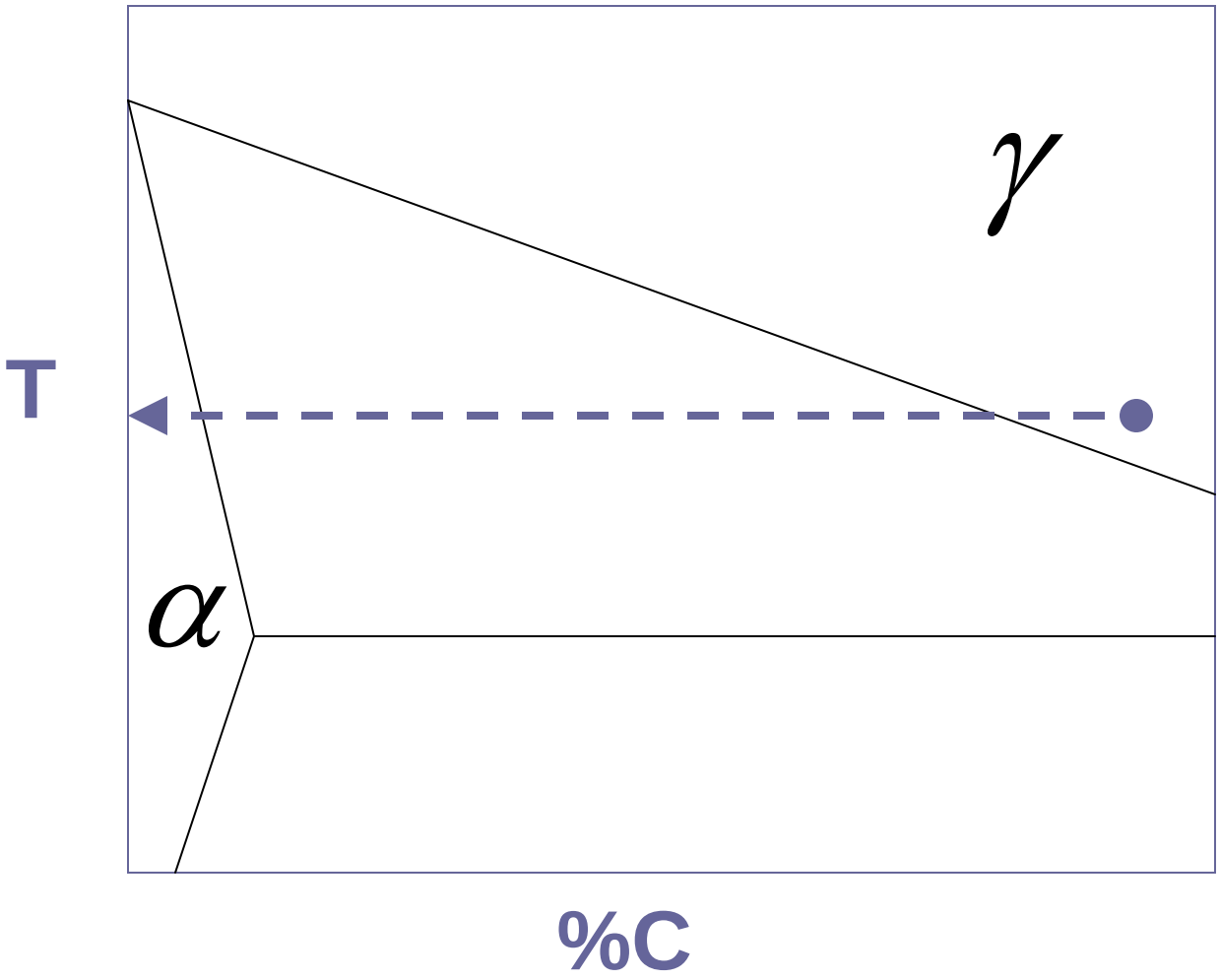
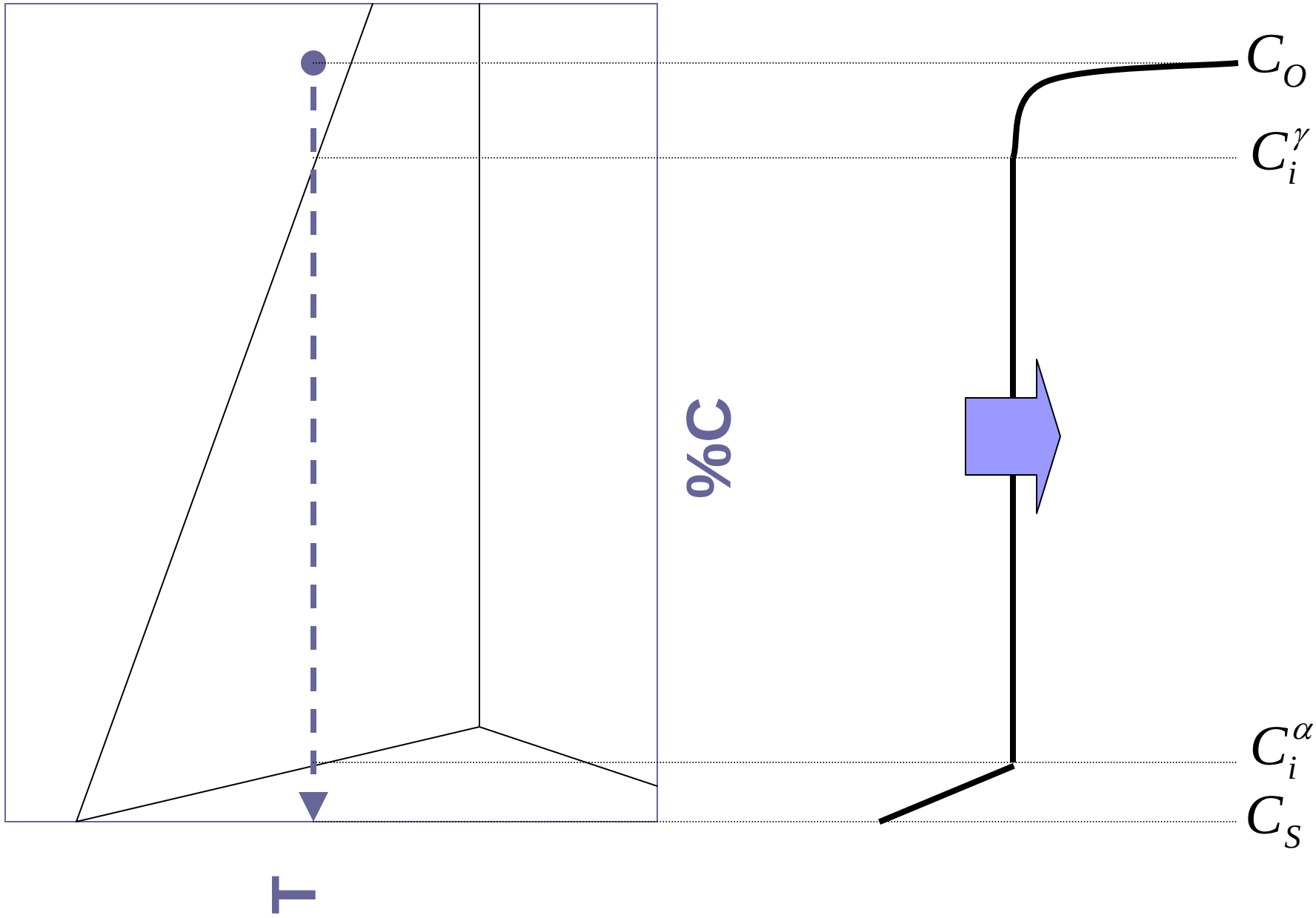
Investigation of Kinetic Transitions during $\gamma \rightarrow \alpha$ Transformation in Fe-C-Mn Alloys Using Decarburization

Hatem Zurob, Chris Hutchinson, Yves Brechet and Gary Purdy.

1. The Decarburization Method




C_o
C_i^{γ}
%C
C_i^{α}
C_s
T

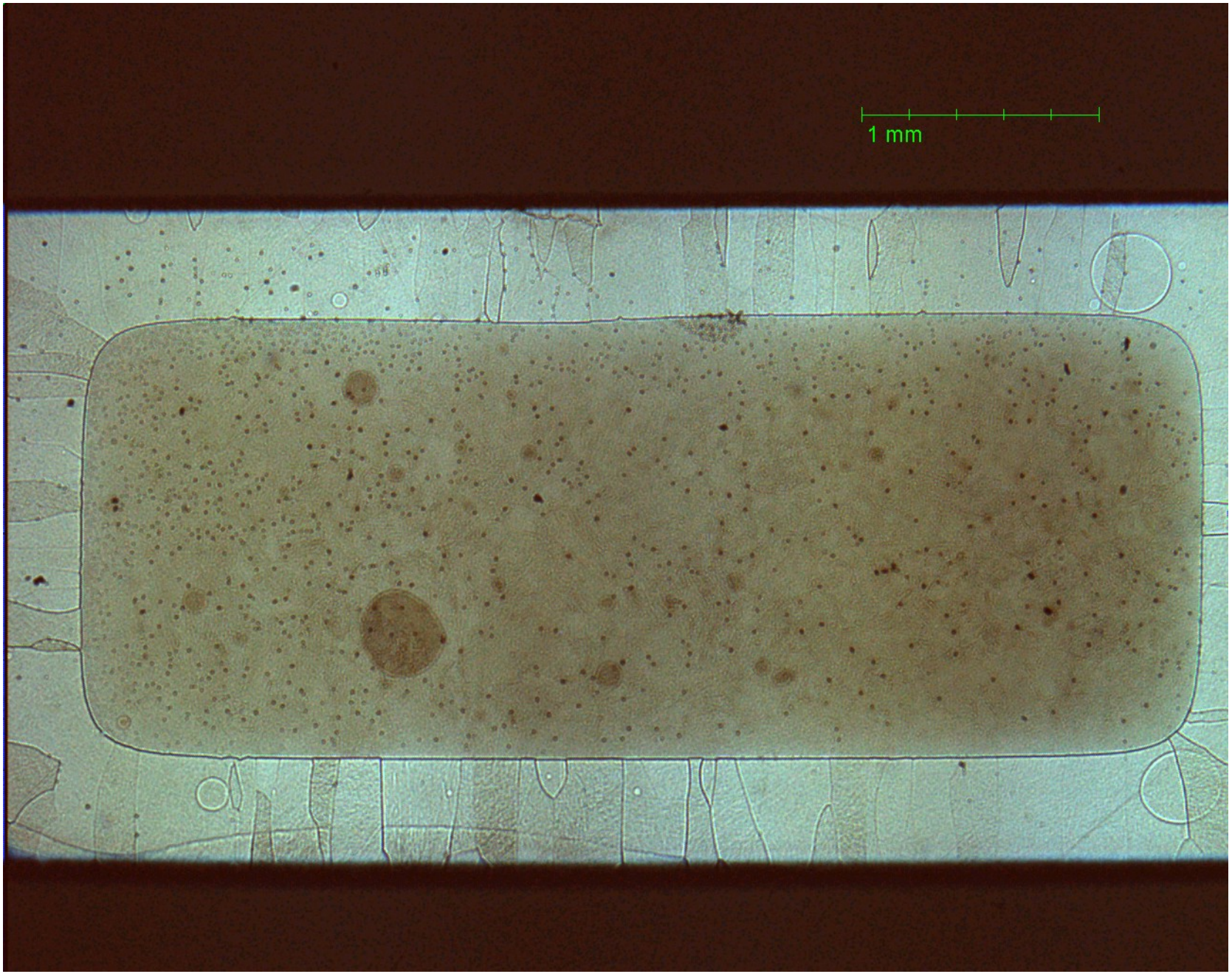
The rate of interface motion is given by:

$$\frac{dz}{dt} = \frac{J_i^{\alpha} - J_i^{\gamma}}{C_i^{\gamma} - C_i^{\alpha}}$$

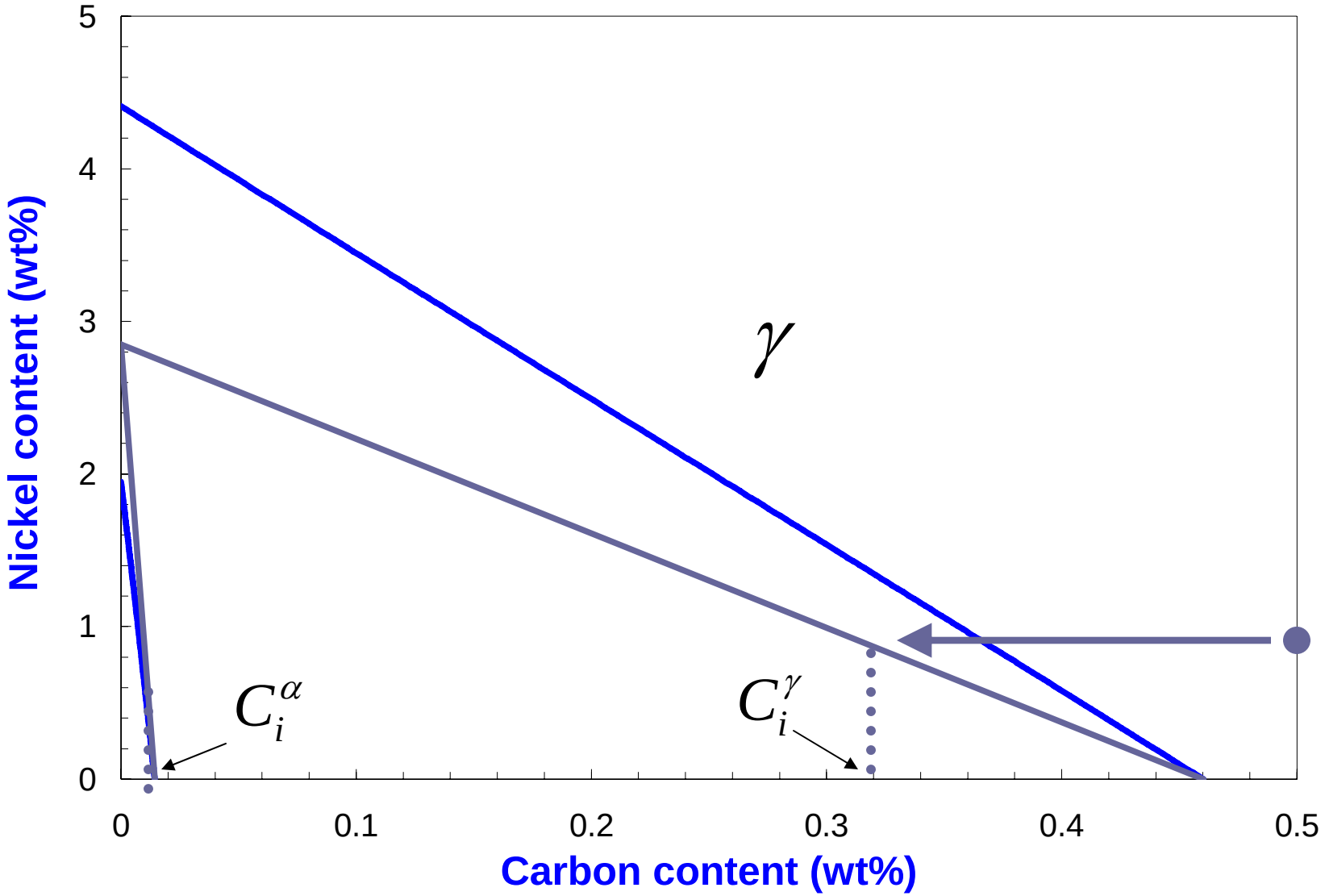
This differential equation has an analytical solution of the form:

$$z = B\sqrt{t}$$

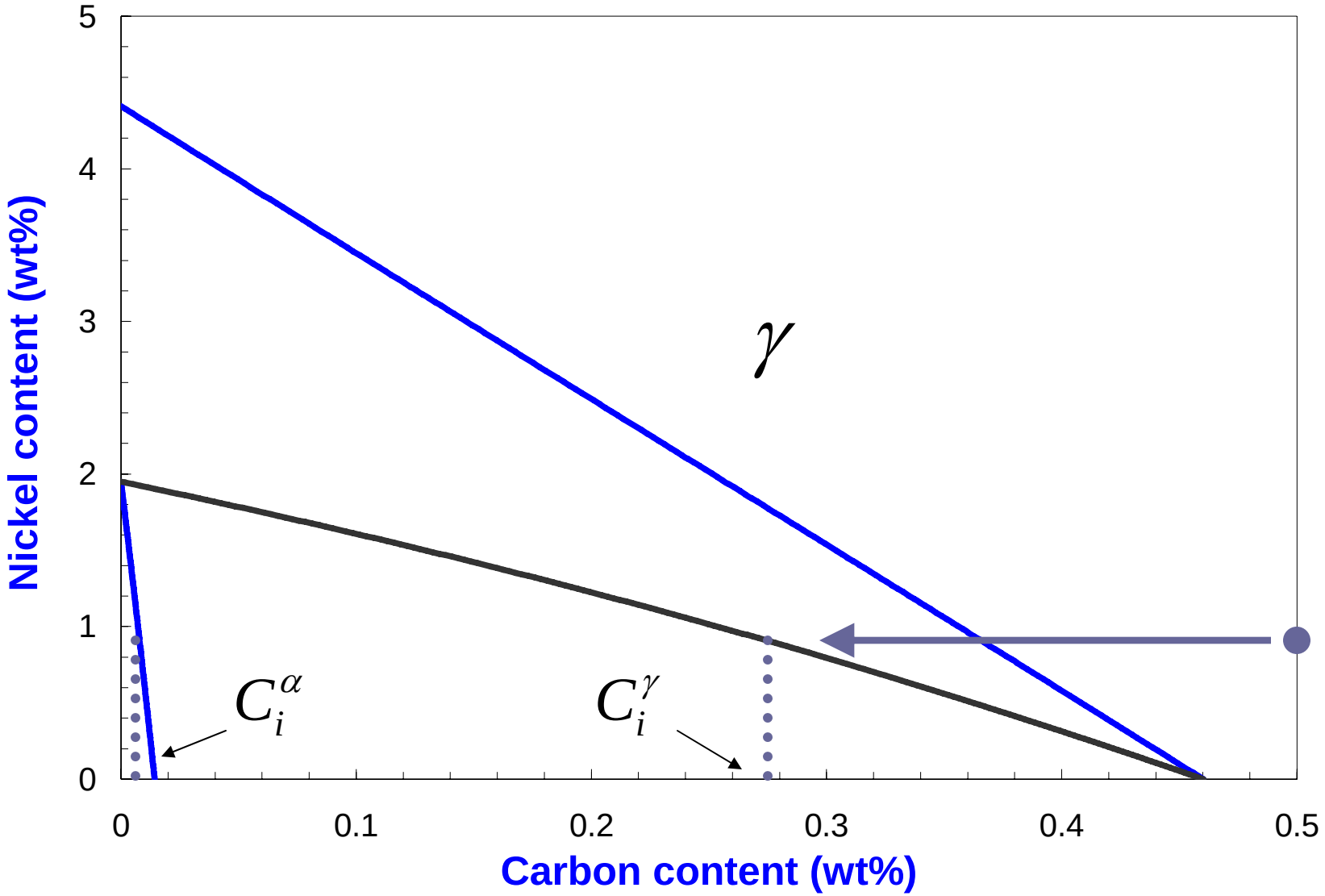
$$B = f(C_i^{\alpha}, C_i^{\gamma}, C_O)$$


1 mm

> *Ternary Alloys: ParaEquilibrium Limit.*



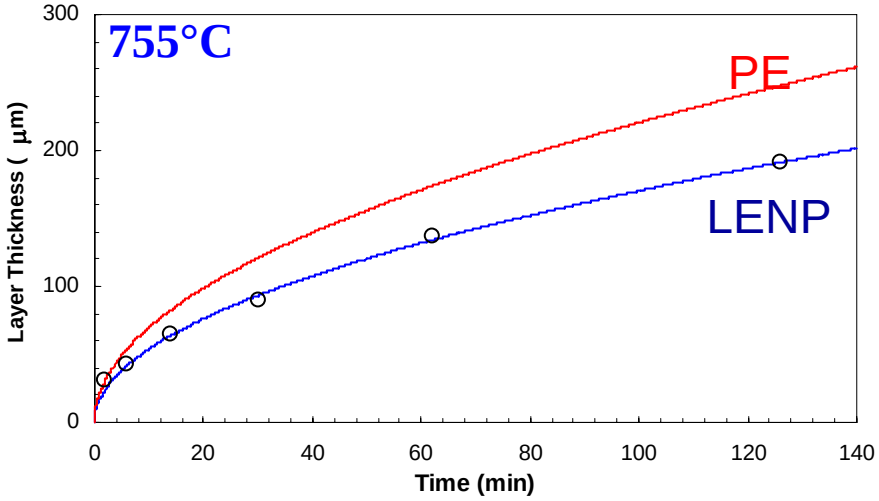
> *Ternary Alloys: LENP Limit.*

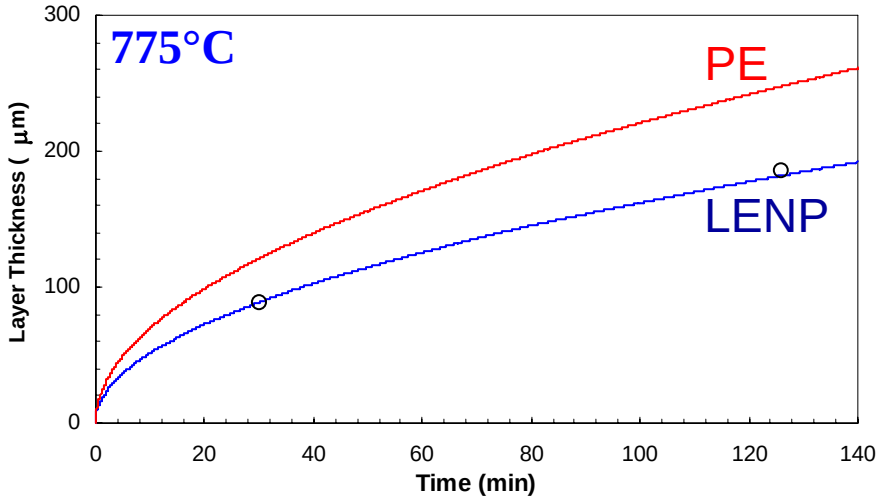


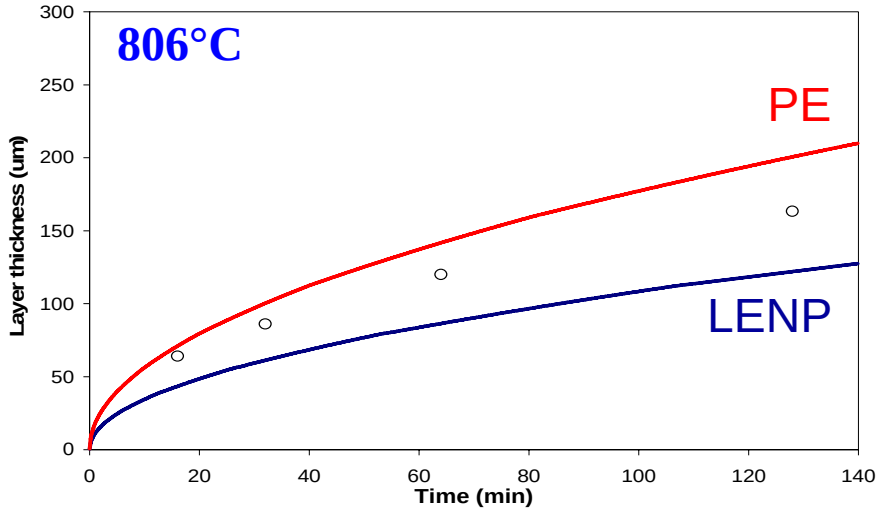
2. Summary of Results:

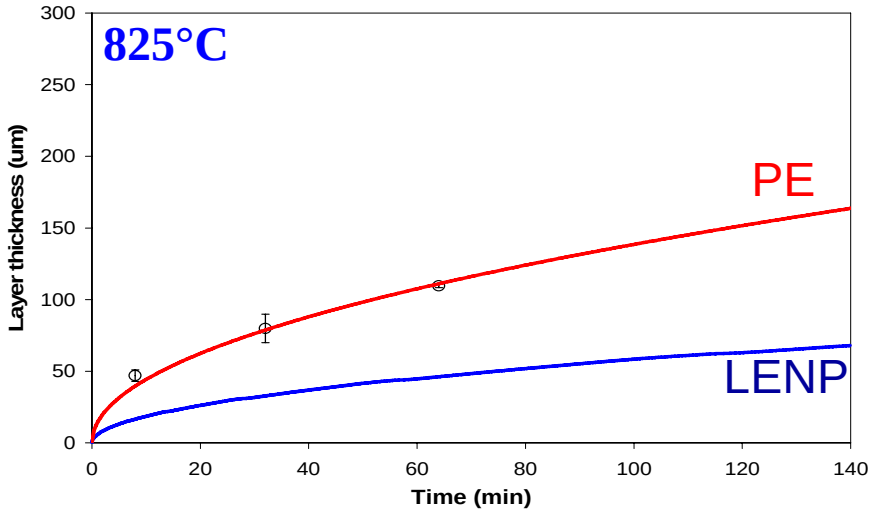
2.1. Fe-C (diffusion coefficient).
2.2. Fe-C-Ni (follows LE-NP limit).
2.3. Fe-C-Mn (transitions).

Fe-0.94%Mn-0.57%C

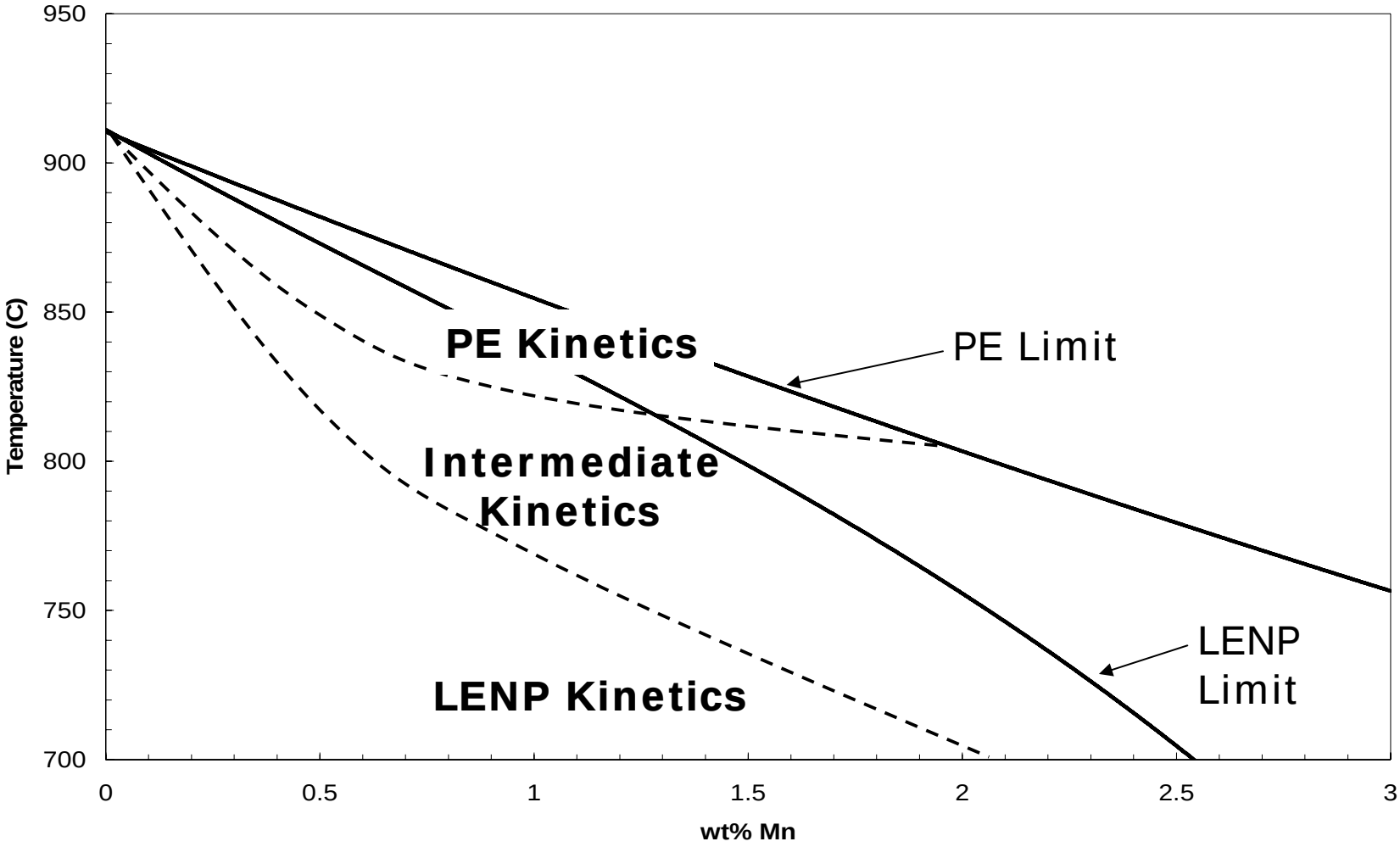








Summary of Results: Fe-C-Mn

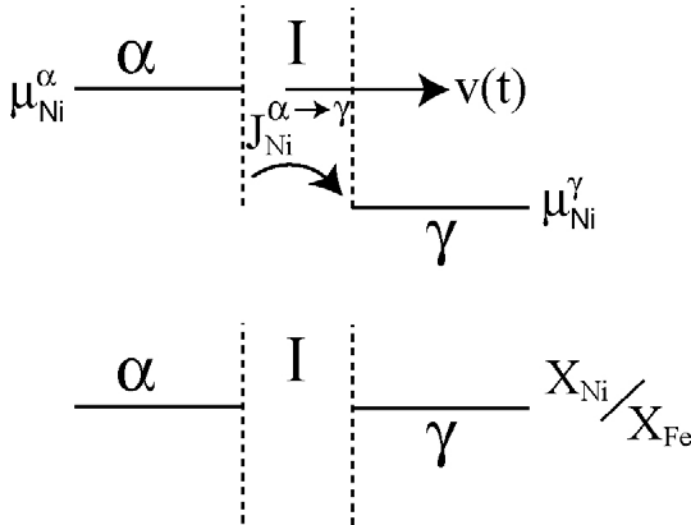


Aspects needing further explanation

- Usually we expect to see a transition from PE to LENP with increasing T.
  - Experimentally, the reverse is observed.
- Any intermediate states (between PE and LENP) would be transitory.
  - Experimentally long-lived intermediate states with parabolic kinetics are observed.
- Initially it was thought the Mn and Ni would not behave very differently.
  - Experimentally the behaviors of the two ternaries are very different.

3. Single Jump Model

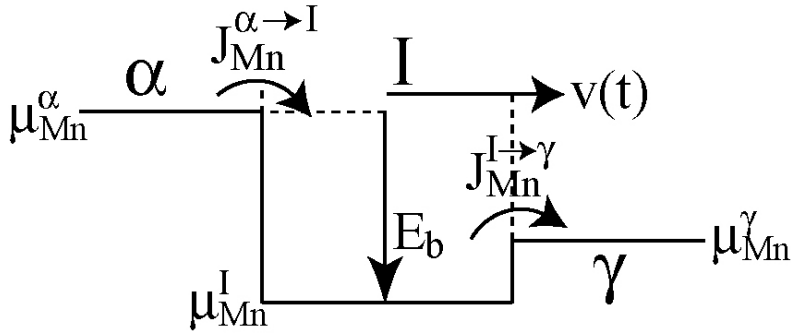
- Model reproduced transitions from PE to LENP during growth consistent with experiments in Fe-Ni-C (precipitation and decarburization)

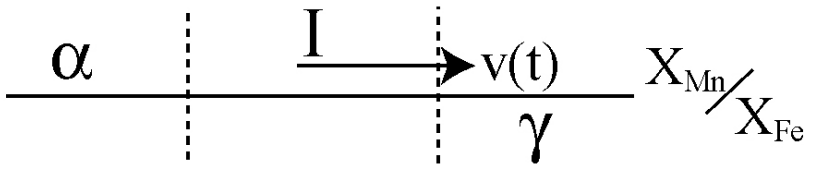


$$J_{Ni}^{\alpha\rightarrow\gamma} = \frac{X_{Ni}\cdot M_{Ni}^{Trans-\text{int}}}{V_m}\cdot\frac{\left(\mu_{Ni}^{\gamma}-\mu_{Ni}^{\alpha}\right)}{\delta}\left(1-\exp\left(\frac{-D_{Ni}^{Trans-\text{int}}}{v\delta}\right)\right)$$

3. Two Jump Model:

- Two jumps one into the interface and one out of the interface.
- Allow for segregation at the interface.



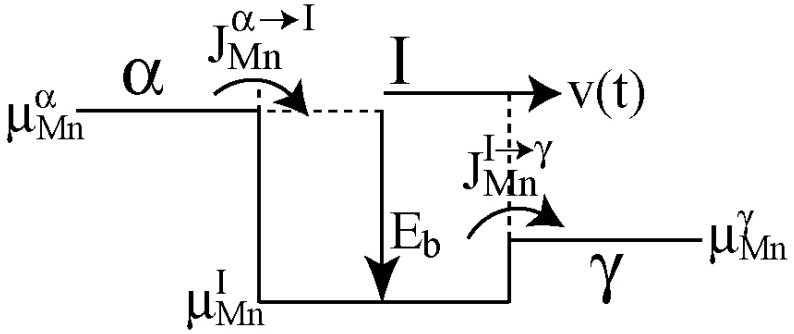


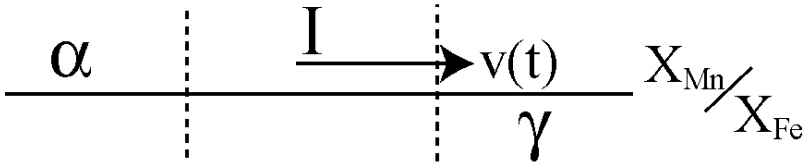
$$J_{Mn}^{\alpha\to I} = \frac{X_{Mn}^{b}\cdot M_{Mn}^{Trans-\text{int}}}{V_m}\cdot\frac{\left(\mu_{Mn}^{I}-\mu_{Mn}^{\alpha}\right)}{\delta}\left(1-\exp\left(\frac{-D_{Mn}^{Trans-\text{int}}}{v\delta}\right)\right)$$

$$J_{Mn}^{I\to\gamma} = \frac{X_{Mn}^{I}\cdot M_{Mn}^{Trans-\text{int}}}{V_m}\cdot\frac{\left(\mu_{Mn}^{\gamma}-\mu_{Mn}^{I}\right)}{\delta}\left(1-\exp\left(\frac{-D_{Mn}^{Trans-\text{int}}}{v\delta}\right)\right)$$

3. Two Jump Model:

- Two jumps one into the interface and one out of the interface.
- Allow for segregation at the interface.
- Assign a capacity for the solute at the moving interface, *X**



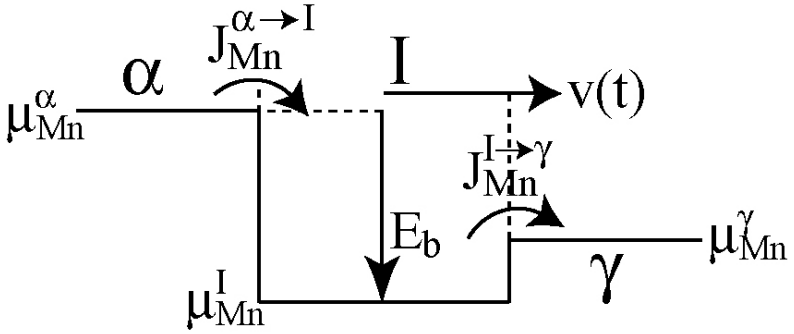


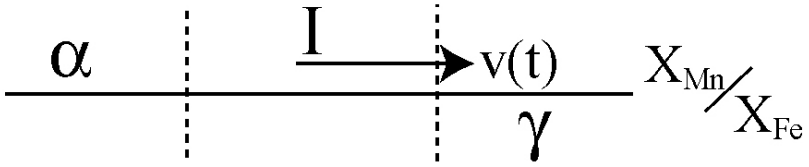
$$J_{Mn}^{\alpha\to I} = \frac{X_{Mn}^{b}\cdot M_{Mn}^{Trans-\text{int}}}{V_m}\cdot\frac{\left(\mu_{Mn}^{I}-\mu_{Mn}^{\alpha}\right)}{\delta}\left(1-\exp\left(\frac{-D_{Mn}^{Trans-\text{int}}}{v\delta}\right)\right)\left(1-\frac{X_{Mn}^{I}}{X_{Mn}^{*}}\right)$$

$$J_{Mn}^{I\to\gamma} = \frac{X_{Mn}^{I}\cdot M_{Mn}^{Trans-\text{int}}}{V_m}\cdot\frac{\left(\mu_{Mn}^{\gamma}-\mu_{Mn}^{I}\right)}{\delta}\left(1-\exp\left(\frac{-D_{Mn}^{Trans-\text{int}}}{v\delta}\right)\right)$$

3. Two Jump Model:

- Two jumps one into the interface and one out of the interface.
- Allow for segregation at the interface.
- Assign a capacity for the solute at the moving interface, *X**
- *X** increases linearly with C content.

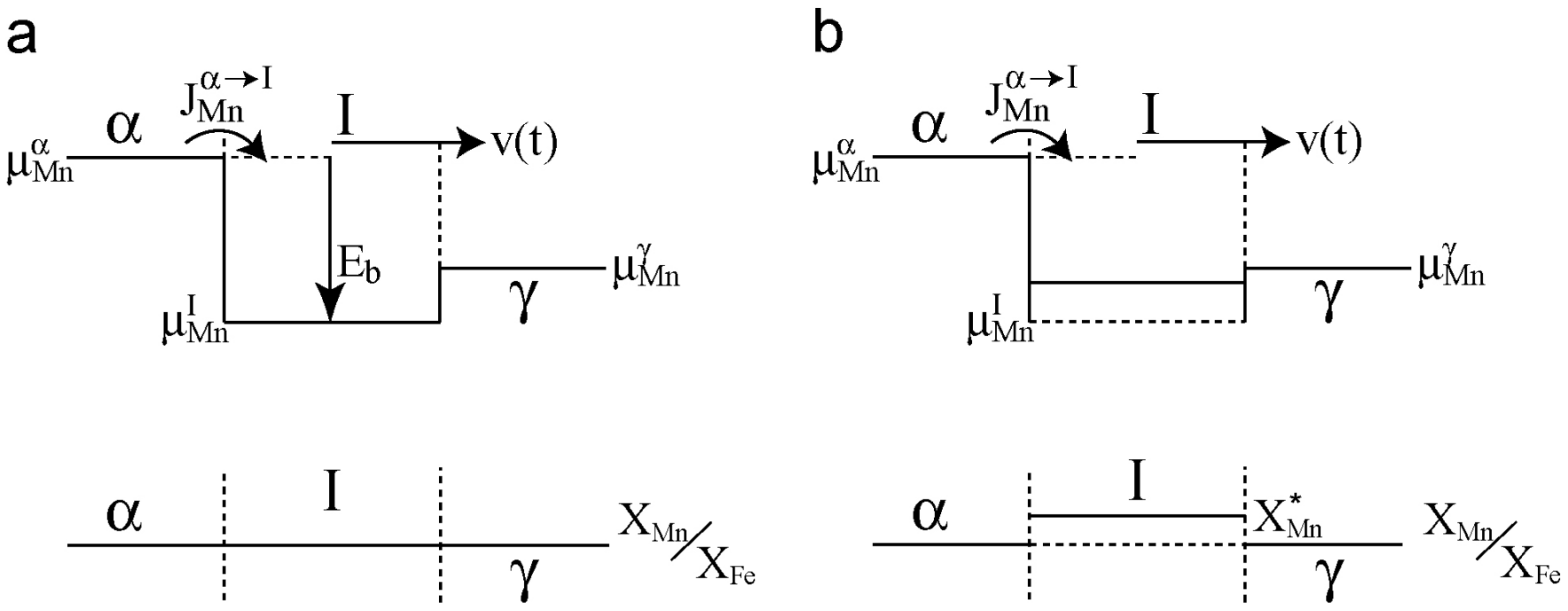




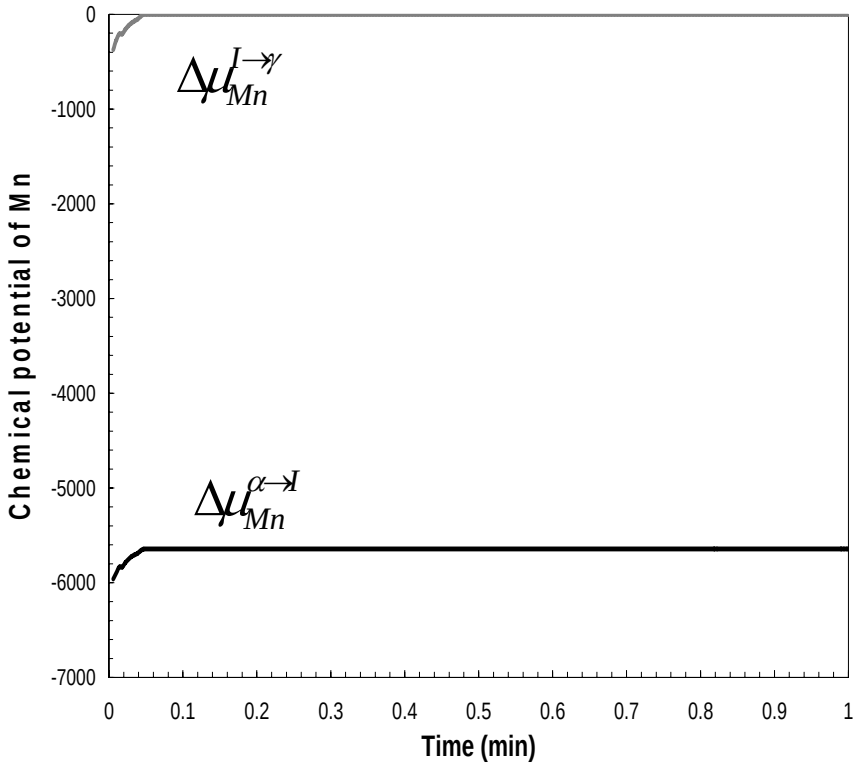
$$J_{Mn}^{\alpha\to I} = \frac{X_{Mn}^{b}\cdot M_{Mn}^{Trans-\text{int}}}{V_m}\cdot\frac{\left(\mu_{Mn}^{I}-\mu_{Mn}^{\alpha}\right)}{\delta}\left(1-\exp\left(\frac{-D_{Mn}^{Trans-\text{int}}}{v\delta}\right)\right)\left(1-\frac{X_{Mn}^{I}}{X_{Mn}^{*}}\right)$$

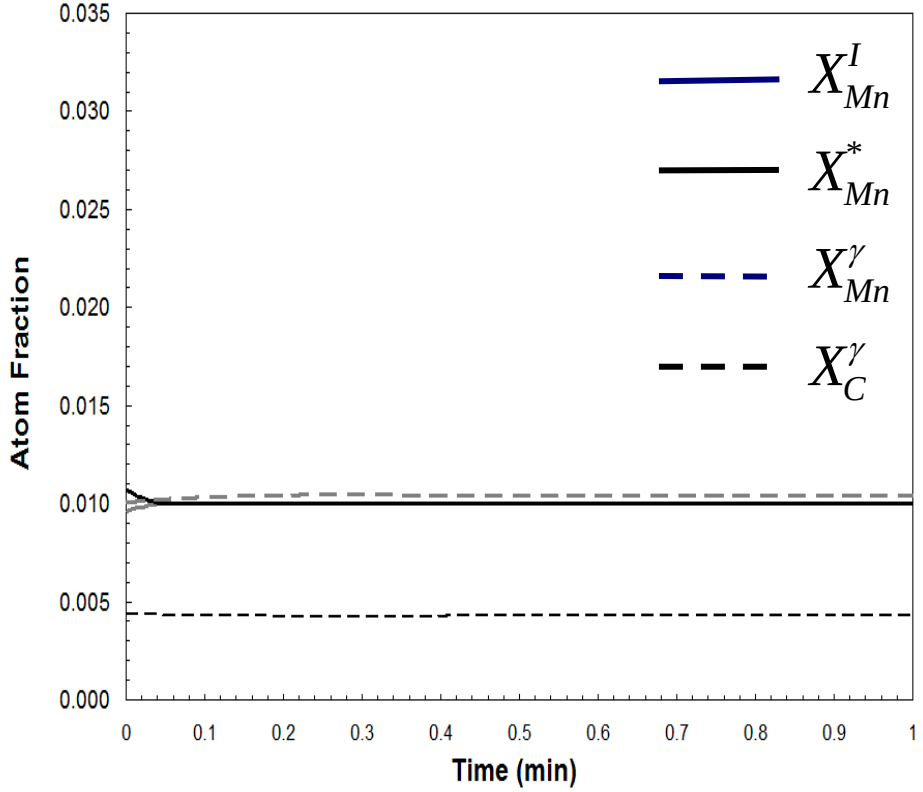
$$J_{Mn}^{I\to\gamma} = \frac{X_{Mn}^{I}\cdot M_{Mn}^{Trans-\text{int}}}{V_m}\cdot\frac{\left(\mu_{Mn}^{\gamma}-\mu_{Mn}^{I}\right)}{\delta}\left(1-\exp\left(\frac{-D_{Mn}^{Trans-\text{int}}}{v\delta}\right)\right)$$

3. Model: PE as a special case High T

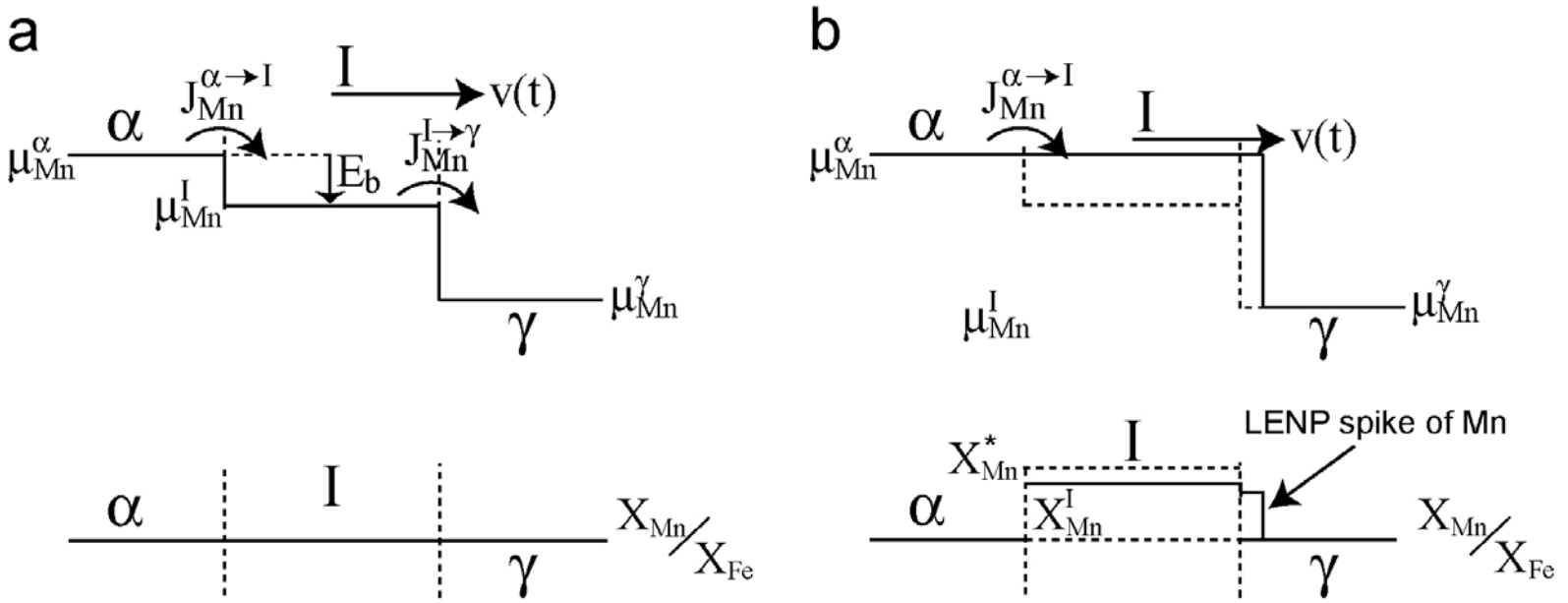


3. Model: PE at high T

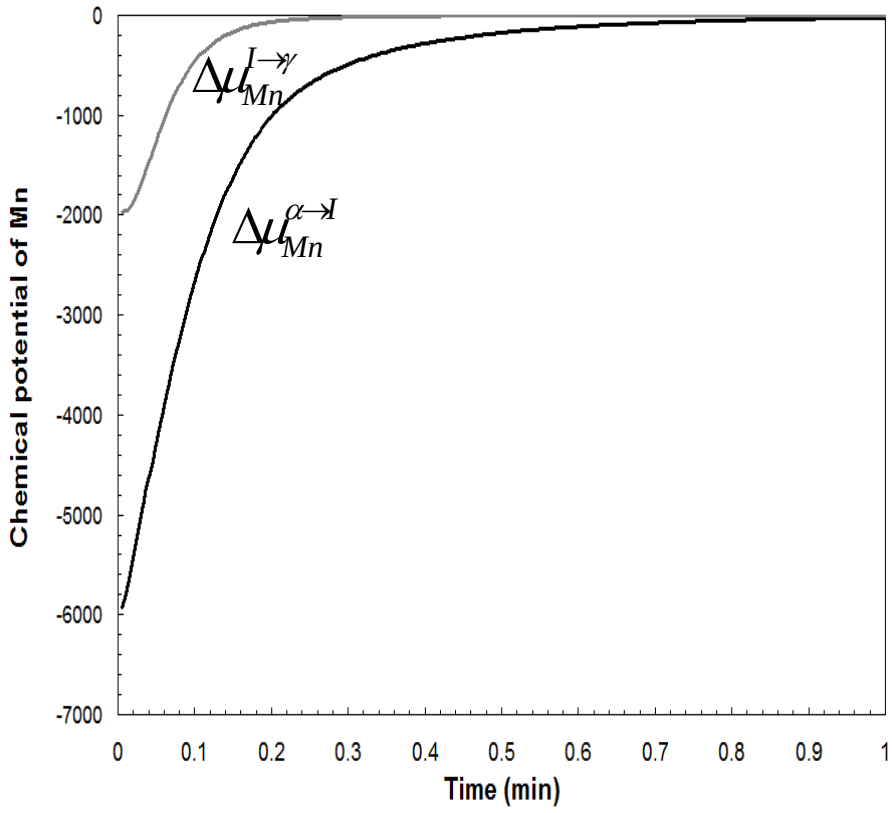


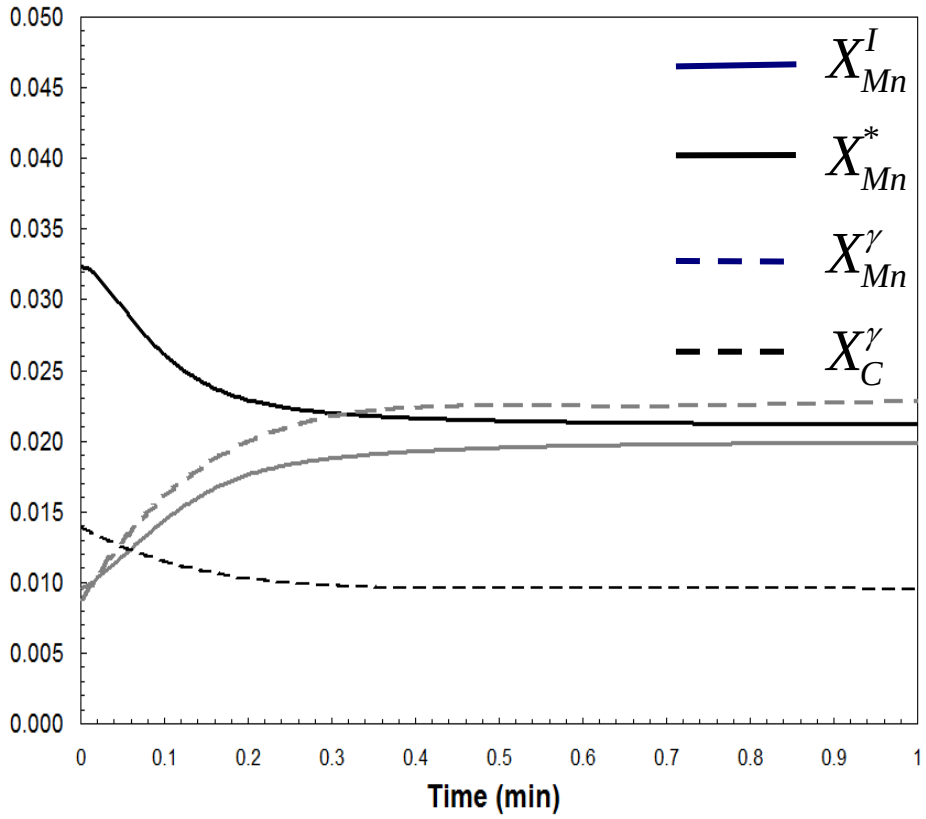


3. Model: LENP at low T

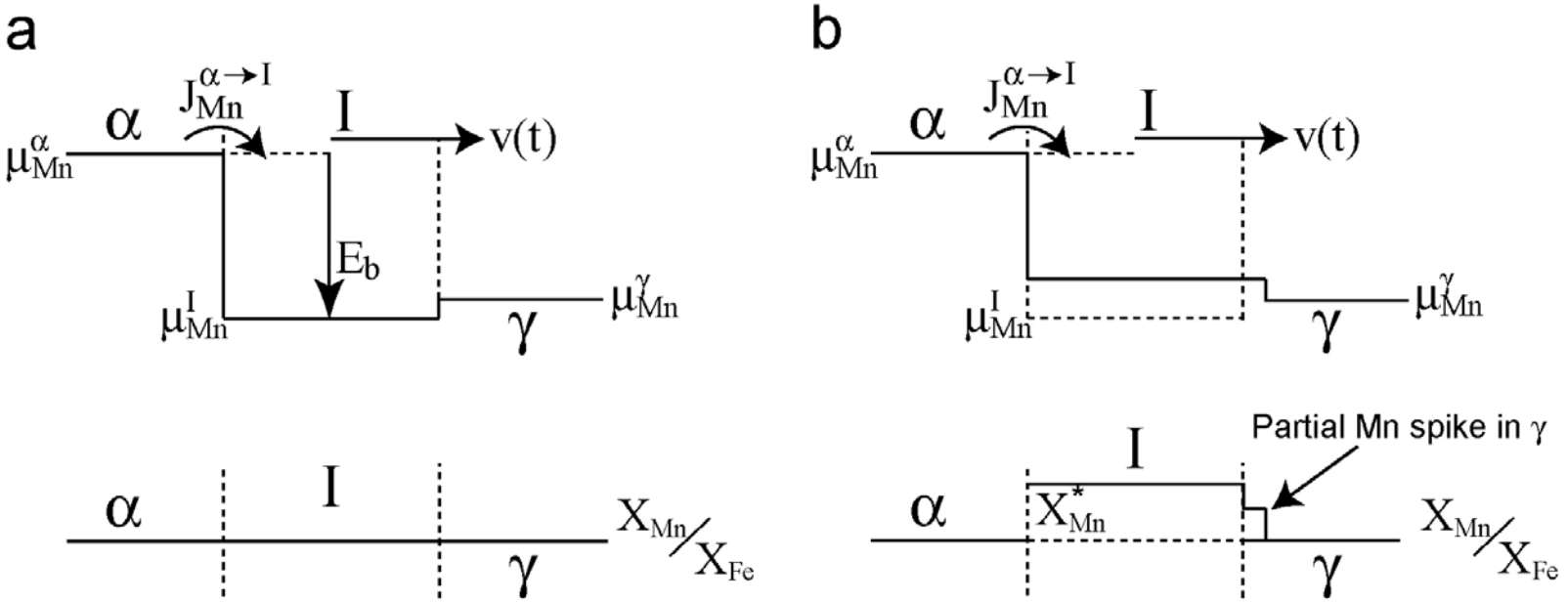


3. Model: LENP at low T

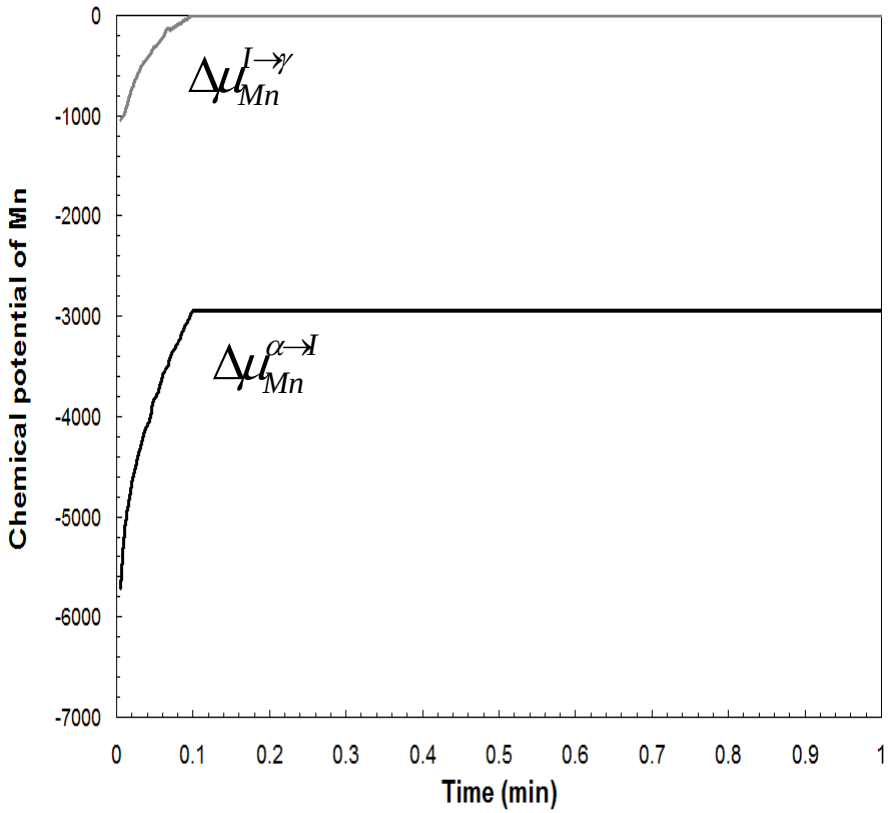


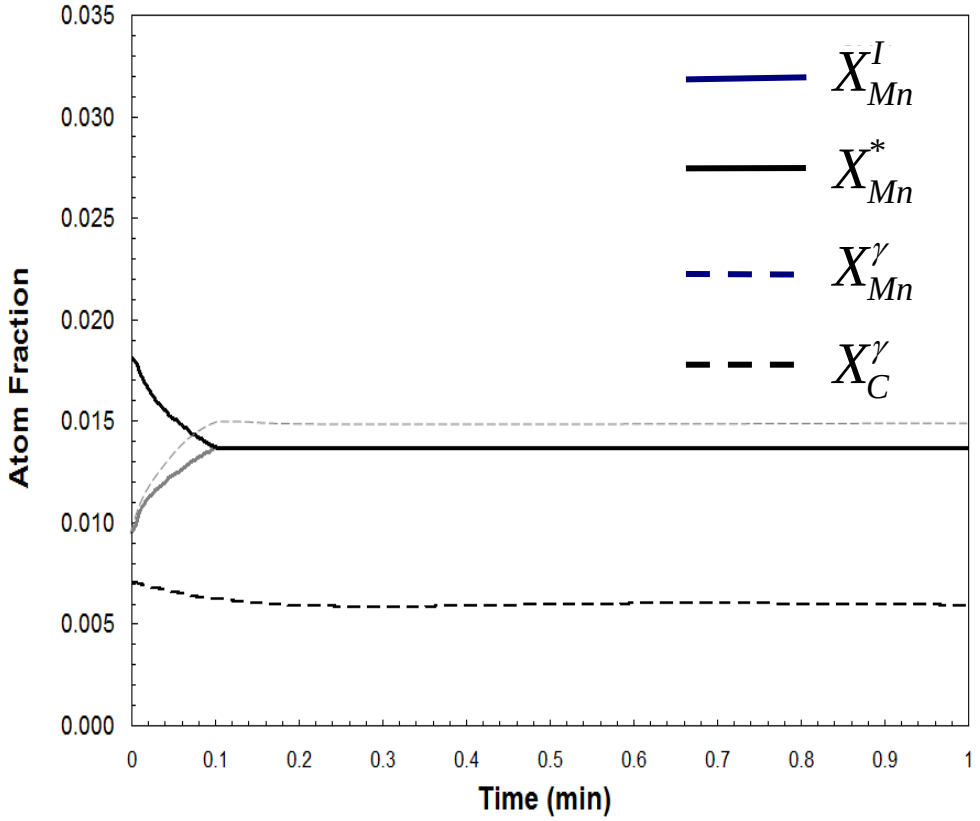


3. Model: Intermediate states

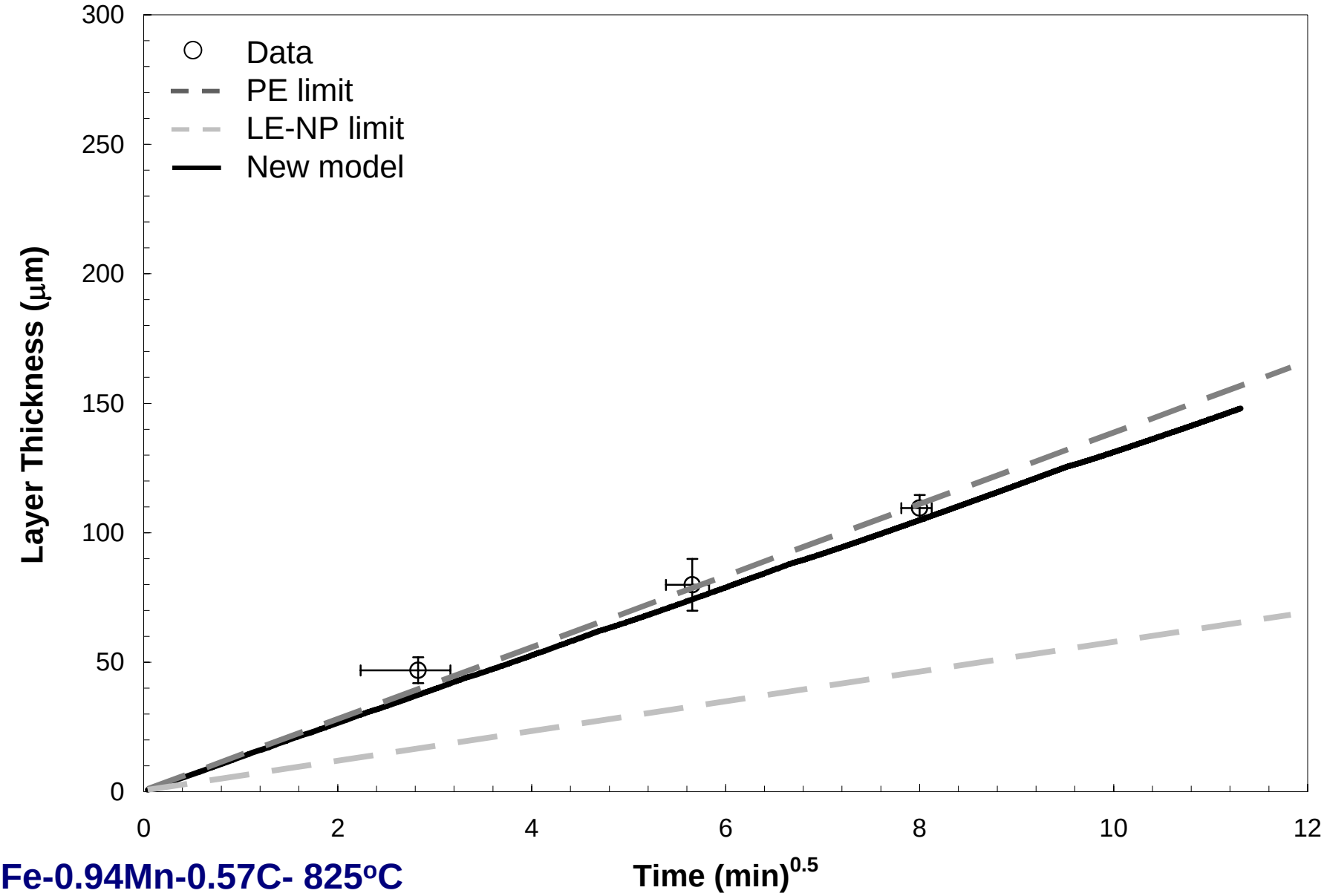


3. Model: Intermediate States

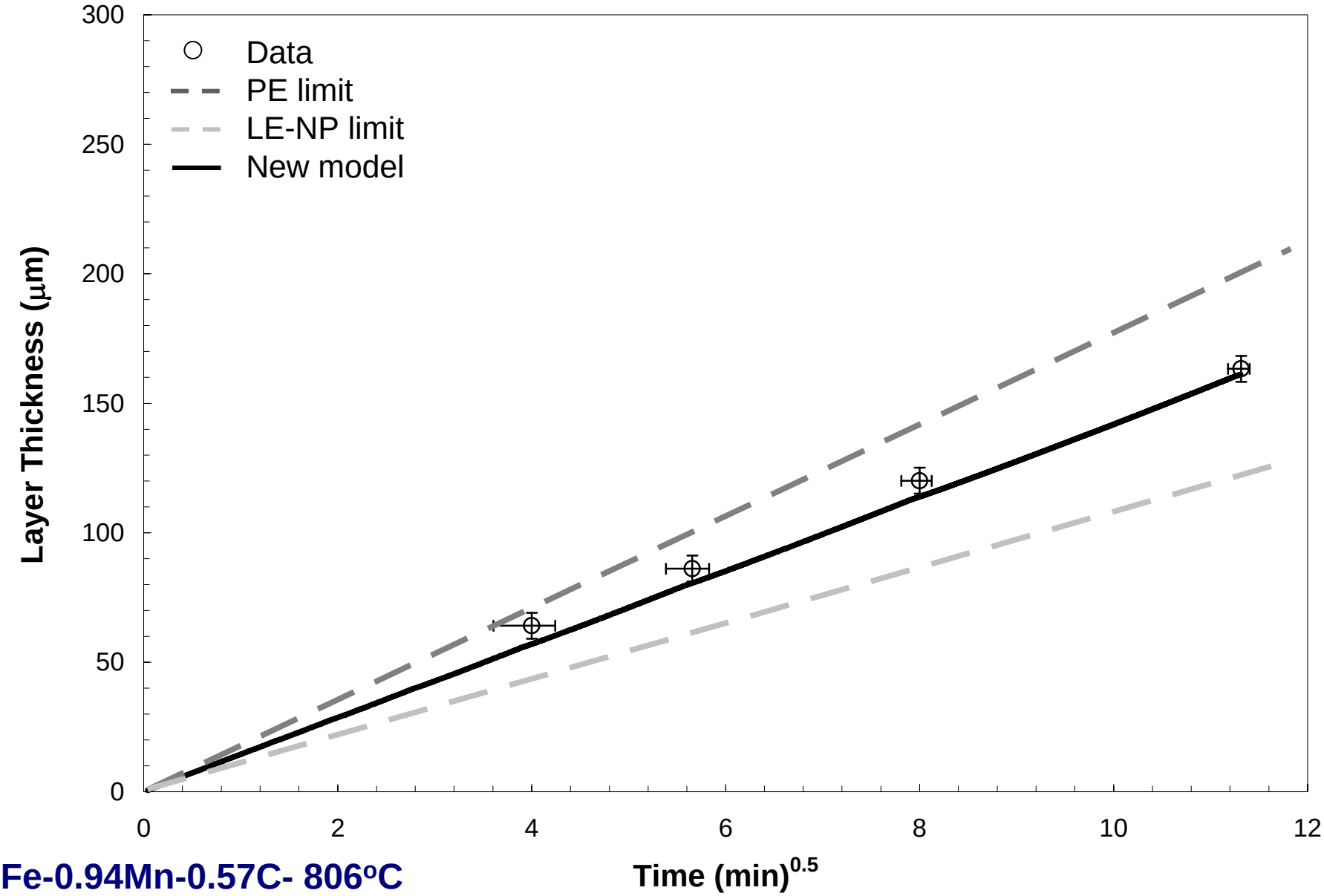




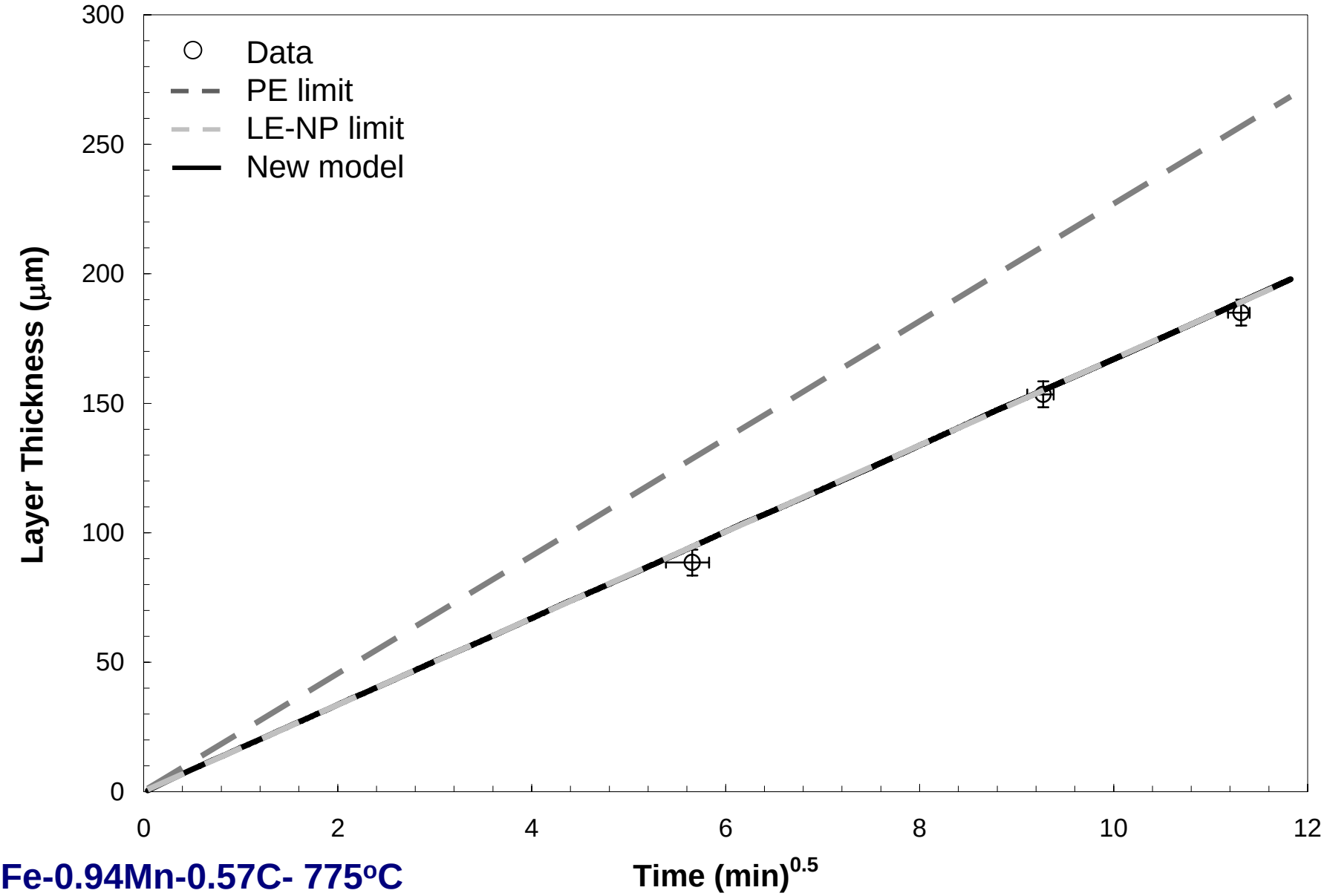
4. Results:



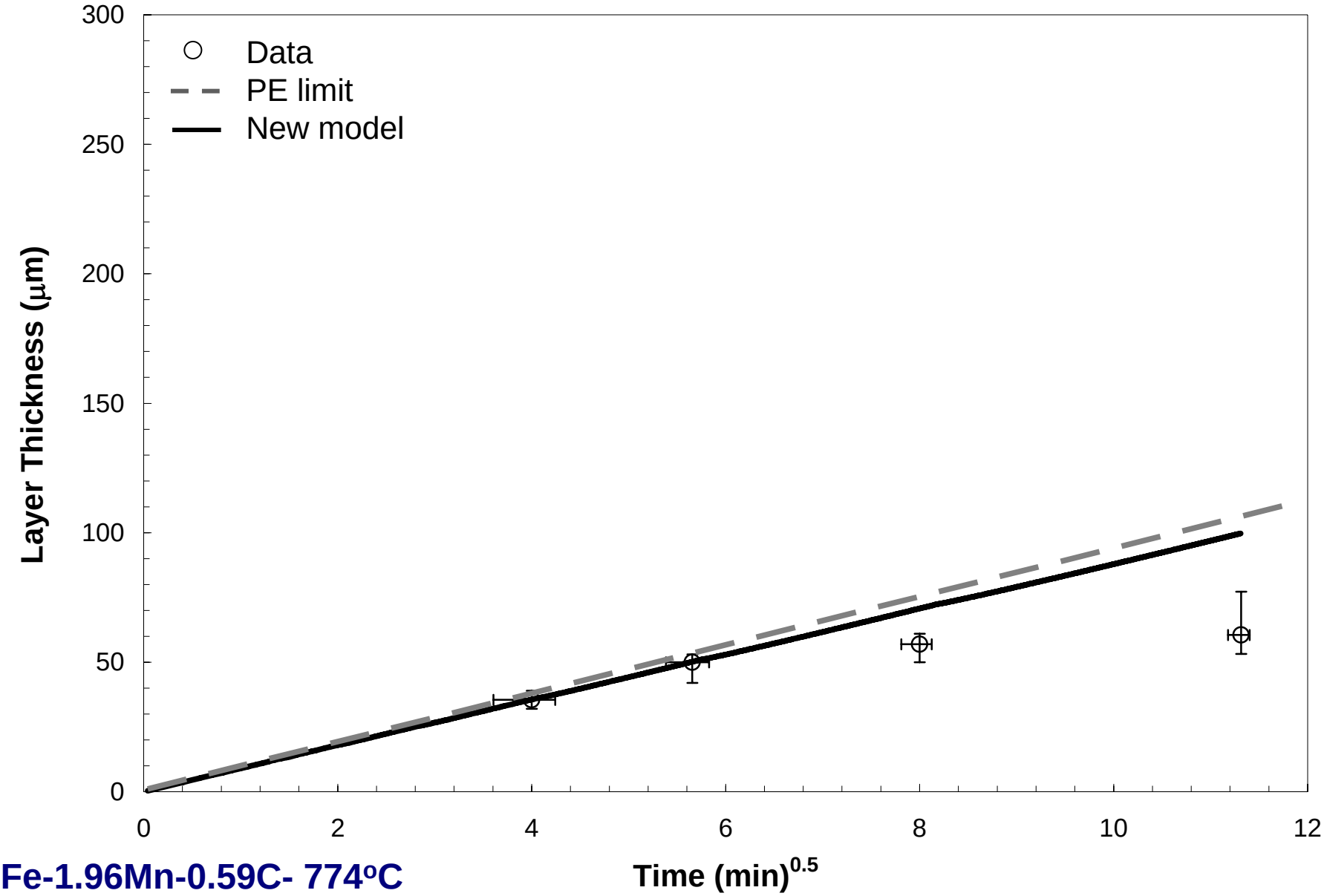
Fe-0.94Mn-0.57C- 825°C



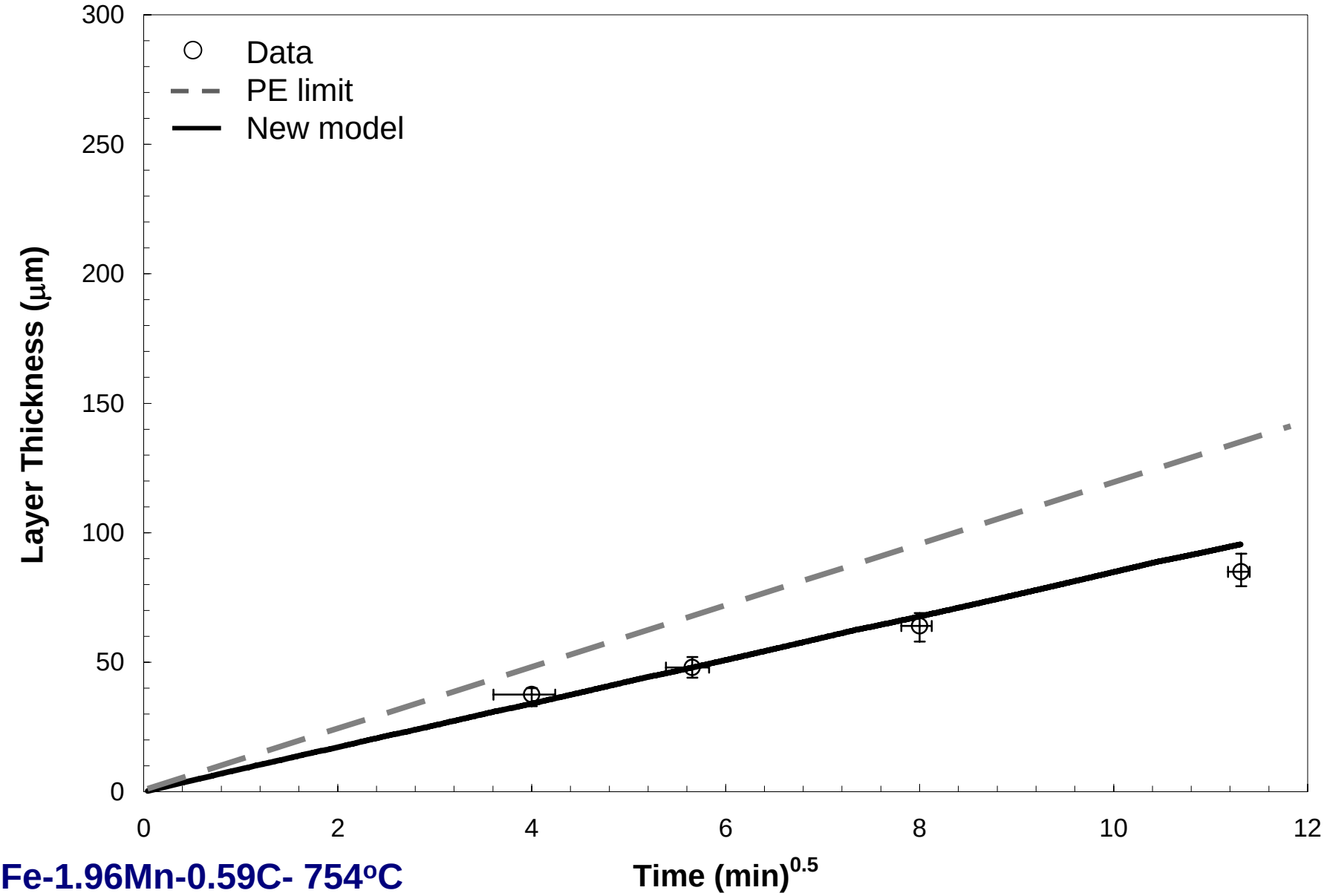
Fe-0.94Mn-0.57C- 806°C



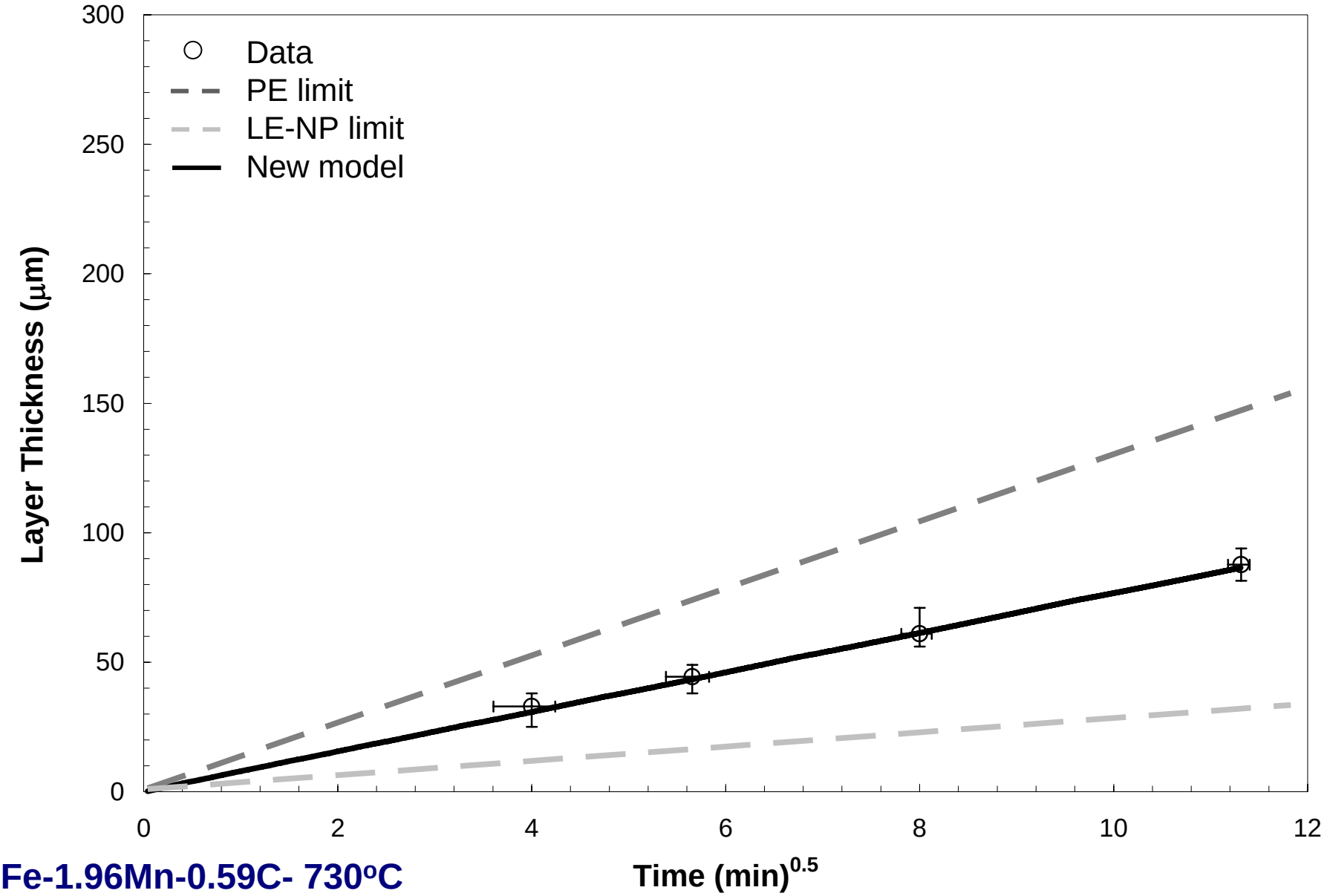
Fe-0.94Mn-0.57C- 775°C



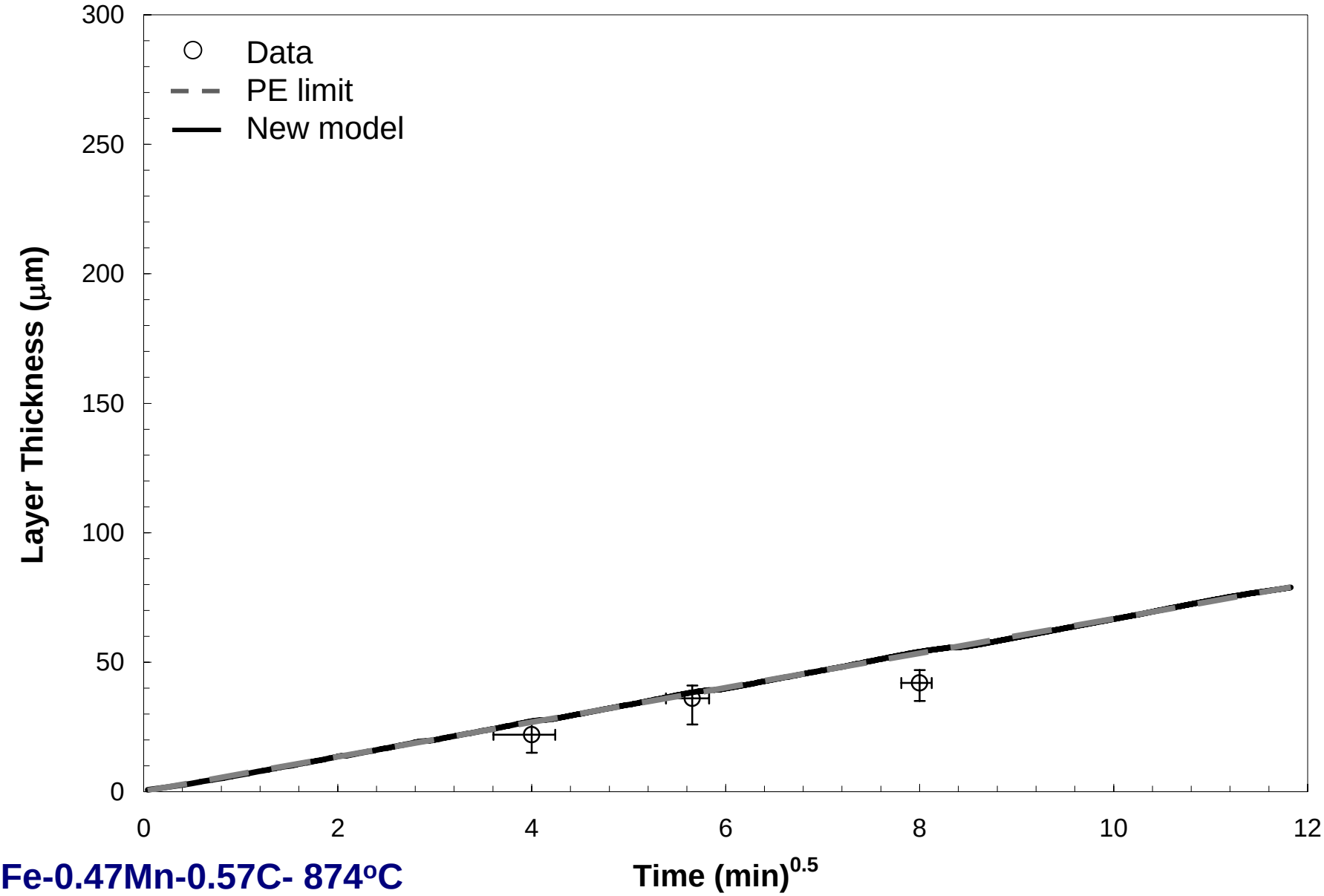
Fe-1.96Mn-0.59C- 774°C



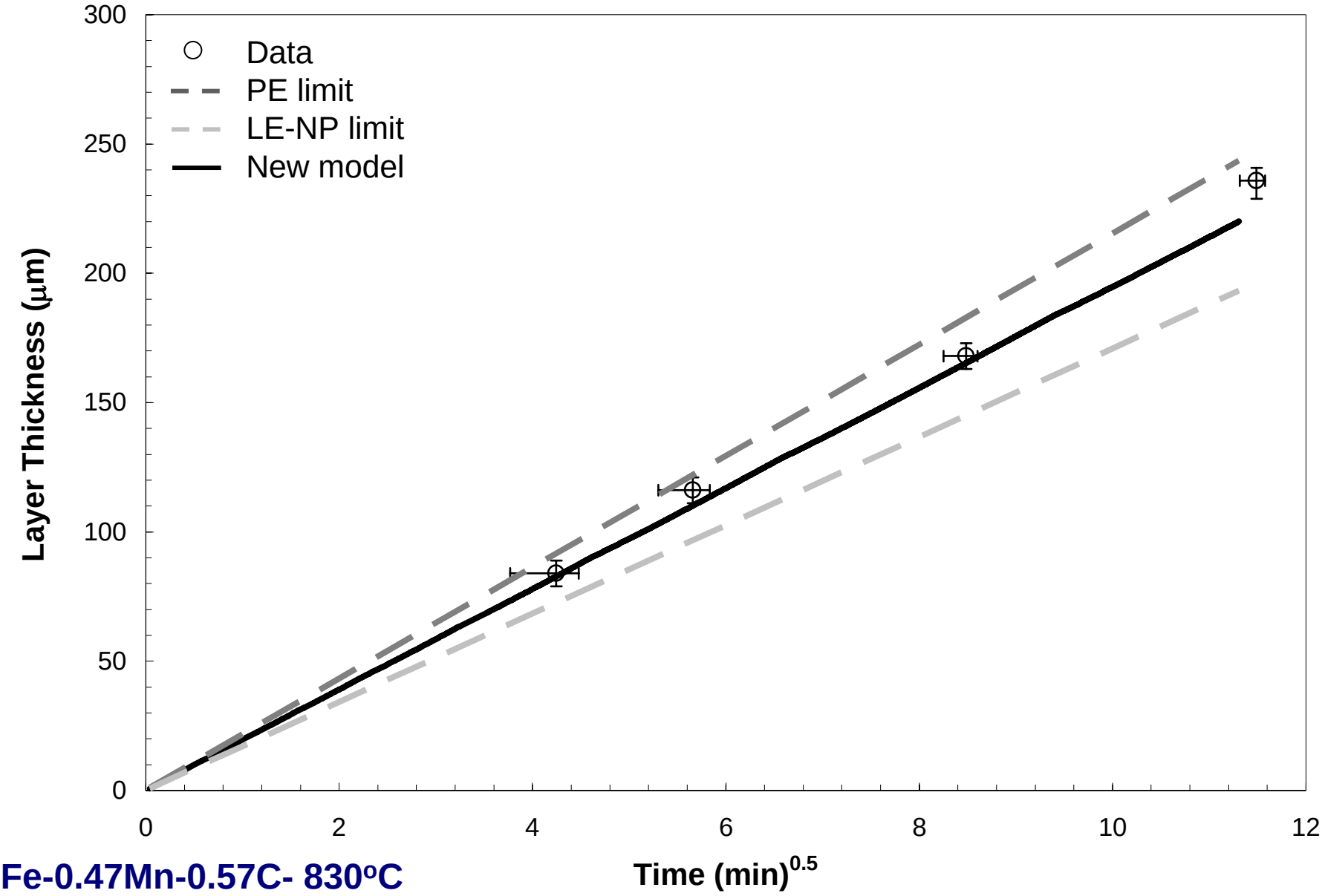
Fe-1.96Mn-0.59C- 754°C



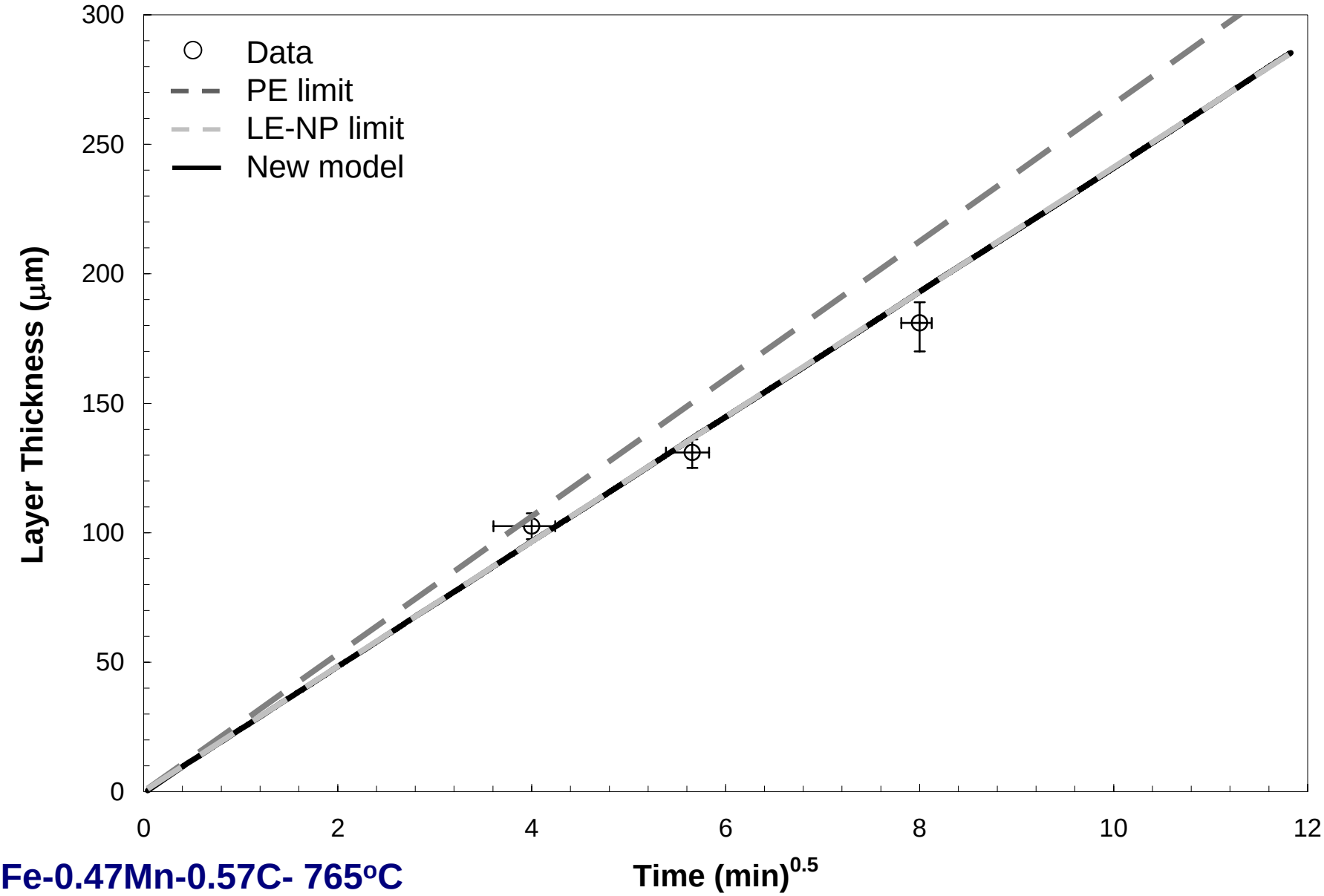
Fe-1.96Mn-0.59C- 730°C



Fe-0.47Mn-0.57C- 874°C



Fe-0.47Mn-0.57C- 830°C



Fe-0.47Mn-0.57C- 765°C

Summary:

It was necessary to introduce a moving interface solute capacity X*.

The difference between a static and a moving interface needs to be explored further.