Multi-faceted Approach to Solving Steelmaking Problems

Industry Needs (Problem formulation)

Scope of Proposed Work (Proposed Research Method)

Multi-scale Modeling (model)

Lab Experiments (data)

Optimization Studies (industry data/parameters)

Industrial Trials/Validation (process, product)
Modeling tools for steel processes

Thermodynamic
- FACTSAGE

Phase equilibrium
- Solidification
- Refining
- Inclusion chemistry

Molten steel flow
- Energy
- Multi-phases
- Inclusion flotation

Macro-kinetics
- Mass balances
- Process analysis
- Process design

CFD
- FLUENT

Process simulator
- METSIM

- Liquid (equilibrium)
- Liquid (Scheil model)
- Cr in liquid (equilibrium)
- Cr in liquid (Scheil model)
Experimental

Automated SEM/EDS ASPEX Analysis

 Levitation melting

Metal casting lab with 200 lb IF

Mechanical tests

10 LB VIF

Thermal simulator
1. New Continuous Steelmaking

Lab experiments + Industrial measurements = Process design

CFD FLUENT + METSIM = Process parameters

Energy Savings:
- less time and less heating in EAF
- no tapping into colder ladle
- no transport
- no holding

- modified Consteel® EAF
  steel mass = 55 t
  main functions:
  melt, heat, de-C, de-P

- Oxidizer
  steel mass = 27 t
  main functions:
  de-C, de-P, de-O,
  float inclusions, homogenize

- Flusher
  steel mass = 23.5 t
  main functions:
  alloy, de-S,
  float inclusions, homogenize

- Reducer
  steel mass = 27 t
  main functions:
  de-O, de-S, alloy
  float inclusions, homogenize

- Tundish

- Transport & sitting on turret

- Tap & transport

- LMF refining

- 3-step refining

- 3-step refining

- 3-step refining

- 3-step refining

- 3-step refining
2. Cleanliness of cast steel

**FACTSAGE**

**CFD FLUENT**

**Improved Properties**

\[
y = -14199x + 28.439
\]

\[
R^2 = 0.9597
\]

**Lab/Industrial Experiments**

**Industrial trials**

**SEM/EDX ASPEX**

**Modeling**

Inclusions formed, weight %

Ca additive, weight %

Charpy Impact Test Values (ft-lbs)

\[
y = -14199x + 28.439
\]

\[
R^2 = 0.9597
\]

Fraction of Inclusions

Fraction of Area Covered by Inclusions
3. Vacuum Tank Degassing

Industrial measurements and model verification

- Overall Average
- Zone 0
- Zone 4
- Zone 1
- Zone 5b

- FACTSAGE: Thermodynamics
- FLUENT: Fluid Flow
- METSIM: Kinetics
- EXCEL VBA: Operator Usable
4. CO$_2$ sequestration using slag

Experimental kinetics

![Image of slag samples](image)

![Graph showing experimental kinetics](graph)

**Process modeling**

```
  1  2  3  4  5  6  7  8  9  10  11  12  13  14  15
  B  D  E  F  A  C
```

**Process design**

```
  Water in
  Fresh Slag
    \rightarrow \rightarrow
  Reactor 1
    \rightarrow \rightarrow
  Pump
    \rightarrow \rightarrow
  Reactor 2
    \rightarrow \rightarrow
  Water out
  Stabilized Slag
  Lower CO$_2$
  Off-gas
  Cleaned Off-gas
```
5. Energy efficiency of melting steel

**Industrial benchmarking**

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<th>Maximum</th>
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**Industrial measurements**

**Heat balances**

**Modeling**

**Heat transfer Mechanisms**
- Radiation from open stream
- Radiation from open surface
- Conductivity through slag, radiation + Convection from slag
- Melting/Dissolution of Alloys
- Conductivity through lining, convection from lining

**Ladle Operations**
- Tapping from furnace to ladle
- Holding in ladle
- Pouring molds
- Re-ladle and handling
Potential Topics/Areas of Steelmaking Research

• Recycling of materials
  – evaluation / economic models / reclamation

• New raw material development
  – Hi Mn DRI / Reduce C footprint / Post-combustion

• Energy / Environmental / Productivity
  – Yield improvement / slag splashing

• Cleanliness / Quality Issues
  – Steelmaking / Refining / Casting

• Process development
  – Melt→Refine→Alloy→Treat→Cast→Roll→Heat-treat→Test