# Thermal Modelling of Platinum Extraction Process

FINAL REPORT

Steve Dima, Stephanie Dwyer, Catherine Hall, Alice Markham, Johannes Mohasoane, Neville Folkes

MISG 2024 Grad Camp

# Background : What is Platinum?

- Platinum is a rare, noble metal
- Desirable appearance for jewellery, metalwork
- High melting point, high electrical and thermal conduction, catalytic ability desireable for various industry use

[1]

[2]

[3]

# Background : How is platinum obtained?

- South Africa has most of the world's platinum reserves
- After mining, platinum ore must be refined to remove impurities
- Various metal sulphides with similar properties found in platinum ore called the PGM are extracted
- There are multiple extraction methods, we discuss furnace extraction

[4]

# Furnace Extraction

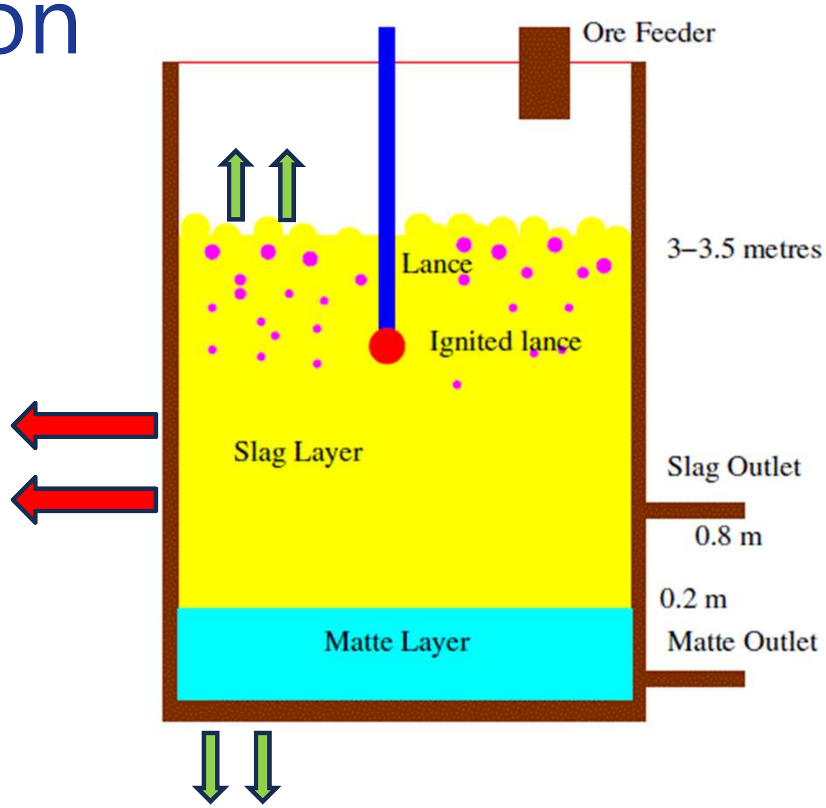



Figure 1: The PGM Furnace: A combustion lance is inserted from the top of the furnace and into the concentrate. This raises the temperature above to about 1,600C; above the melting point of the in-feed to cause smelting .

# Challenges to address

- At high temperatures the slag starts to boil and release various gasses
- The process is violent, so explosions can occur
- We seek to prevent any mis-match between the heat input needed for the process and the heat supplied by the lance
- This imbalance can occur because
  - The in-feed is not continuous, so steady state conditions are not maintained
  - Non-uniformity in the slag layer
  - Fluid dynamic instabilities can occur because there are different bubble production regimes

# Aim and objectives

- Derive a **basic model** to describe the **steady state** of the system
- Assess the effect of **volume** and **temperature** changes
- Create a **coupled system model** of the slag and matte layers
- Investigate further approach

# Model I – Slag Model

$$\frac{d}{dt}\rho_S V_S C_S u_S(t) = \Delta H = H_{S,IN} - H_{S,OUT} \qquad (1)$$

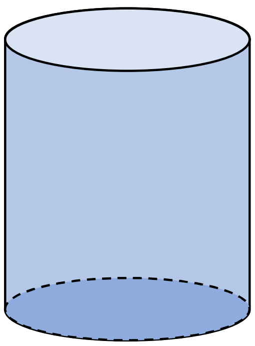
$[\rho] = kg \cdot m^{-3}$ : Density
$[V] = m^3$ : Volume
$[u] = K$ : Temperature
$[C] = J \cdot kg^{-1} \cdot K^{-1}$ : Specific heat
$[H] = J = kg \cdot m^2 \cdot s^{-2}$ : Heat

We assume $\rho, V, C$ and $H_{IN,S}$ are constant with respect to time.

For simplicity we used the notation $u_S = u_S(t)$.

# Model I Assumptions

1) Heat loss through walls of the furnace

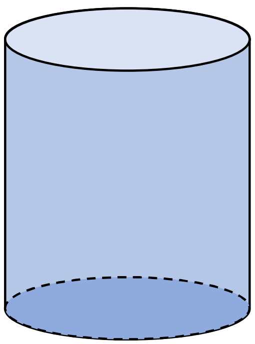


$$H_{OUT,F} = \lambda(u_S - u_F) \cdot A_F$$
$$A_F = 2\pi r(z - z_M)$$

$$[\lambda] = kg \cdot m^{-1} \cdot s^{-2} \cdot K$$

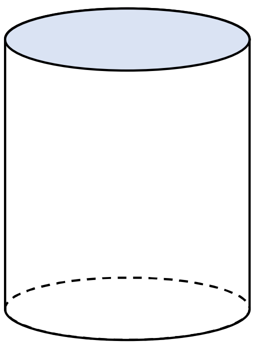
# Model I Assumptions

1) Heat loss through walls of the furnace



$$H_{OUT,F} = \lambda(u_S - u_F) \cdot A_F$$
$$A_F = 2\pi r(z - z_M)$$

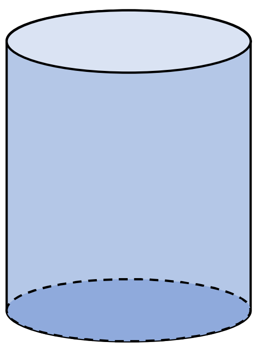
2) Heat loss to air



$$H_{OUT,AIR} = \lambda(u_S - u_{AIR}) \cdot A_{TOP}$$
$$A_{TOP} = \pi r^2$$

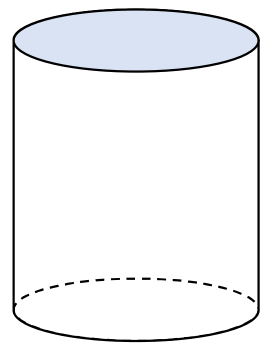
# Model I Assumptions

1) Heat loss through walls of the furnace



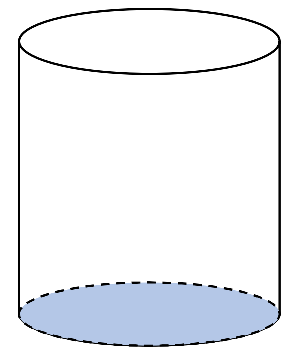
$$H_{OUT,F} = \lambda(u_S - u_F) \cdot A_F$$
$$A_F = 2\pi r(z - z_M)$$

2) Heat loss to air



$$H_{OUT,AIR} = \lambda(u_S - u_{AIR}) \cdot A_{TOP}$$
$$A_{TOP} = \pi r^2$$

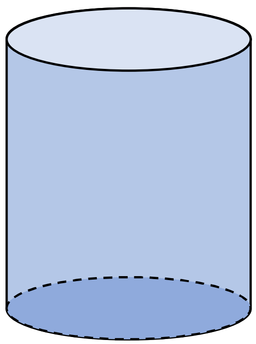
3) Heat loss to matte layer



$$H_{OUT,M} = \mu(u_S - u_M) \cdot A_{BOTTOM}$$
$$A_{BOTTOM} = A_{TOP} = \pi r^2$$

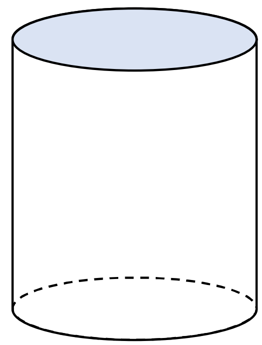
# Model I Assumptions

1) Heat loss through walls of the furnace



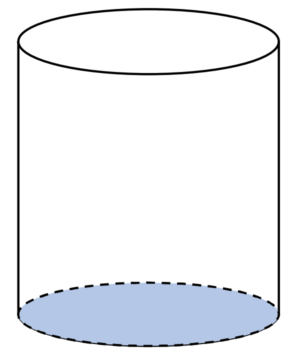
$$H_{OUT,F} = \lambda(u_S - u_F) \cdot A_F$$
$$A_F = 2\pi r(z - z_M)$$

2) Heat loss to air



$$H_{OUT,AIR} = \lambda(u_S - u_{AIR}) \cdot A_{TOP}$$
$$A_{TOP} = \pi r^2$$

3) Heat loss to matte layer



$$H_{OUT,M} = \mu(u_S - u_M) \cdot A_{BOTTOM}$$
$$A_{BOTTOM} = A_{TOP} = \pi r^2$$

$$H_{S,OUT} = H_{OUT,F} + H_{OUT,AIR} + H_{OUT,M}$$
$$= \lambda[(u_S - u_F) \cdot A_W + (u_S - u_{AIR}) \cdot A_{TOP} = +\big(u_S - u_M(t)\big) \cdot A_{BOTTOM}]$$

# Model I Assumptions

From the $H_{S,OUT}$ equation (1) may be written as:

$$\rho_S V_S C_S \cdot \frac{d}{dt} u_S = H_{S,IN} - [\lambda(u_S - u_F) \cdot A_F + \mu(u_S - u_{AIR}) \cdot A_{TOP} + \eta\big(u_S - u_M(t)\big) \cdot A_{TOP}] \qquad (2)$$

$$\frac{d}{dt} u_S = -\lambda \cdot u_S \cdot \frac{(A_F + 2A_{TOP})}{\rho_S V_S C_S} + \frac{H_{S,IN} + (\lambda u_F \cdot A_F + [\mu u_{AIR} + \eta u_M] \cdot A_{TOP})}{\rho_S V_S C_S}$$

# Model I - Scaling

Using the heat loss through walls of the furnace, to the air, and to the matte layer equation (1) becomes:

$$\alpha \frac{du_S}{dt} = -u_S + \tau$$

$$\alpha = \frac{-\lambda \cdot (A_W + 2A_{TOP})}{\rho_S V_S C_S}$$

$$\tau = \frac{H_{S,IN} + (\lambda u_F \cdot A_F + [\mu u_{AIR} + \eta u_M] \cdot A_{TOP})}{\rho_S V_S C_S}$$

# Model I

$$u_S(t) = (u_S(0) - \tau)e^{-\alpha t} + \tau$$

- We now want to examine the relationship between volume and temperature

# Changing volume

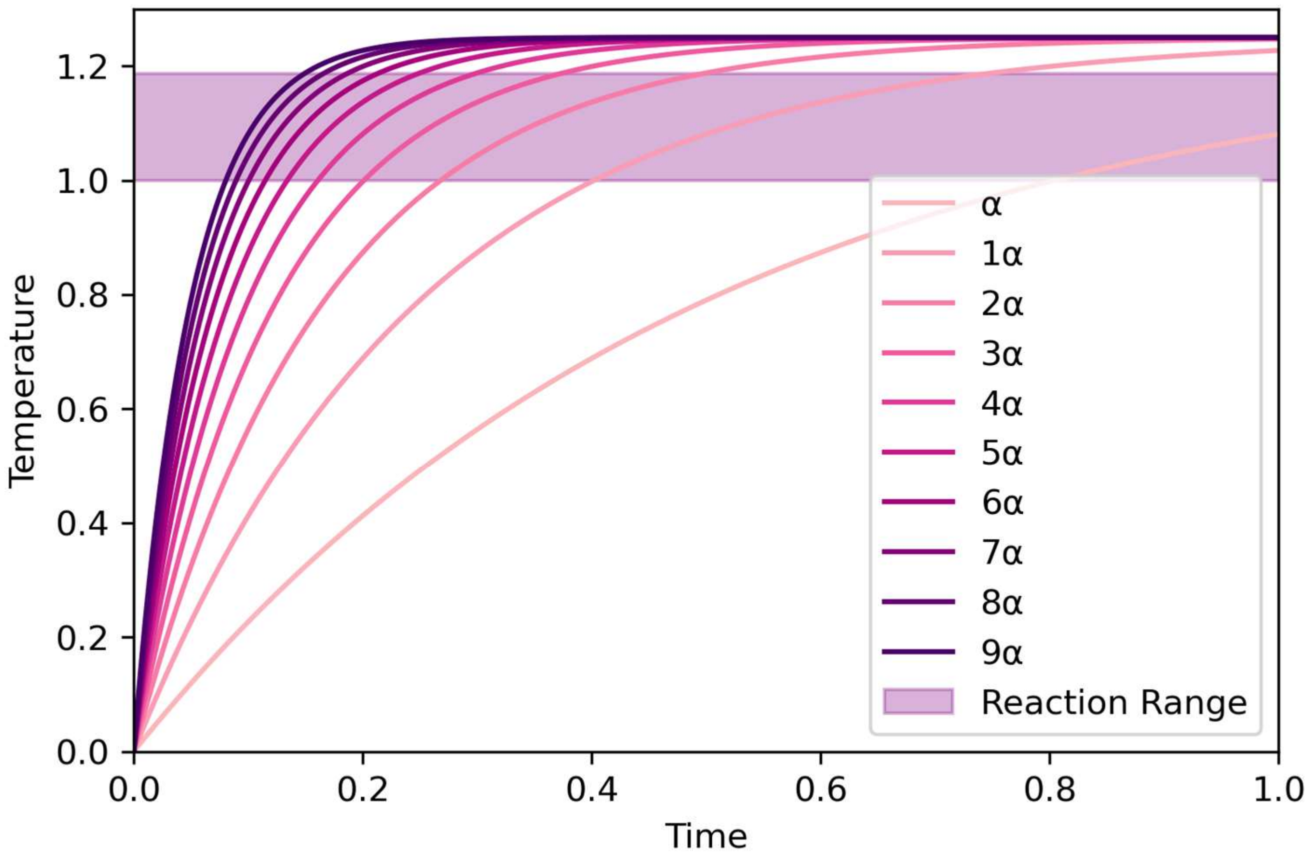



Fig 1a: Temperature profile for increasing volume parameter α

# Changing power input

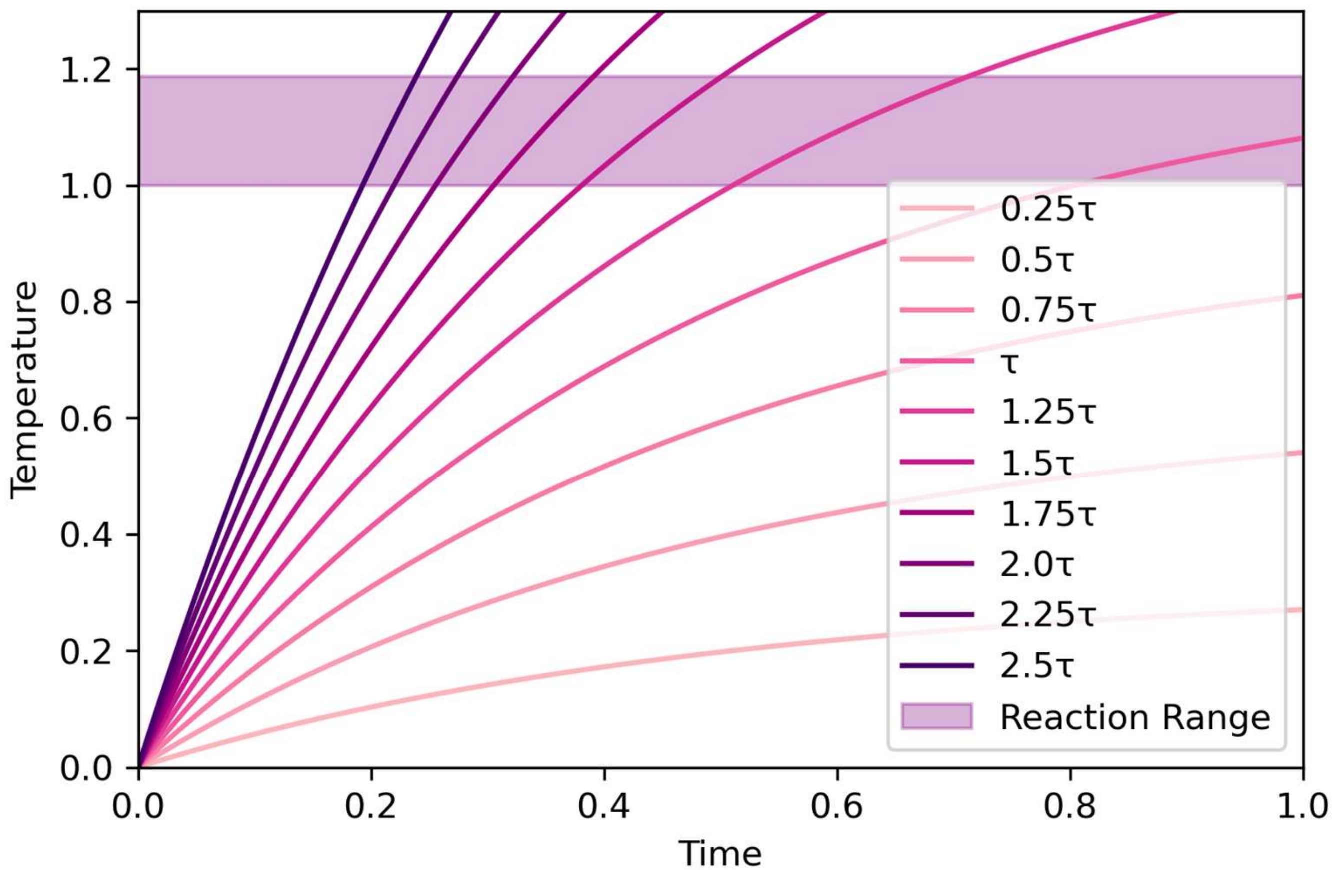



Fig 1b: Temperature profile for increasing steady state temperature τ

# Conservative volume change with lower power input

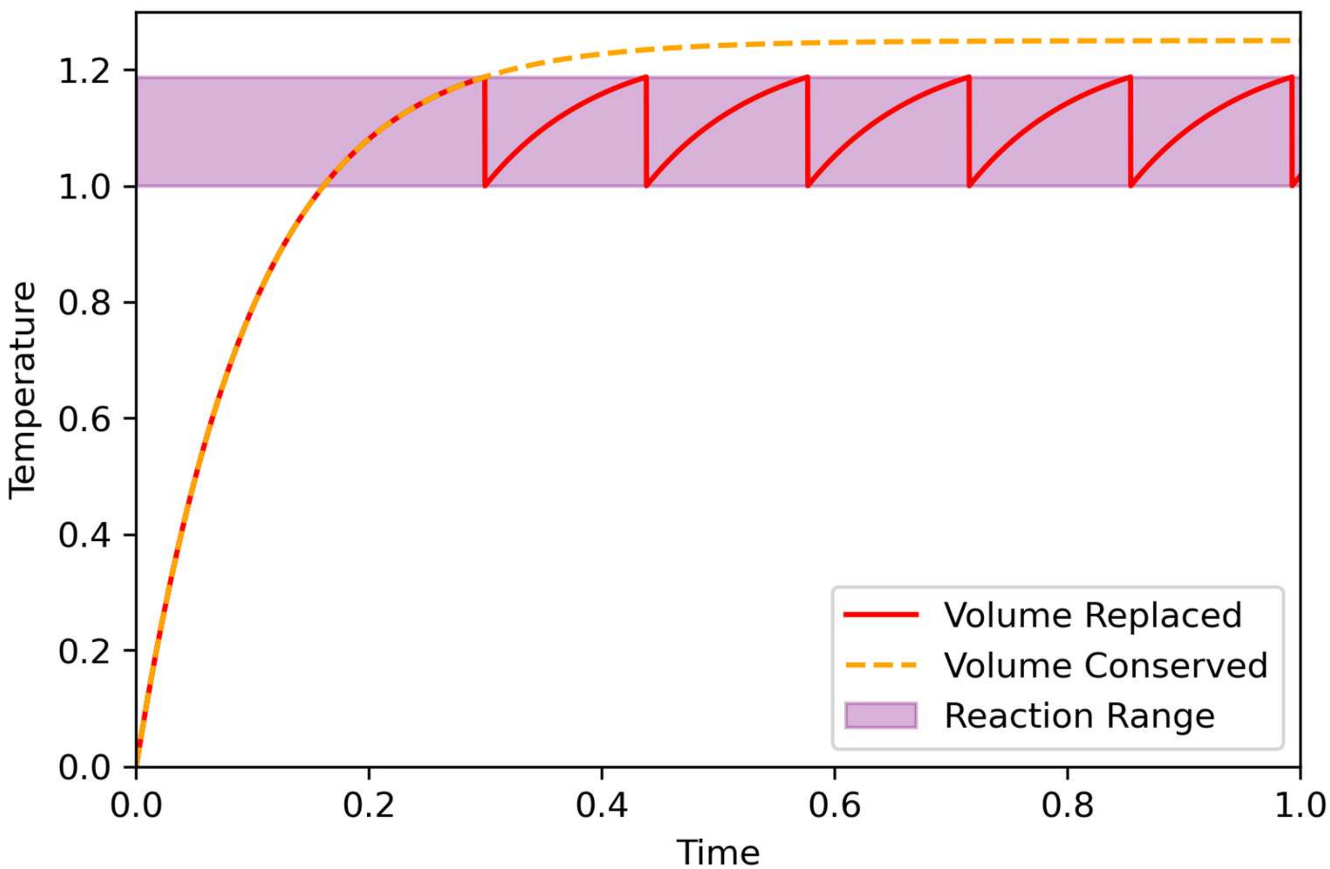



Fig 2: Temperature profile with a 15% instant volume replacement and 2000 $^\circ C$ equilibrium temp

# Volatile volume change with lower power input

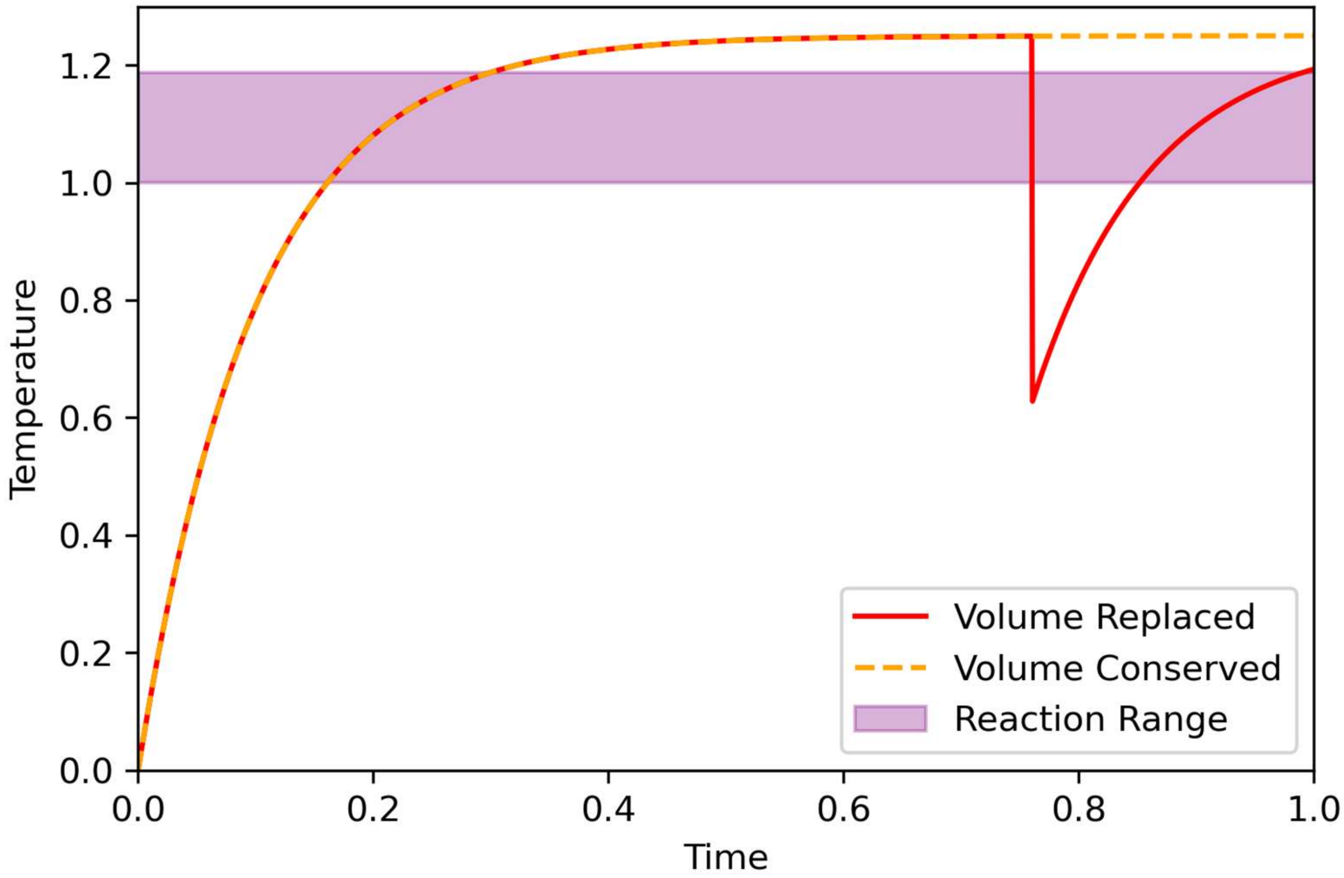



Fig 3: Temperature profile with a 50% instant volume replacement and 2000 $^\circ C$ equilibrium temp

# Conservative volume change with higher power input

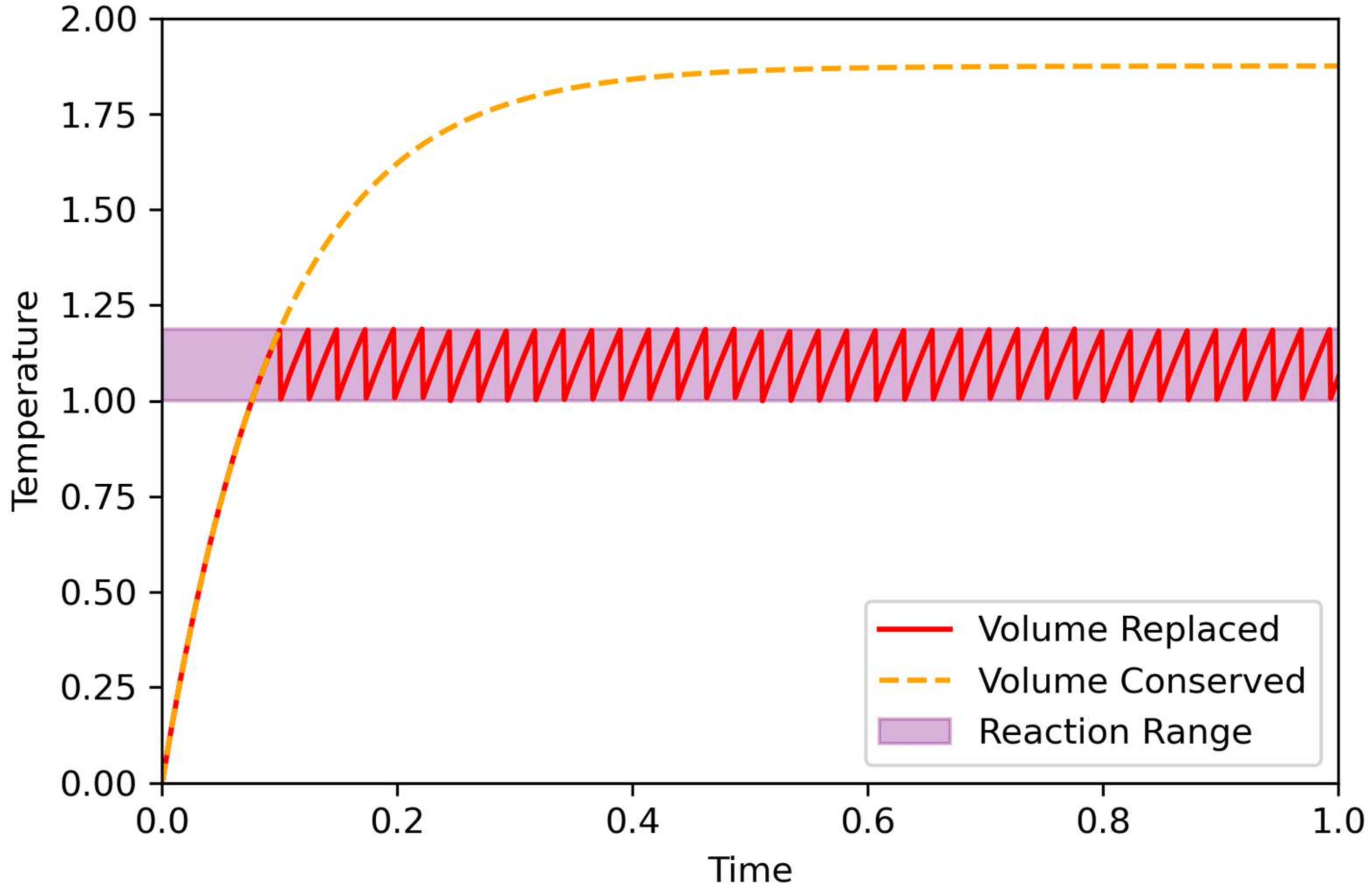



Fig 4: Temperature profile with a 15% instant volume replacement and 3000$^\circ C$ equilibrium temp

# Volatile volume change with higher power input

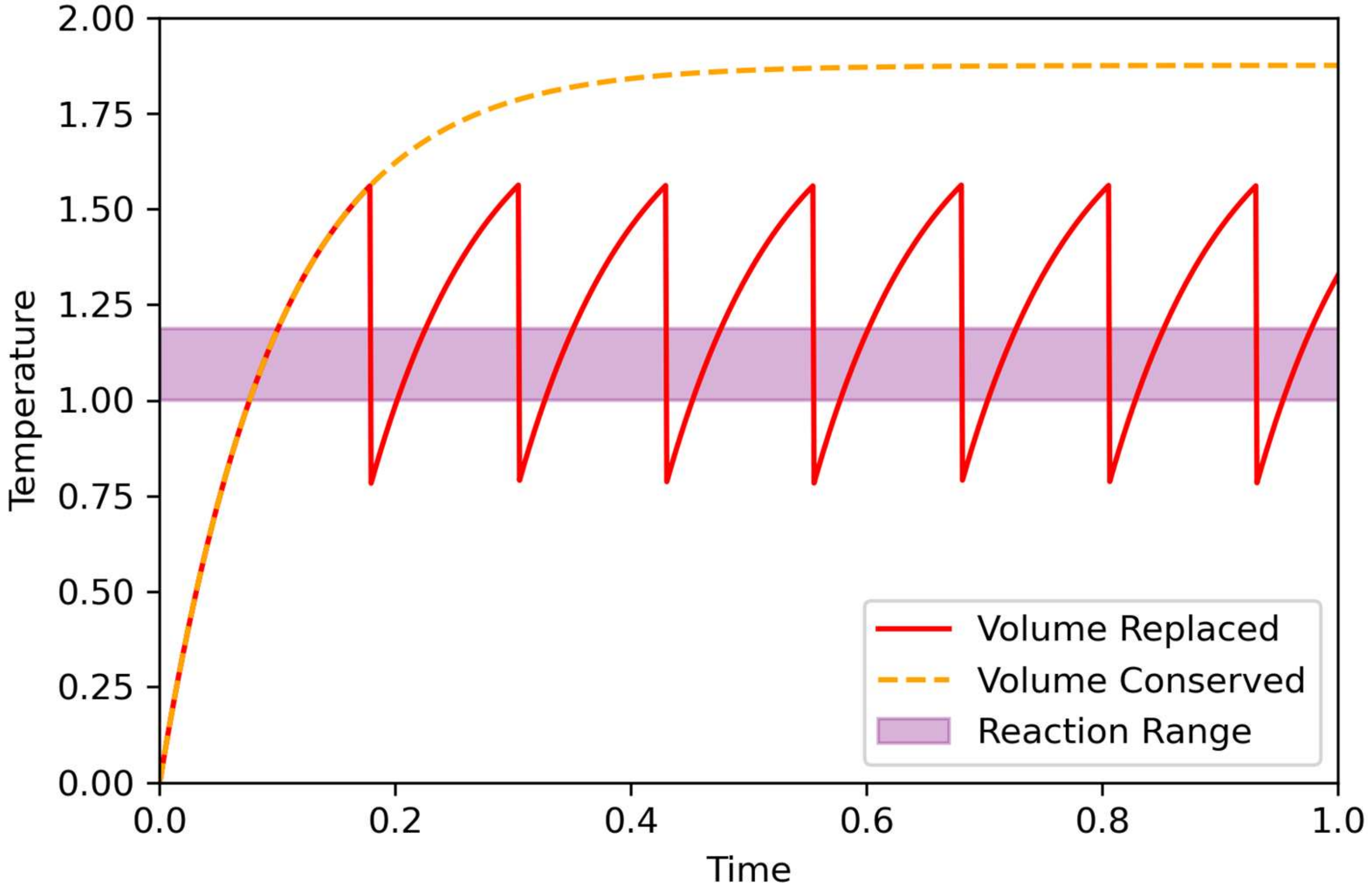
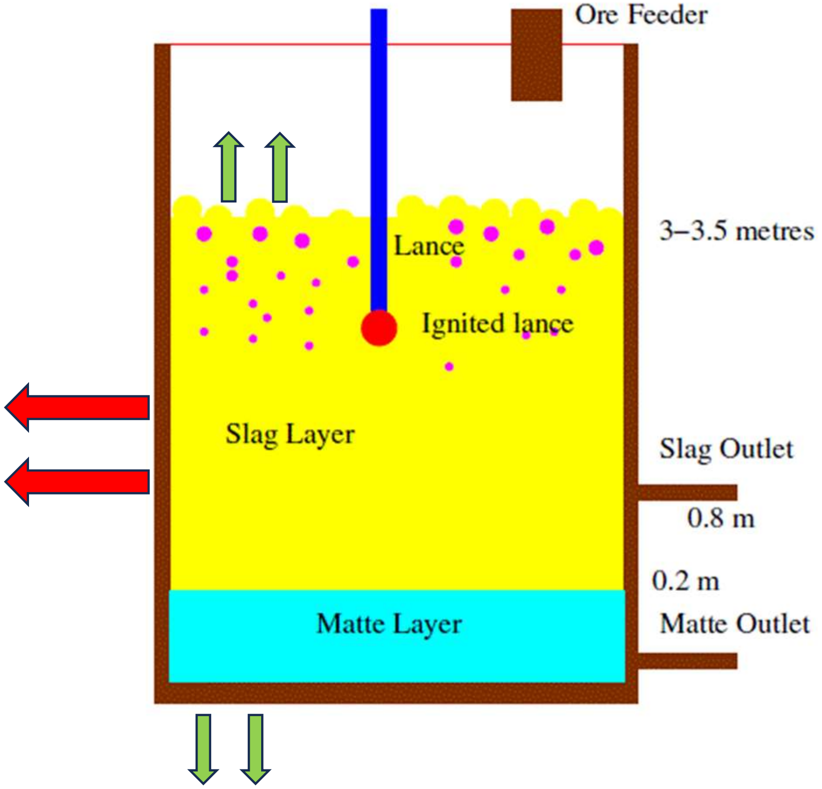


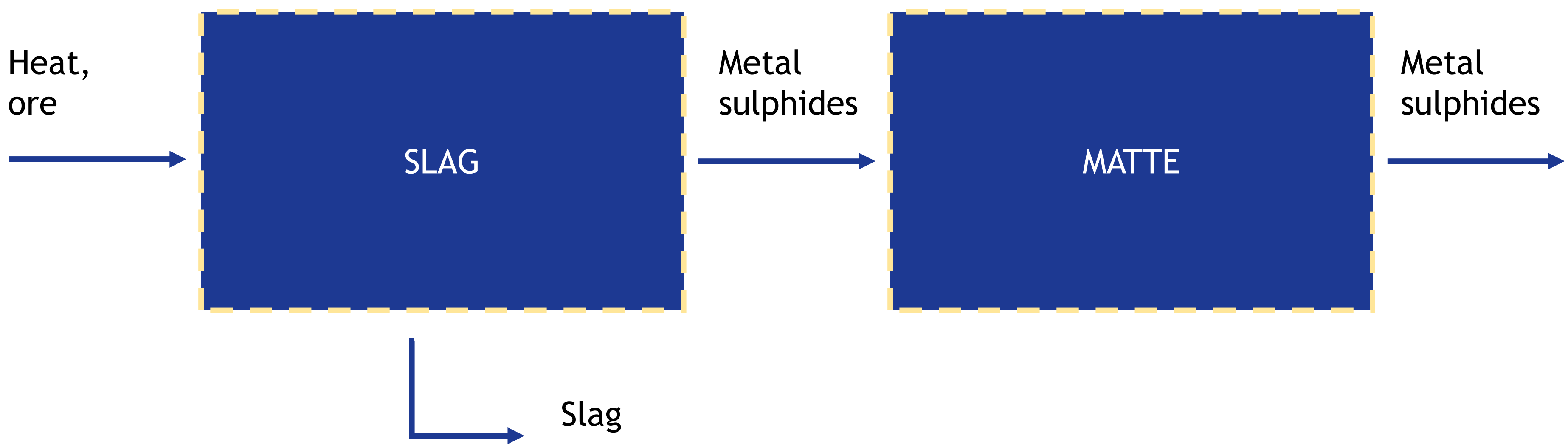

Fig 5: Temperature profile with a 50% instant volume replacement and 3000 $^\circ C$ equilibrium temp

# Model II – Two Compartment System



# Model II – Two Compartment System

- Introduce matte layer of metal sulphides into model



# Model II - Scaling

$$t = t \cdot t' \quad (4)$$

$$T_m = T_w + (T_{1600°C} - T_w)\, T'_m(t') \quad (5)$$

$$T_s = T_w + (T_{1600°C} - T_w) T'_s(t') \quad (6)$$

Using equations 4,5 and 6 in equations 2 and 3 to find the time scale leads to:

$$t_0 = \frac{\rho_s V_s C_s (T_{1600°C} - T_w)}{H_{IN}} \quad (7)$$

$$\frac{du_s'}{dt'} = 1 - \xi u_s' - \varepsilon(u_s' - u_m') \tag{8}$$

$$\xi = \frac{\lambda A_s}{H_{IN}}(T_{1600} - T_w), and\ \varepsilon = \frac{\mu}{H_{IN}} A_{BOTTOM}(T_{1600} - T_w) \tag{9}$$

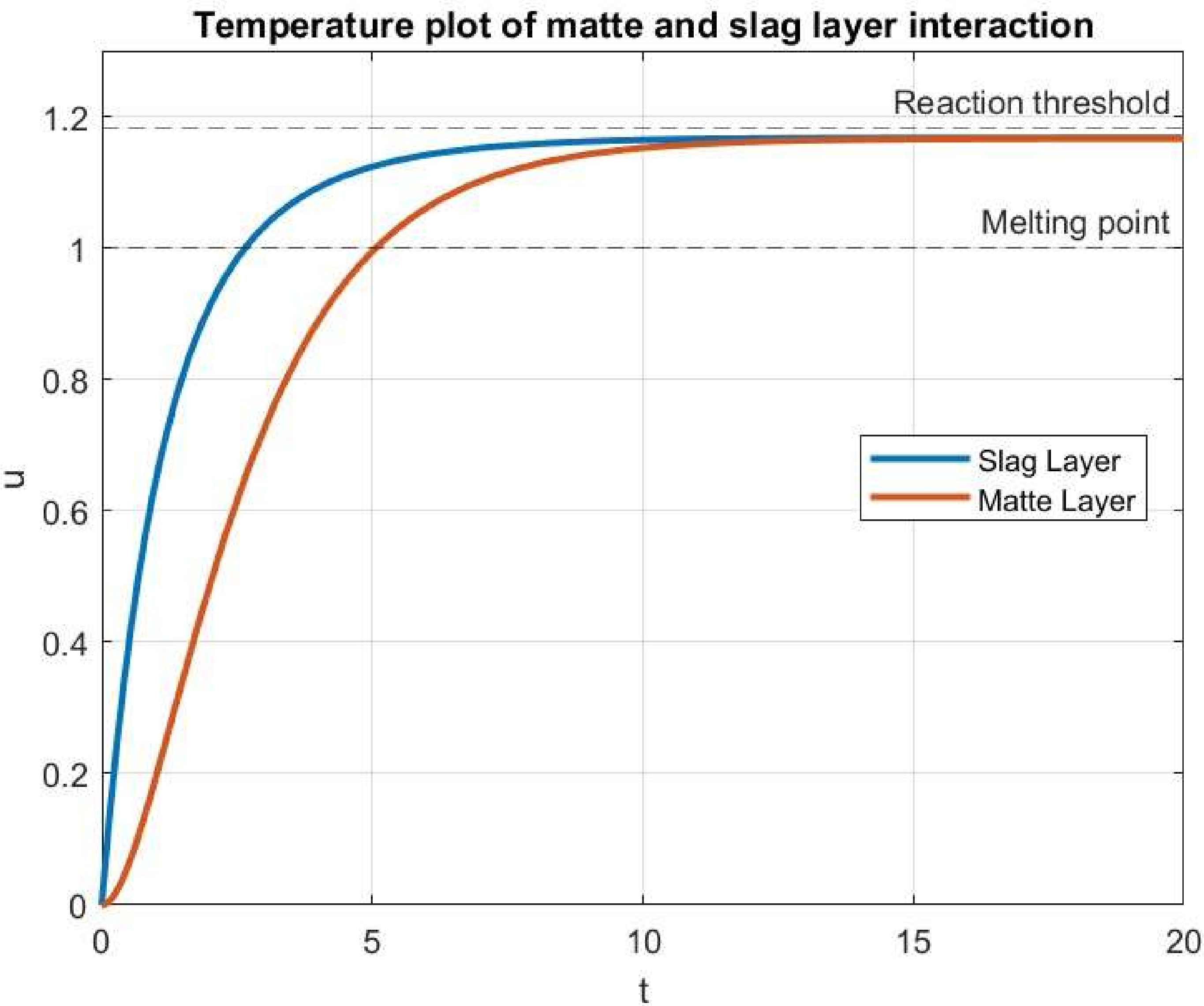
Heat transfer for the matte

$$\frac{du_m'}{dt'} = \gamma(u_s' - u_m') - \nu u_m' \tag{10}$$

$$\gamma = \frac{\mu A_{BOTTOM}}{H_{IN}} \frac{\rho_s}{\rho_m} \frac{V_s}{V_m} \frac{C_s}{C_m} \frac{1}{H_{IN}} (u_{1600} - u_w) \tag{11}$$

and

$$\nu = \frac{\lambda(u_{1600} - u_w)}{H_{IN}} \frac{\rho_s}{\rho_m} \frac{V_s}{V_m} \frac{C_s}{C_m} A_m \tag{12}$$



Temperature plot of matte and slag layer interaction
Reaction threshold
Melting point
Slag Layer
Matte Layer
u
t
0
0.2
0.4
0.6
0.8
1
1.2
0
5
10
15
20

# Conclusions

- Steady state temperature and volume replacement proportion must be chosen to keep temperature stable

# Recommendations

- Consider gradual volume replacements
- Consider volume changes with the coupled system
- Derive an appropriate time scale
- Include changes in specific heat
- Model diffusion
- More investigation of parameters are needed
- Consider high temperature $u_s > 1900°C$ reactions and state changes (bubbling, gas release etc.)

# References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Questions?