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Faculty of Metals Engineering and Industrial Computer Science
Department of Ferrous Metallurgy

The secondary steel refining processes control based on equilibrium states analysis in heterogeneous system

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Contents

- Vacuum steel refining
- Tools for computational calculations
- Dissolubility of nitrogen in liquid Fe solution
- Model of the RH vacuum degassing unit
- Conclusions

Vacuum steel refining
Objective of use

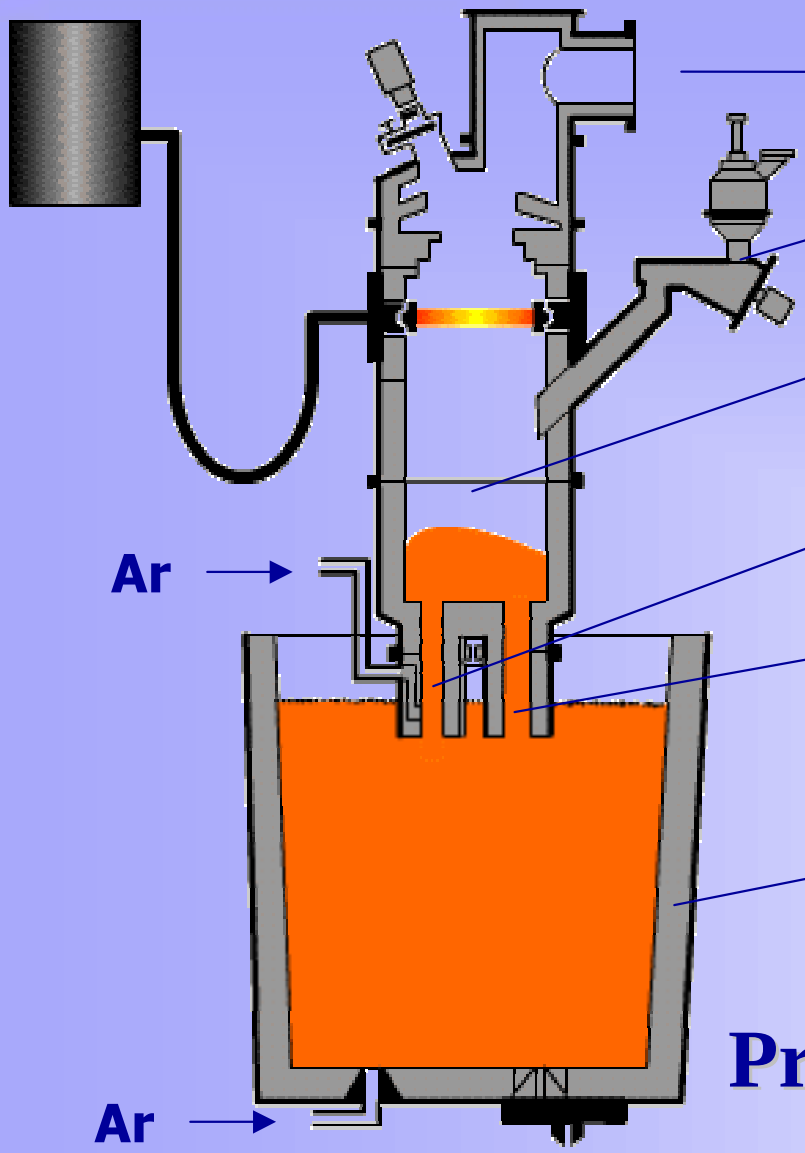
REMOVING
HYDROGEN AND NITROGEN
FROM METAL BATH

$$a_{[G]} = K\sqrt{p_G}$$

Sieverts Law

- **Deoxidation and Decarburization**
- **Alloying**
- **Homogenization of chemical composition and temperature**
- **Level of pollution of non-metallic inclusions decreasing**

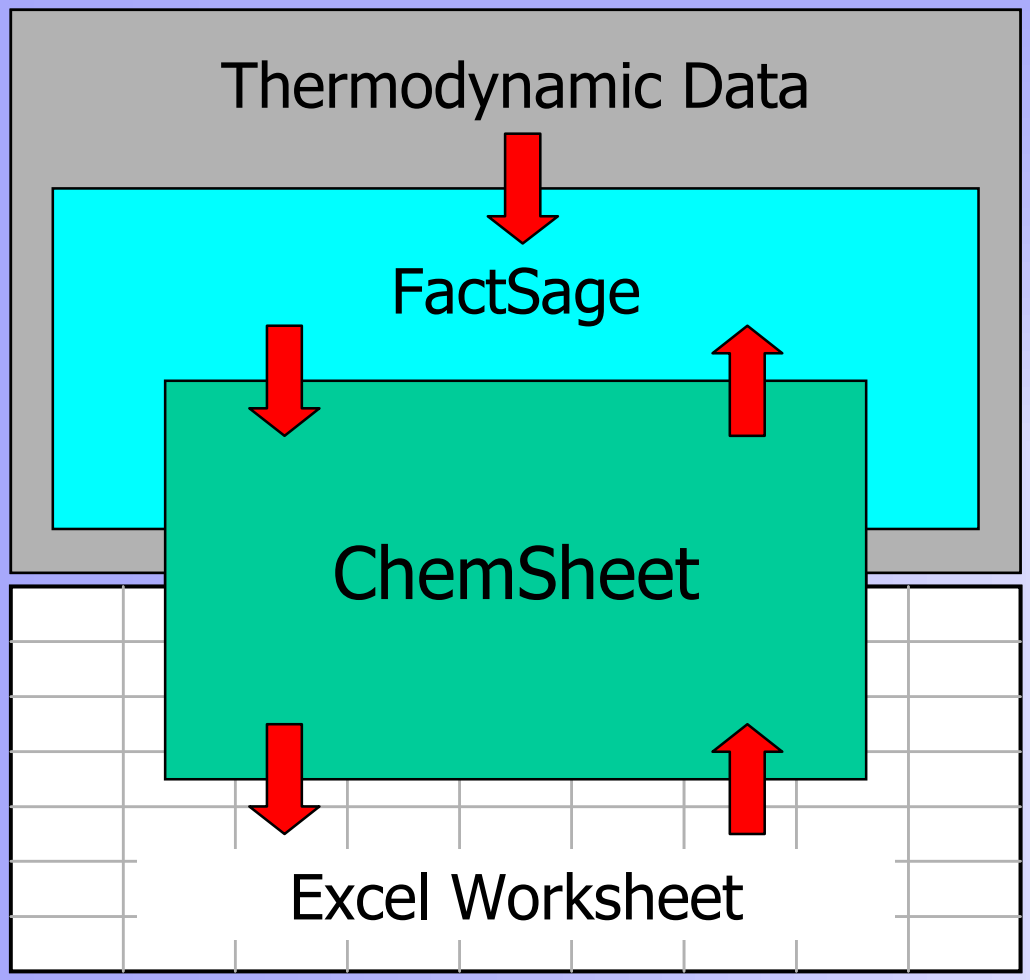
RH degasser



Principle of operation

Tools for computational calculations

FACT - Facility for the Analysis of Chemical Thermodynamics – the database for treating thermodynamic properties and calculations in chemical metallurgy



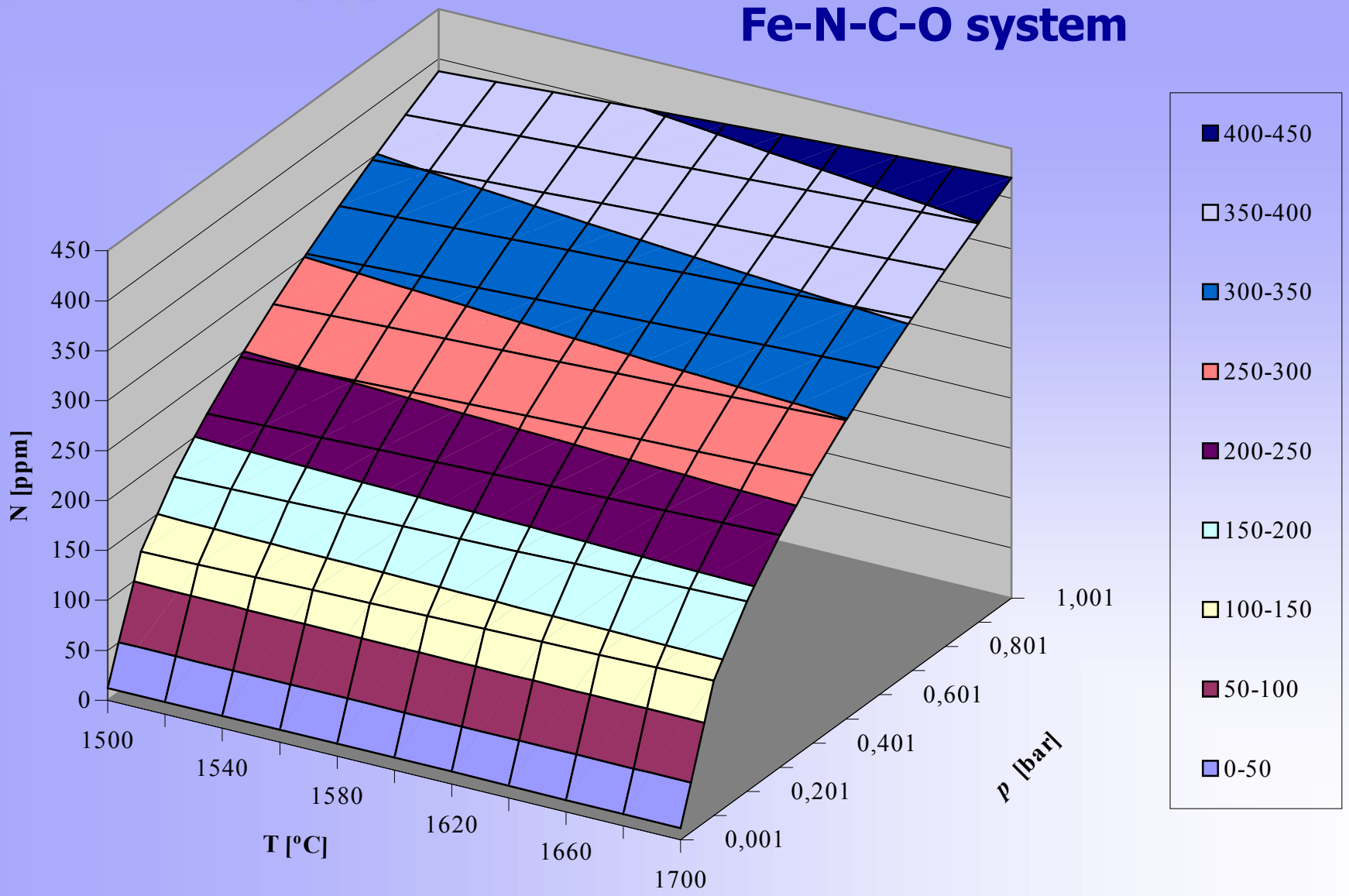
Dissolubility of nitrogen in liquid Fe solution

- **Temperature and pressure**
  chemical composition: 99,64% Fe, 0,15% N, 0,2% C, 0,01% O

- **Alloying components and pressure**
  Fe-N-alloying component system (Al, B, C, Ca, Co, Cr, Cu, Mn, Mo, Nb, Ni, O, P, Pb, S, Sb, Si, Sn, Ta, Ti, V, W, Zn)

Temperature and pressure

Fe-N-C-O system

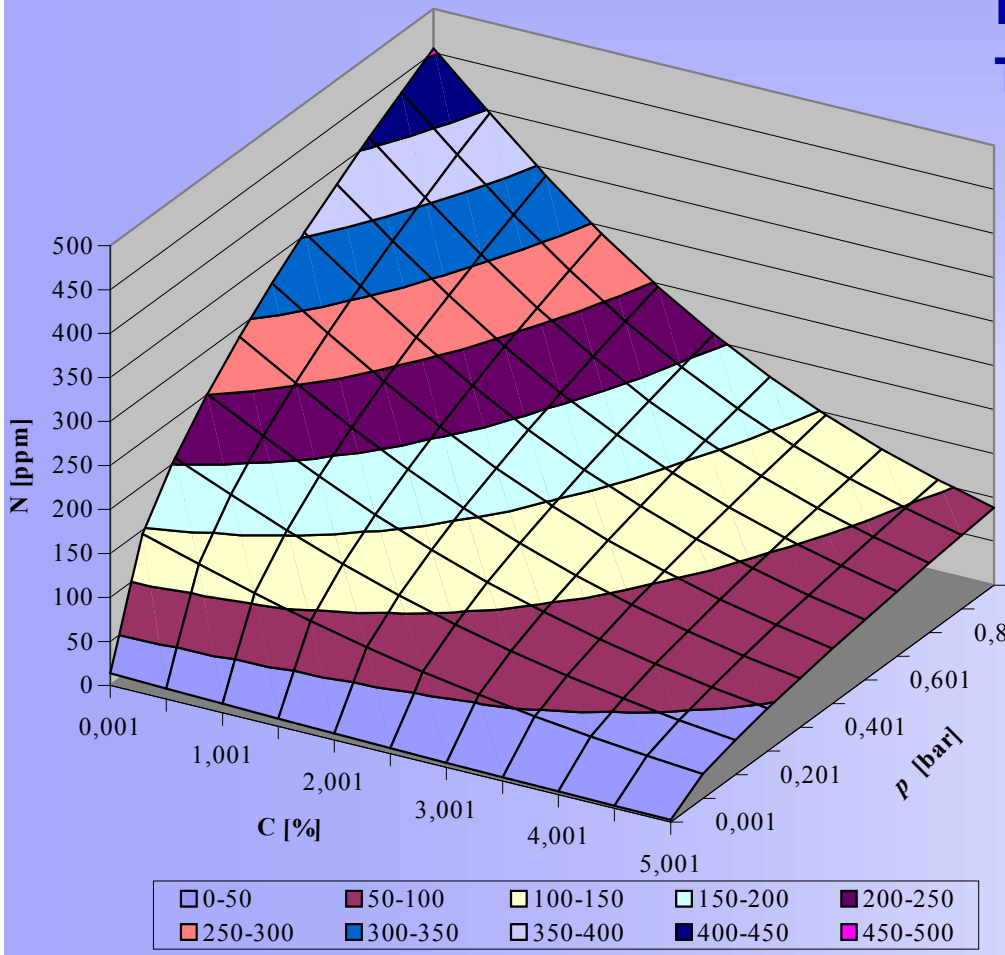


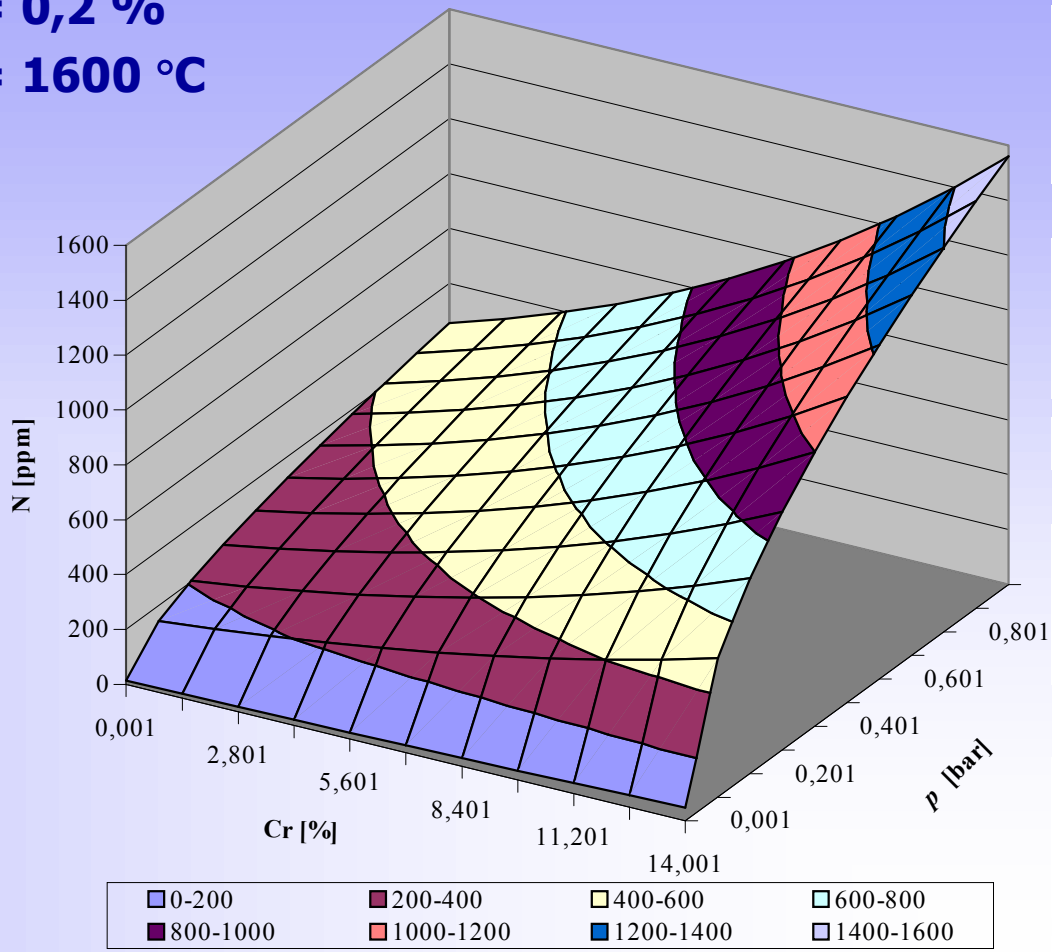
Alloying components and pressure

Fe-N-C system

Fe-N-Cr system

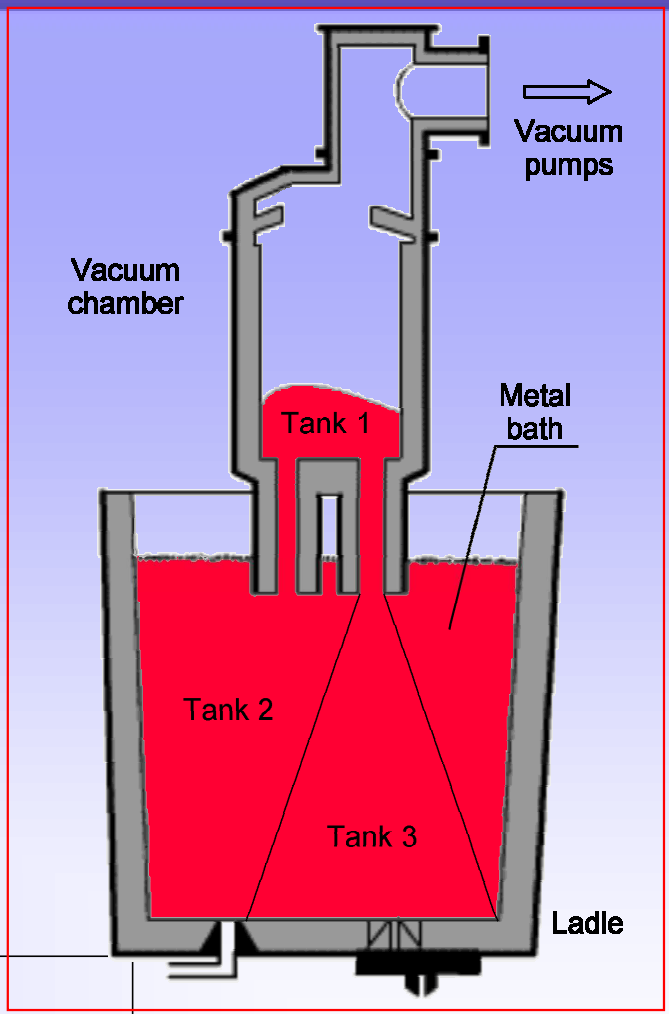
N = 0,2 %
T = 1600 °C





Mathematical model of RH vacuum degassing unit – Tank Model

Structure of Tank Model



Δm_{eq} (gasses)

Reactor 1
(vacuum chamber)
$m_1^{(i)}, M_1$

V_{13}

V_{21}

Scheme of flowrate streams

V_{32}

Reactor 2
(upper ladle region)
$m_2^{(i)}, M_2$

Reactor 3
(lower ladle region)
$m_3^{(i)}, M_3$

V_{23} V_{32} V_{21}

Arrangement of equations describing mass flow

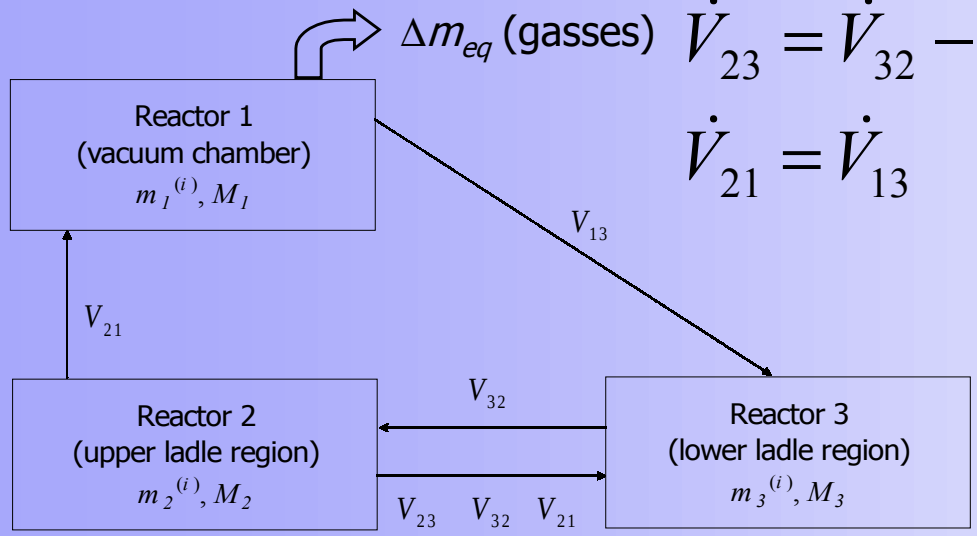
$$\mathrm{d}m_1 = -\frac{m_1}{M_1}\dot{V}_{13}\mathrm{d}t + \frac{m_2}{M_2}\dot{V}_{21}\mathrm{d}t$$

$$\mathrm{d}m_2 = \frac{m_3}{M_3}\dot{V}_{32}\mathrm{d}t - \frac{m_2}{M_2}\dot{V}_{23}\mathrm{d}t - \frac{m_2}{M_2}\dot{V}_{21}\mathrm{d}t$$

$$\mathrm{d}m_3 = \frac{m_1}{M_1}\dot{V}_{13}\mathrm{d}t + \frac{m_2}{M_2}\dot{V}_{23}\mathrm{d}t - \frac{m_3}{M_3}\dot{V}_{32}\mathrm{d}t$$

$$\dot{V}_{23} = \dot{V}_{32} - \dot{V}_{21}$$

$$\dot{V}_{21} = \dot{V}_{13}$$



m_i – mass of reactant in i^{th} reactor, [Mg],
M_i – mass of i^{th} elementary reactor, [Mg],
$\dot{V}_{ij}$ – flow rate of metal bath stream between i i j reactors, [Mg/min],
t – time, [min].

Mass of reactants in next step of calculations

Mixing model

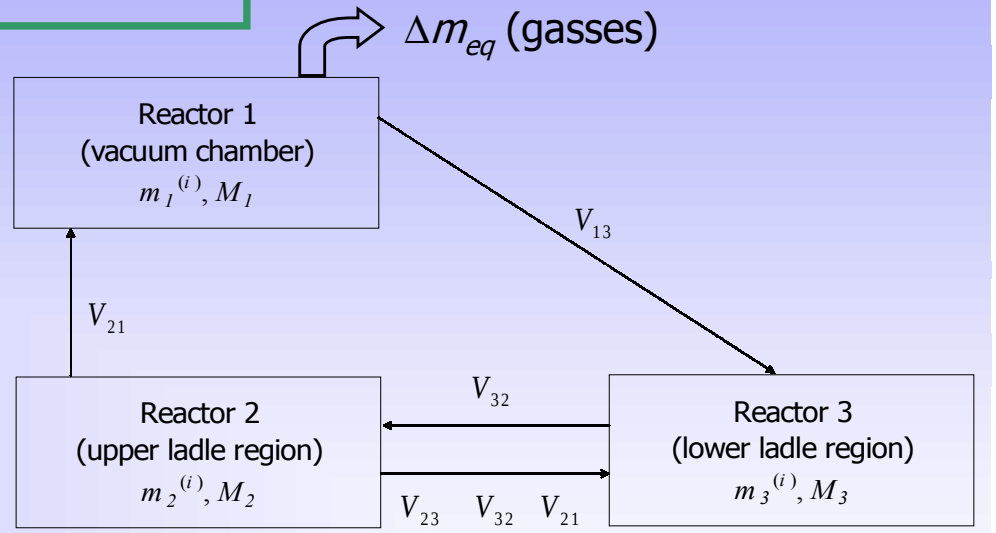
$$m_1(t+?t) = m_1(t) + dm_1(t) + ?m_{eq}(t)$$
$$m_2(t+?t) = m_2(t) + dm_2(t)$$
$$m_3(t+?t) = m_3(t) + dm_3(t)$$

Thermodynamic model

Input FactSage

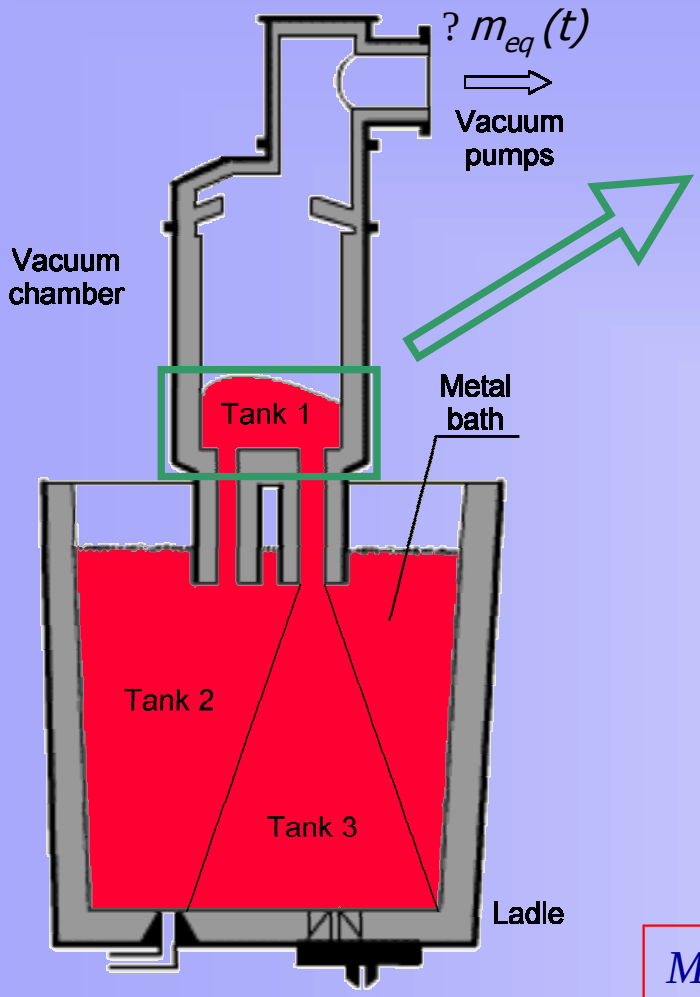
$$?m_{eq}(t) = m_{eq}(t) - \alpha \cdot m_1(t)$$

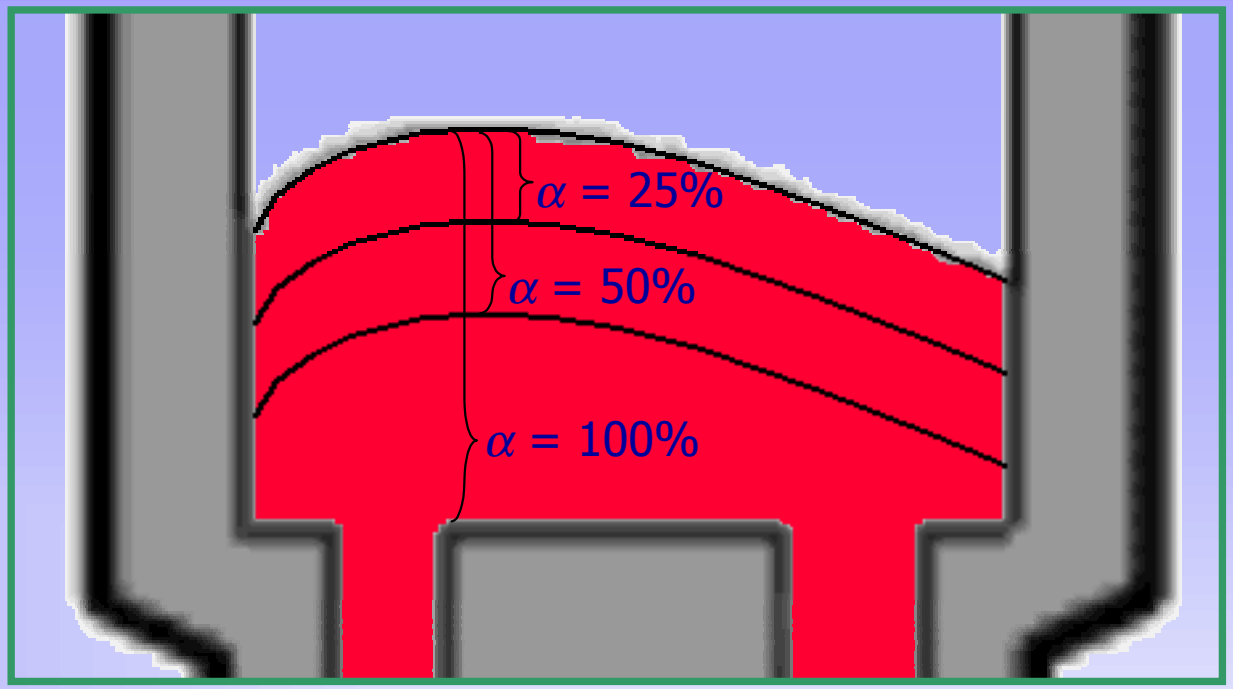
Output FactSage



m_{eq} – equilibrium mass of reactant in degassing metal bath region, [Mg],
α – factor of metal bath degassing in vacuum chamber, [%].

Factor of metal bath degassing in vacuum chamber - α



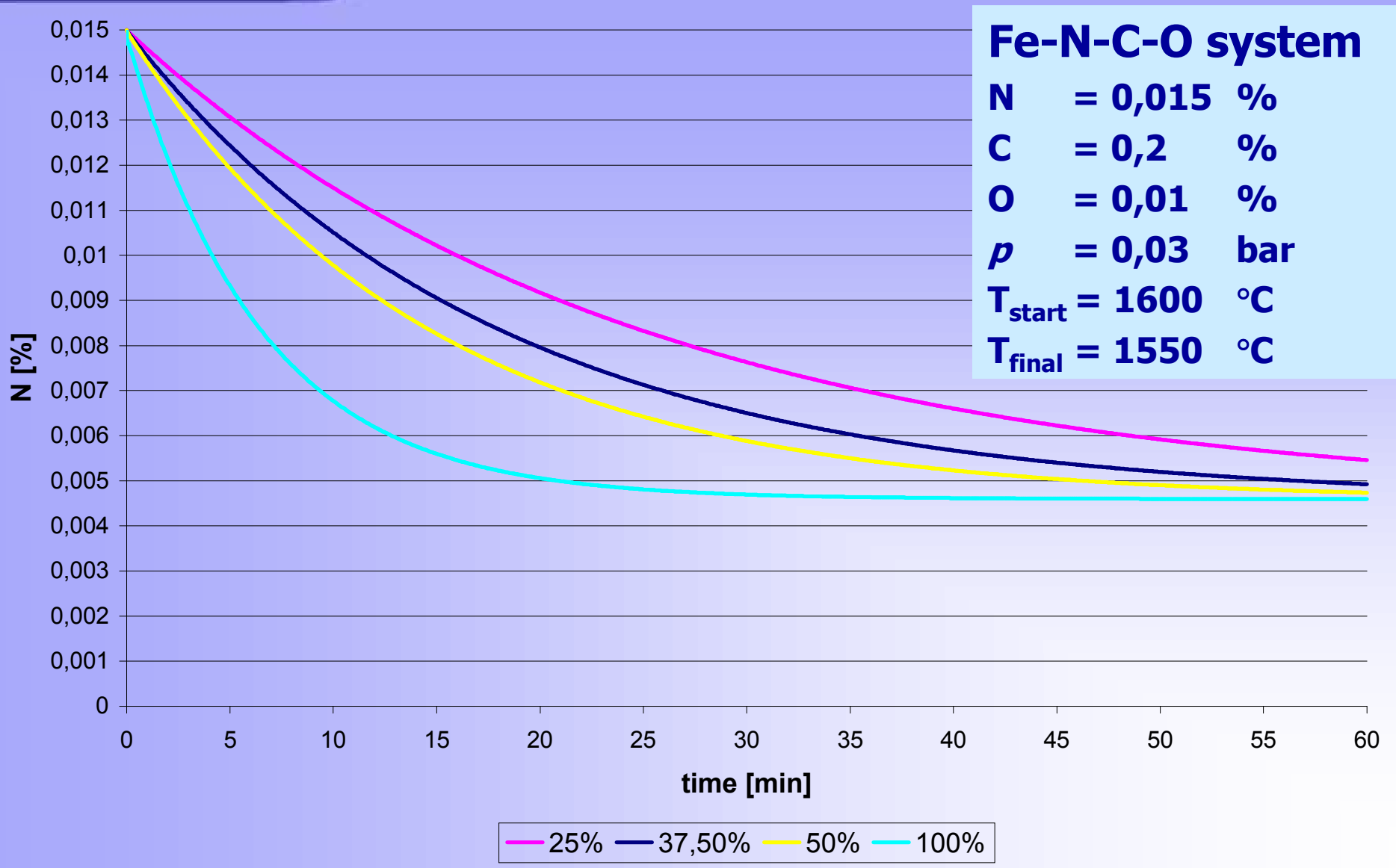


$$? m_{eq}(t) = m_{eq}(t) - \alpha \cdot m_1(t)$$

$$\frac{t}{t_R} \qquad t_R \quad \frac{M_1}{\dot{V}_{21}}$$

M_i – mass of i^{th} elementary reactor, [Mg],
$\dot{V}_{ij}$ – flow rate of metal bath stream between i i j reactors, [Mg/min],
t_R – residence time, [min]

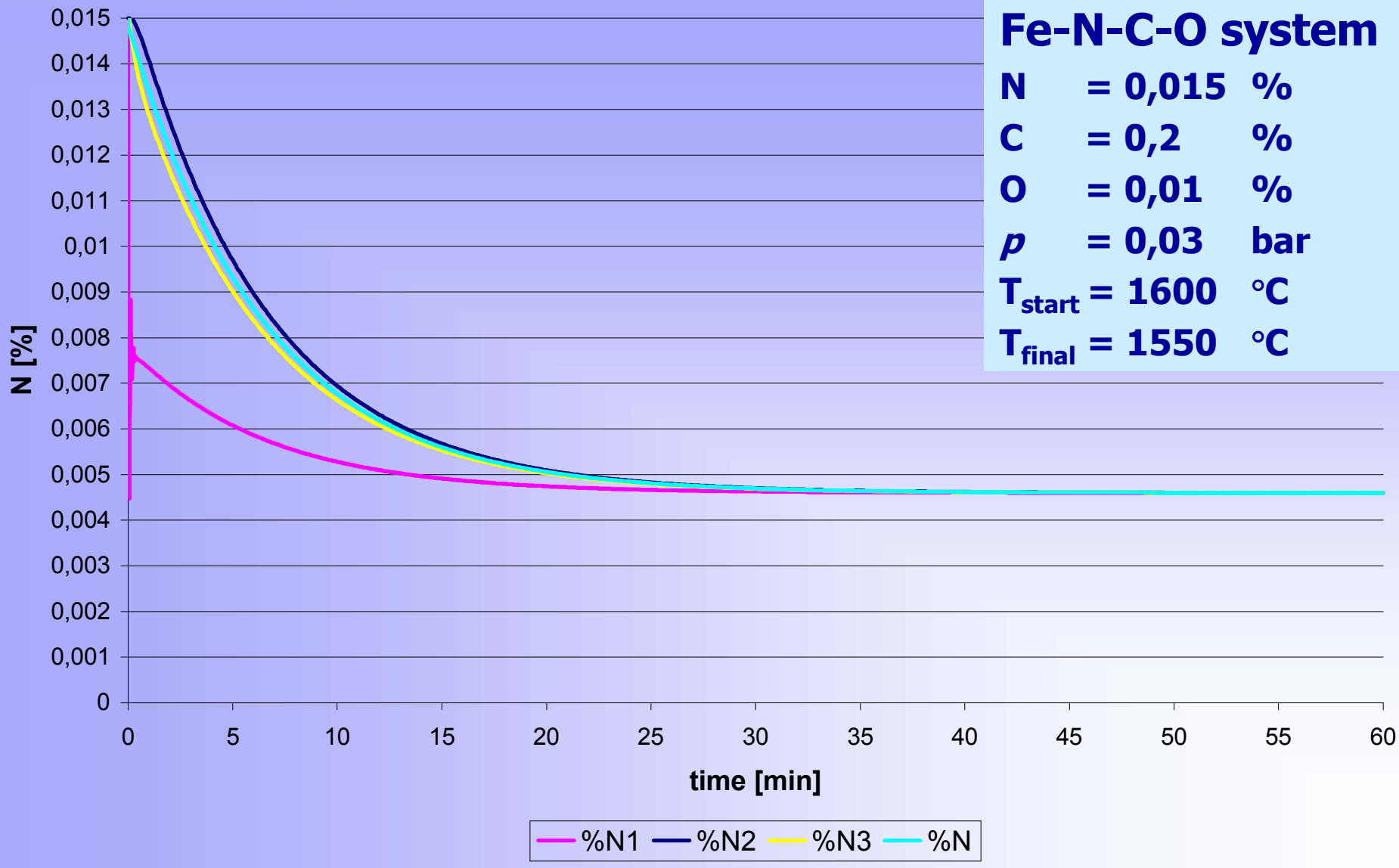
Influence of the degassing rate α



Fe-N-C-O system

N	= 0,015	%
C	= 0,2	%
O	= 0,01	%
p	= 0,03	bar
T_{start}	= 1600	°C
T_{final}	= 1550	°C

Change of nitrogen content in the reactors



Fe-N-C-O system

N	= 0,015	%
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T_{start}	= 1600	°C
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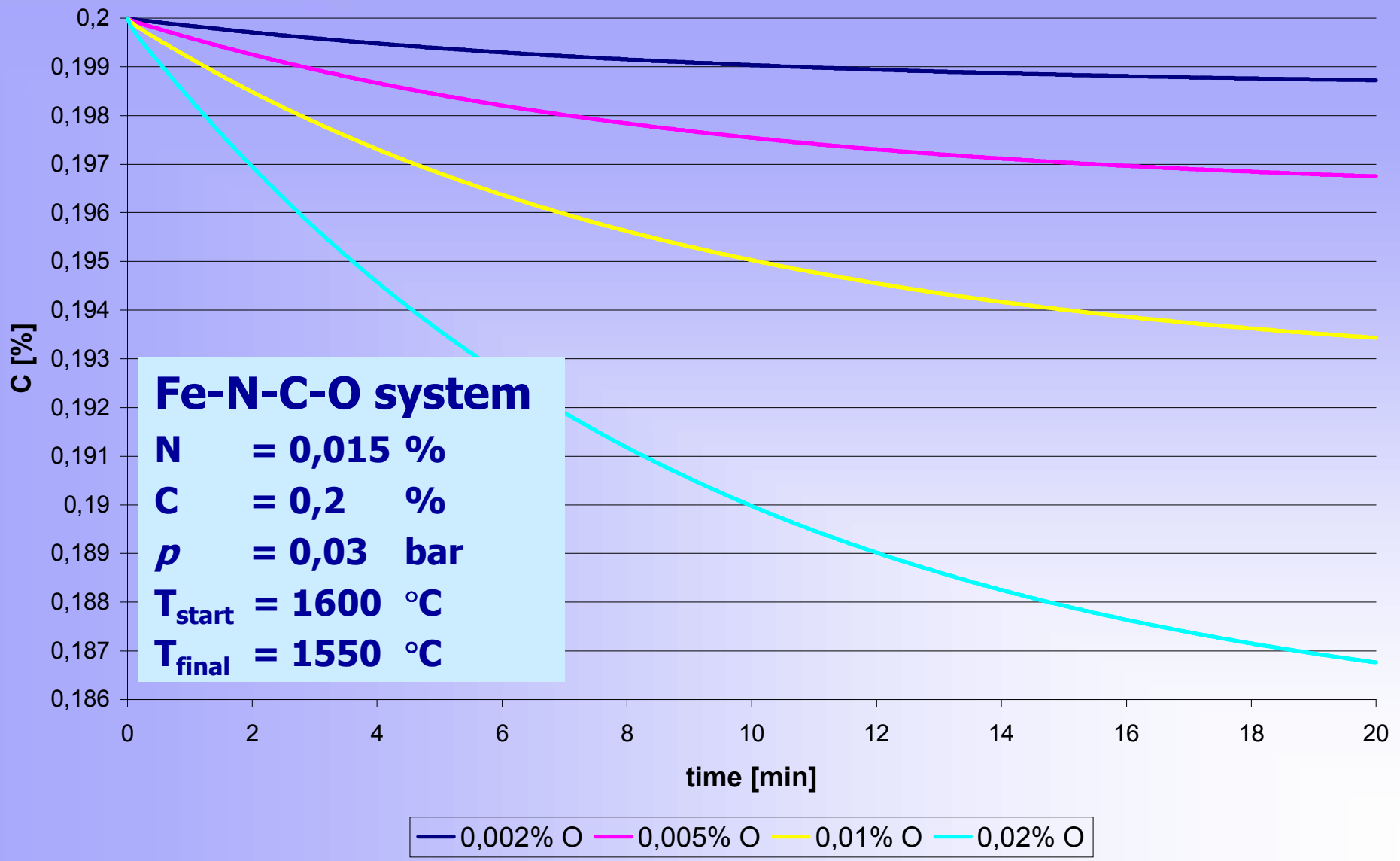
Content of oxygen influence



Fe-N-C-O system

N = 0,015 %

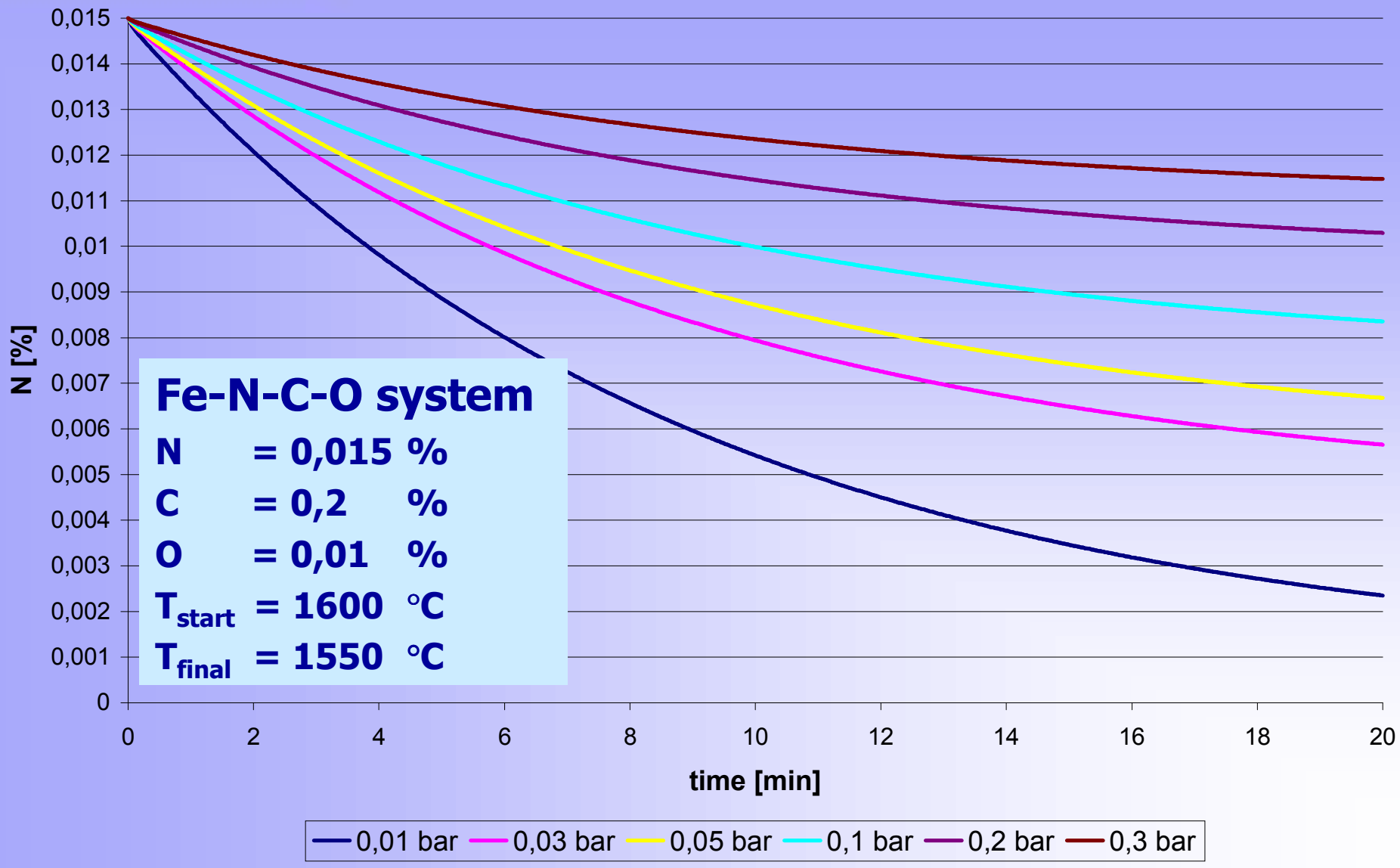
C = 0,2 %

p **= 0,03 bar**

T_{start} = 1600 °C

T_{final} = 1550 °C

Pressure influence



Verification

Fe-N-C-O-Cr-Mn-Si system

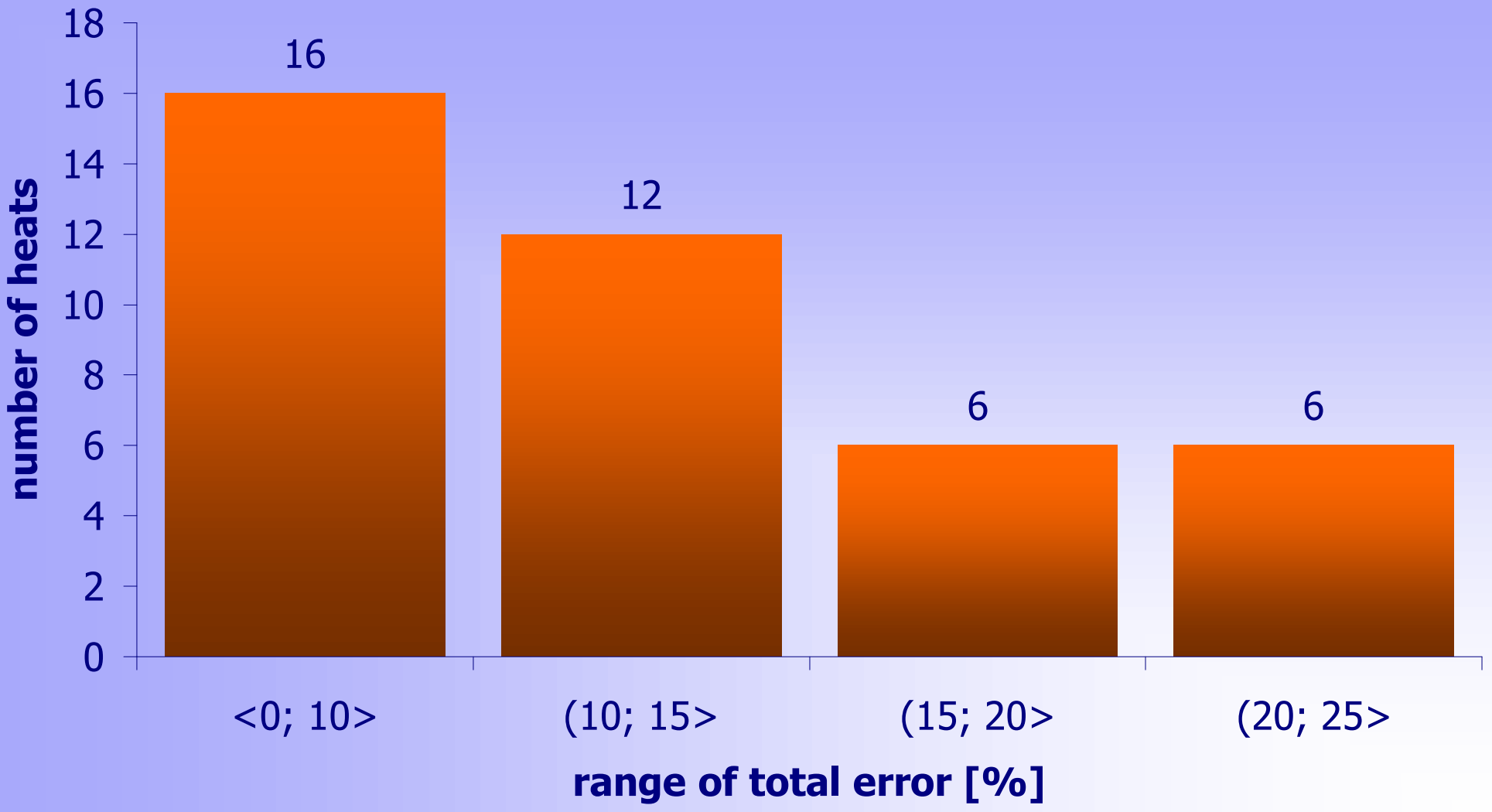
N = 0,015 %, O = 0,01 %

Simulation of 40 heats:

- **chemical compositions,**
- **temperature,**
- **pressure,**
- **alloying additives,**
- **time**

$[N]_{real}$ = 60 ppm ÷ 80 ppm

Verification



Conclusions

- **Level of vacuum has the greatest influence on equilibrium content of nitrogen in metal bath. Also affirmed small influence of temperature on dissolubility of nitrogen.**
- **Cr, Mn and Si as a main alloying components has maximum influence on final content of nitrogen**
- **Precision of received model permits to put possibility of use of him to virtual simulation helping difficult and expensive experimental investigations.**

Conclusions

- Created tool can become adopted to simulation of different processes of vacuum refining and to be of service to prognosing of final content of nitrogen in metal bath in industrial conditions into straight way.

- Computer programs FactSage and ChemSheet together with the FACT database permits the simulation of RH process based on the mixing model and thermodynamic model.

Thank you

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