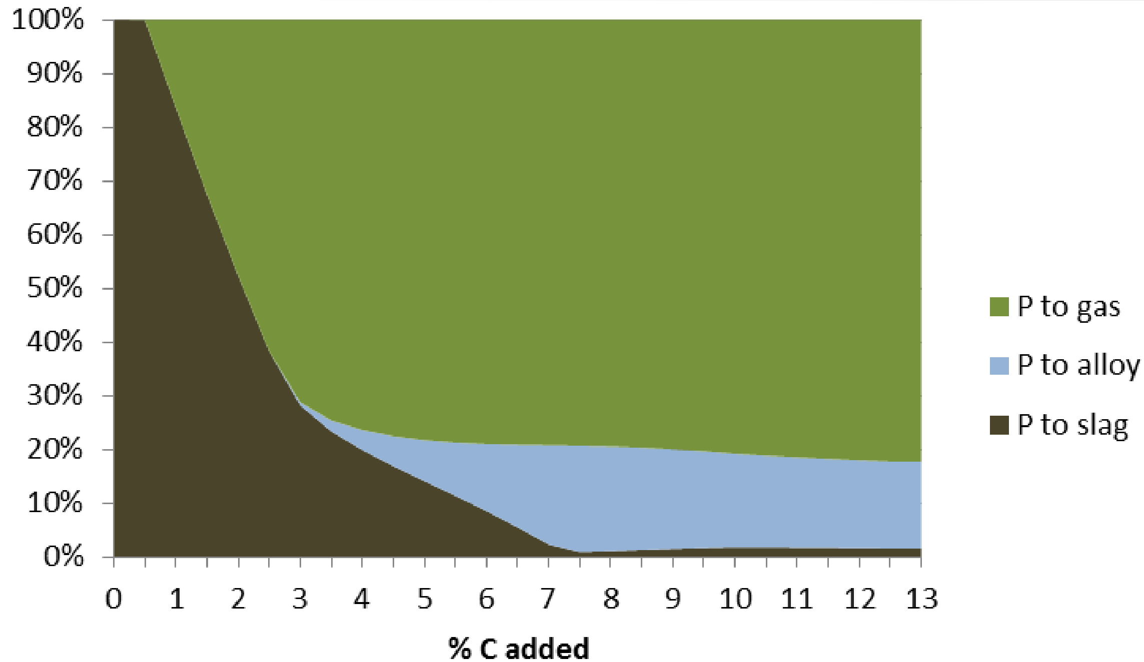


P yield and distribution

- The effect of reduction degree, basicity and temperature on the behaviour of phosphorus be can precisely studied



Phosphorus distribution as a function of reduction degree

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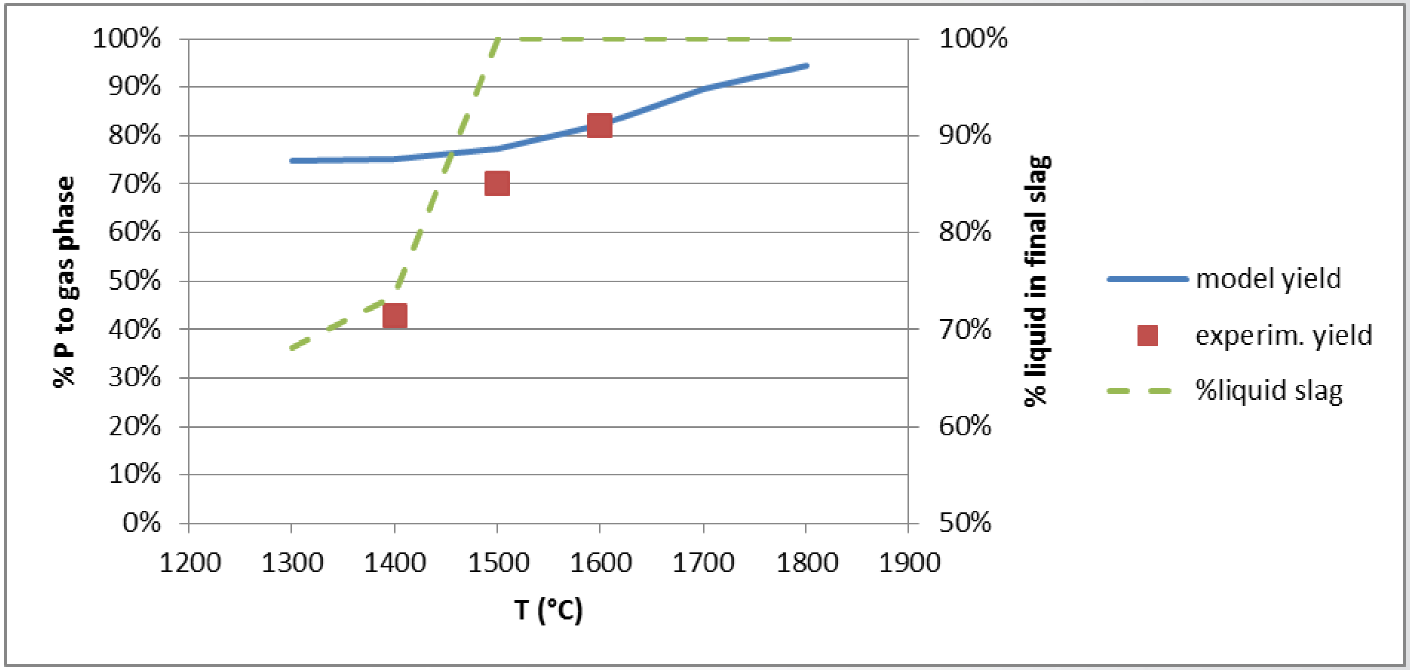
Model-experiment comparison

- Temperature effect:
  - Good agreement at high T (extrapolation)
  - Lower temperature lowers P yield
  - Quicker decrease in experiments, probably reaction speed, ~ liquid fraction final slag



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Model agreement with demo

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- Demo reactor: number of experiments limited
- Clear influence of basicity:
  - Natural slag is low C/S and highly viscous
  - Reduction and flow can be optimized by fluxing with CaO
  - With better flowability, good agreement with modelled equilibrium
- Even with short residence time, thermodynamic model provides a good framework
  - Composition of all phases in good agreement
  - Mass balance and overall yield

Gas precipitation model

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- Predict precipitation upon cooling
  - Precipitation temperatures allowing thermal design and separation
  - Impurities as phosphates or sulphates
  - Form of P as a function of conditions
- Assume equilibrium or Scheil cooling
  - Enable or disable further reaction of precipitated solids

Slag model

- Predict high temperature behaviour:
  - Viscosity
  - Melting point
  - Solid phases present
  - Starting ash and final slag have different properties!
- Predict solidification and low temperature mineralogy
  - Link to cementitious properties
  - Slag as largest volume product

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Slag model

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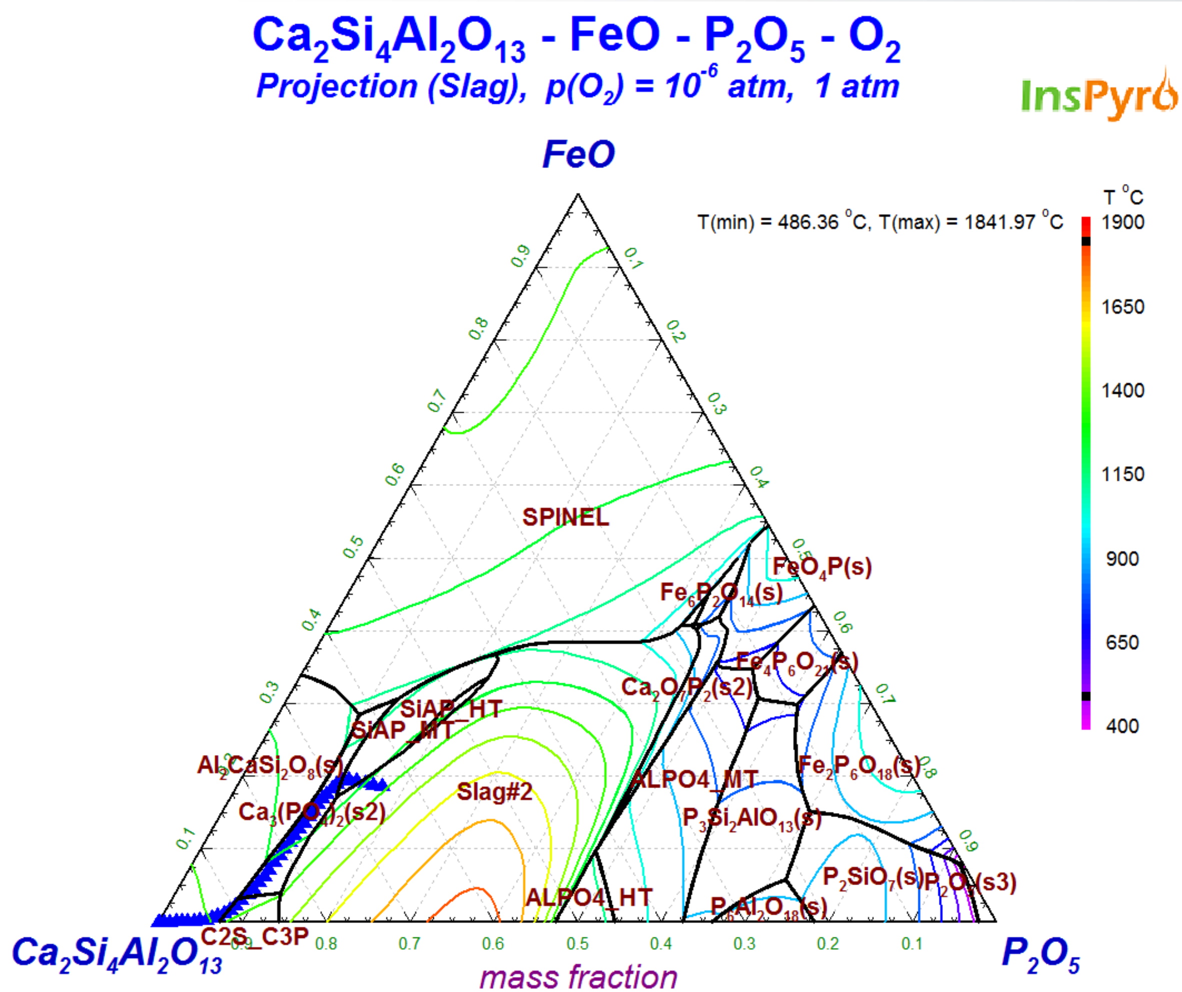
- Evolution of melting point during reduction



Conclusions

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- Recovering P from sewage sludge is possible
- Understanding the chemistry is an essential need for a succesful high temperature process
  - P yield and quality
  - Slag behaviour and quality
  - Expected alloy formation
- The models have shown good agreement with experimental results

Thank you for your attention

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