SIMTEC

SisAl Pilot

Top-Blown Rotary Converter Preheating and Charge Heating with an Oxy-Fuel Burner

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The project has received funding from the European Union’s Horizon 2020 research and innovation program under Grant Agreement N°869268

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Outline

I. Background – Motivations – Objectives

II. Methodology and Numerical Model

III. Main Results

IV. Conclusions

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I. Background – Motivations – Objectives

Background

- EU Horizon 2020 project SisAl Pilot
- Optimization of the silicon production in Europe
- Recycling materials and using a carbon-emission friendly technology
- Silicon production experiments are conducted on laboratory and pilot scales
- Different types of furnaces
- The process optimisation relies on both the experiments and the numerical modelling

SisAl Pilot

NTNU Norwegian University of Science and Technology · SIMTEC · MINTEK · BNW ENERGY · Metlen Energy & Metals · RWTH AACHEN UNIVERSITY · BEFESA · Erimsa · Hydro · SINTEF · CIT MAGA · SBC · FUNDICIONES REY · WACKER · SiQAL Supplying the energy revolution · DOW · HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF · Silicor MATERIALS · Elkem A Bluestar Company · CiaoTech BY PNO GROUP · INNOVATION ENGINEERING BY PNO GROUP · Háskólinn í Reykjavík Reykjavik University

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SIMTEC : Fundamentals

- French Numerical modelling consultancy
- Leader in France of the COMSOL Certified Consultants, key partner worldwide
- 9 members Eng.D. + Ph.D.
- Main partners:
  - big international companies
  - laboratories
- Involved in the Research projects like EU FP (SHARK, SisAl Pilot) / PhD supervision

COMSOL Certified Consultant

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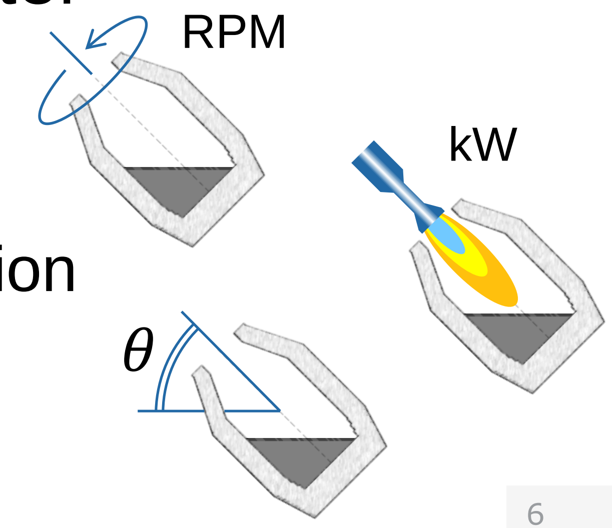
Motivations

- Modelling support of the pilot campaign of MINTEK
- Numerical testing of a new design of TBRC

Objectives

- Numerical modelling of a Top-Blown Rotary Converter
  - Optimise the TBRC rotation frequency
  - Determine the optimal burner power for TBRC operation
  - Determine the optimal inclination angle of TBRC



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II. Methodology and Numerical Model

Methodology

- Developing a numerical model / digital twin of new TBRC design with help of COMSOL Multiphysics®

- Performing multiple simulations to determine the best TBRC configuration

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Numerical Model

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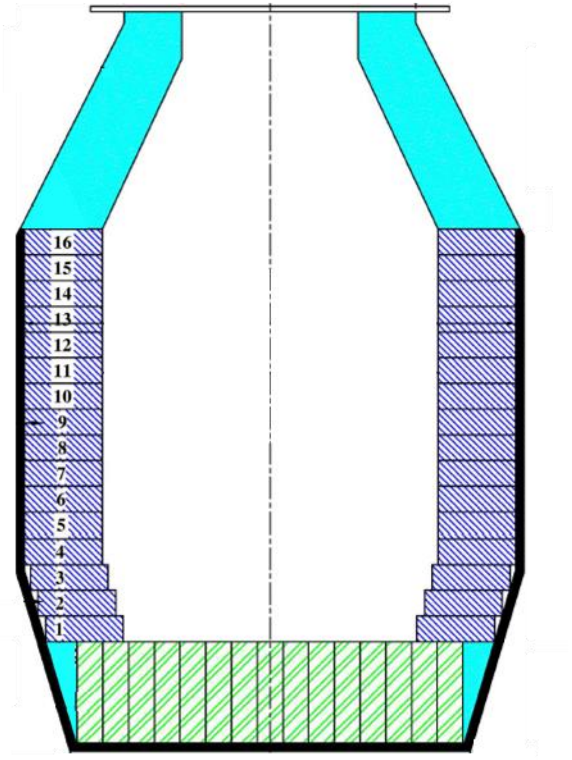
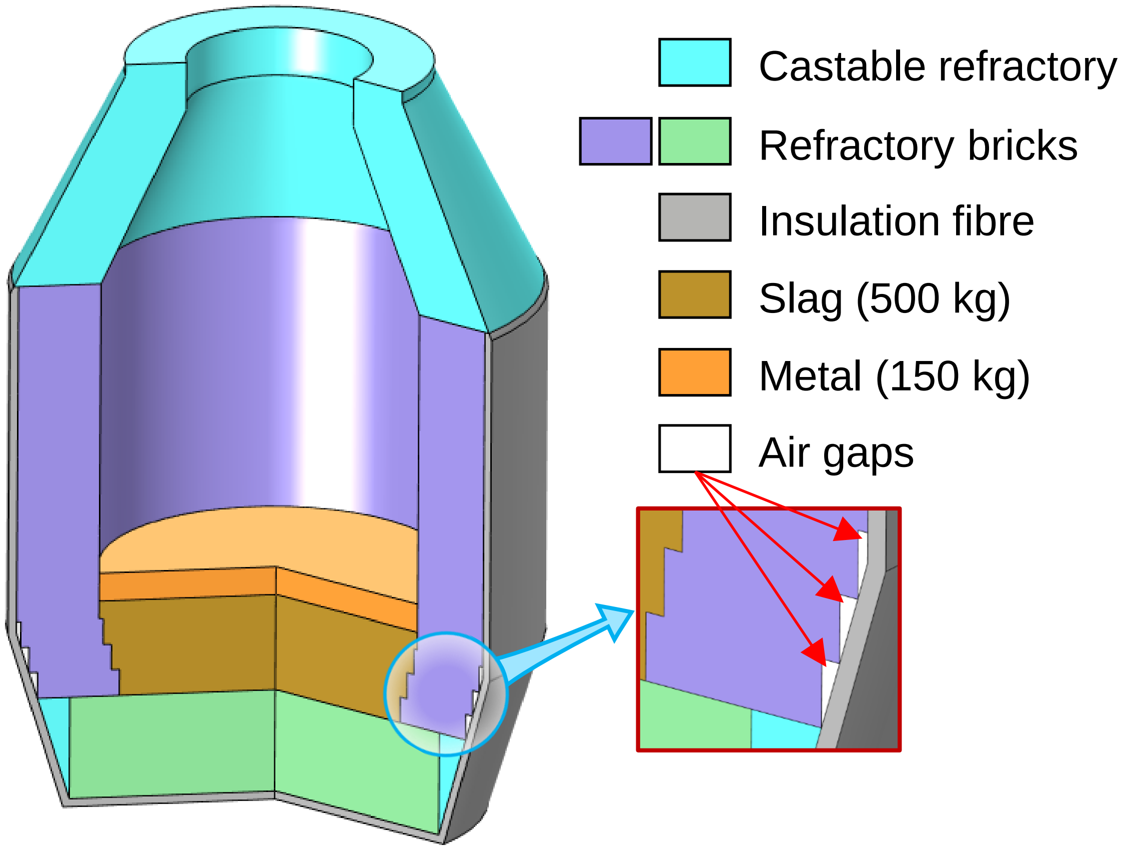
Geometry

- ▶ TBRC geometry is based on **MINTEK** technical drawings

MINTEK technical drawings



Numerical model geometry



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Material properties

► Properties of **furnace materials** are based on the data provided by **MINTEK**

Insulation fibre 1260 ST-RB

陶瓷纤维毯（卷毡）
Ceramic Fiber Blanket(Rolling Felt)
HENAN ANDY HIGH TEMPERATURE PRODUCTS CO LTD
Your Valuable Partner, A leading supplier,A Superstore Since 2003.
In Advanced High Thermal Material And Equipment with high quality.

产品技术参数 Technical Index

陶瓷纤维毯 Ceramic Fiber Blanket		1050 C-RB	1260 ST-RB	1260 HP-RB	1350 HA-RB	1400 LZ-RB	1430 HZ-RB	1500 Cr-RB	1600 PCF-RB
最高使用温度（℃） Max Service Temperature		1050	1260	1260	1350	1400	1430	1500	1600
体积密度（KG/m³）Density		96/128/140/160							130-170
永久线变化%（24h,128 Kg/M³）Liner Shrinkage		≤4.0 950℃	≤4.0 1050℃	≤4.0 1100℃	≤4.0 1200℃	≤4.0 1250℃	≤4.0 1350℃	≤4.0 1400℃	≤1.0 1500℃
抗拉强度 Kpa(128Kg/M³) Tensile Strength		70	75	75	55	75	75	55	75
导热系数(W/m.k) 128 Kg/M³ Thermal Conductivity Rate	600℃	0.20	0.15	0.15	-	-	-	-	-
	800℃	0.29	0.22	0.21	0.21	0.21	0.21	0.19	0.19
	1000℃	-	0.31	0.30	0.31	0.31	0.31	0.28	0.28
化学组成（%）（灼减后）Chemical Composition(After burning)	Al_2O_3	≥38	≥42	≥45	52-55	≥37	≥37	≥37	≥70
	$Al_2O_3+SiO_2$	≥97.0	≥98.0	≥98.0	≥98.0	≥92	≥83	≥93	≥99
	ZrO_2	-	-	-	-	5-7	15-17	-	-
	Cr_2O_3	-	-	-	-	-	-	3-5	-
	Others	≤3.0	≤2.0	≤2.0	≤2.0	≤2.0	≤2.0	≤2.0	≤1.0

推荐使用温度：在氧化性或中性气氛下，比最高使用温度低 100℃-250℃，在还原性气氛下，比最高使用温度低 200℃-350℃。Recommended using temperature: In oxidizing or neutral atmosphere, 100 ~250℃ lower than the maximum service temperature, In reductive atmosphere, 200 ~350℃ lower than the maximum service temperature.

产品规格及包装 Standard Size and Package

长度（Length）mm	宽度(Width)mm	厚度(Thickness)mm
7200/14400/28000	610(1220)	6
7200/14400	610(1220)	10/12.5
7200/10000	610(1220)	15
7200	610(1220)	20/25
6000/5000	610(1220)	30
4500/3600	610(1220)	40/50
包装（Package）	纸箱或编织袋（Cartons or woven bags）	
其它尺寸可依照客户要求制作(Other specifications according to customer's inquires)。		

Andy Group - HENAN ANDY HIGH TEMPERATURE PRODUCTS CO LTD
No 36 HongSong Road, High-Tech Zone, Zhengzhou city, Henan Provice,China.
Cell Phone or Wechat: 86-138-3855 0579 136-3384 7323 QQ: 20911 64858 Skype: ANDY.GROUP
FACEBOOK: https://www.facebook.com/andylau198 Email: sales@andygroup.com shiransophie@hotmail.com

3

Castable refractory L-Cast 18

REFRACTORY & METALLURGICAL SOLUTIONS
www.rmsolution.co.za

ALUMINO – SILICATE: HI-TECH LOW CEMENT CASTABLES CONTINUED

PRODUCT NAME	L-Cast 171B *	L-Cast 18 *	L-Cast 180 *
Raw Material Base	Chrome Alumina	Tab/Fused Alumina	Fused Alumina
CHEMICAL ANALYSIS (%)			
SiO_2	5.4	5.1	5.6
Al_2O_3	82.1	91.8	89.7
Fe_2O_3	0.6	0.1	0.3
CaO / MgO	2.1	1.8	1.7
TiO_2	0.1	0.8	2.1
Cr_2O_3	8.1	-	-
PHYSICAL PROPERTIES			
Max. service temperature (°C)	1750	1800	1800
Bulk Density (Kg/m³)	2950	2940	2910
Cold Crushing Strength (MPa)	62	72	69
Grading: Max Size (mm)	6	6	6
Water required (~%)	5.5	5	5

Typical data, not for specification purposes.

* All products are registered proprietary products from our partner LTM Technologies, with RMS having exclusive distribution rights, other than LTM Technologies, for these products

Application For areas requiring high strength, abrasion, chemical and mechanical resistance. Typical uses are ladles for PGM's and base metal operations, launders, metal/matte/slag transport systems, furnace roofs and delta sections, rotary kilns and driers. Contact us for more information regarding your applications.

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Exceeding Expectations

Refractory bricks VR 90B

TECHNICAL DATABOOK | Refractory & Metallurgical Solutions |

ALUMINA – SILICATE: EXTRA HIGH ALUMINA BRICK

PRODUCT NAME	VR 85	VR 90B	VR 90BR
TYPE OF PRODUCT	MULLITE BONDED HIGH ALUMINA	MULLITE BONDED TABULAR ALUMINA	MULLITE BONDED TABULAR ALUMINA
RAW MATERIAL BASE	Bauxite	Tab or white fused alumina	Tab or white fused alumina
CHEMICAL ANALYSIS (%)			
SiO_2	11,8	9,0	9,5
Al_2O_3	83,0	90,0	88,0
Fe_2O_3	1,5	0,2	0,3
TiO_2	3,0	0,2	0,2
CaO / MgO	} 0,4	} 0,2	} 0,9
$Na_2O + K_2O$	0,3	0,4	0,5
Cr_2O_3	-	-	-
PHYSICAL PROPERTIES			
PCE Orton Cone	36	40	40
App. porosity (%)	20,0	16,0	18,0
Bulk density (kg/m³)	2760	2900	2750
App. specific gravity	3,45	3,48	3,25
Cold crushing strength (MPa)	50	90	45
Permanent linear change 2 hours at 1600° C (%)	0	0	0
Modulus of rupture at room temp. (MPa)	16	18	18
Thermal conductivity at 1000° C (W/mK)	2,3	1,4	1,4
Thermal expansion 20° – 1000° C (%)	0,7	0,7	0,7
Spalling resistance	Very Good	Excellent	Excellent

Typical data, not for a specification purpose.

VR 85 | Abrasion resistant fired high alumina brick for use in steel casting and process la arc furnace roofs, submerged arc furnace sub-hearths, lime, and cement rotary kilns.

VR 90B | A high alumina mullite bonded brick with excellent spalling resistance, utilised i hole blocks and petrochemical reactors.

VR 90BR | VR90B specifically modified to improve thermal cycling performance applications of non-direct contact with molten materials and where thermal shock resist is important like roof dome brick for DC and AC electric arc furnaces.

10 | Customised to meet the needs of tomorrow |

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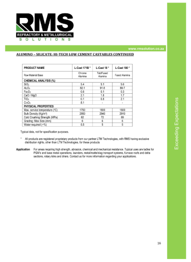
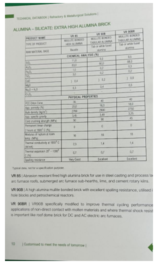
Castable refractory L-Cast 18



Refractory bricks VR 90B



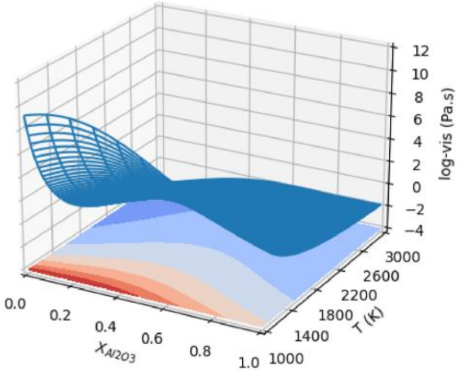
- ► Slag viscosity is extracted from…

CALPHAD: Computer Coupling of Phase Diagrams and Thermochemistry 77 (2022) 102421

Rheological properties of Al_2O_3–CaO–SiO_2 slags

Kai Tang [a,*], Casper van der Eijk [a], Sylvain Gouttebroze [b], Qiang Du [b], Jafar Safarian [c], Gabriella Tranell [c]

[a] *SINTEF Industry, N-7465, Trondheim, Norway*
[b] *SINTEF Industry, N-0314, Oslo, Norway*
[c] *Department of Materials Science and Engineering, Norwegian University of Science and Technology, Trondheim, Norway*



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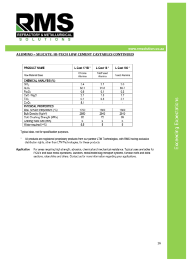

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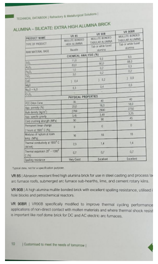

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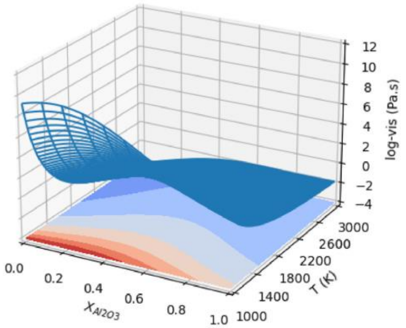

- ► Slag thermal conductivity = 1 W/m/K
- ► Other slag properties → Ken Mills model

K. C. Mills et al., "Estimating the physical properties of slags," J. S. Afr. Inst. Min. Metall., vol. 111, no. 10, pp. 649-658, 2011

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Physics

- Heat transfer with phase change
- Surface-to-surface radiation
- Fluid mechanics (k-ω model)

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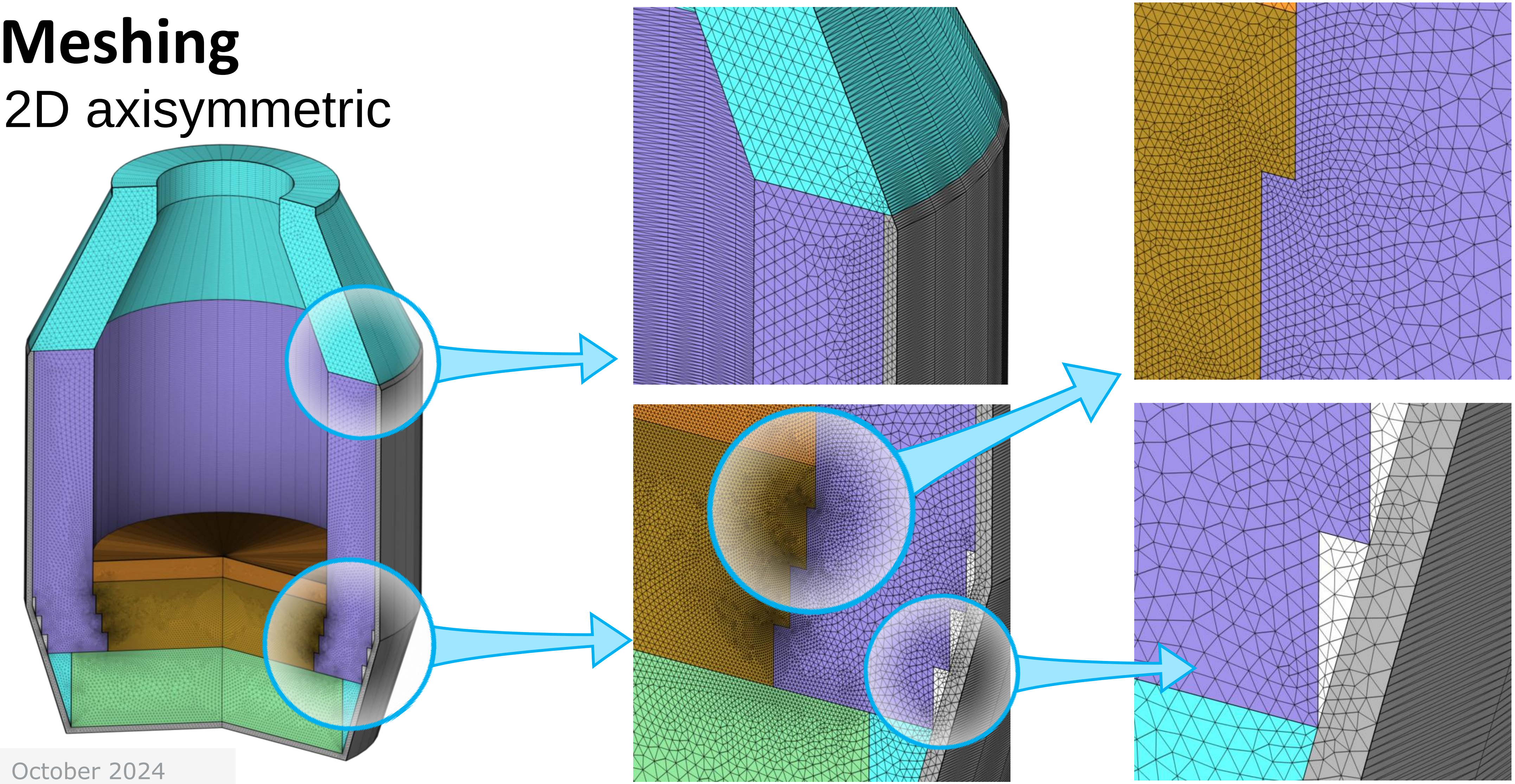
Meshing

2D axisymmetric



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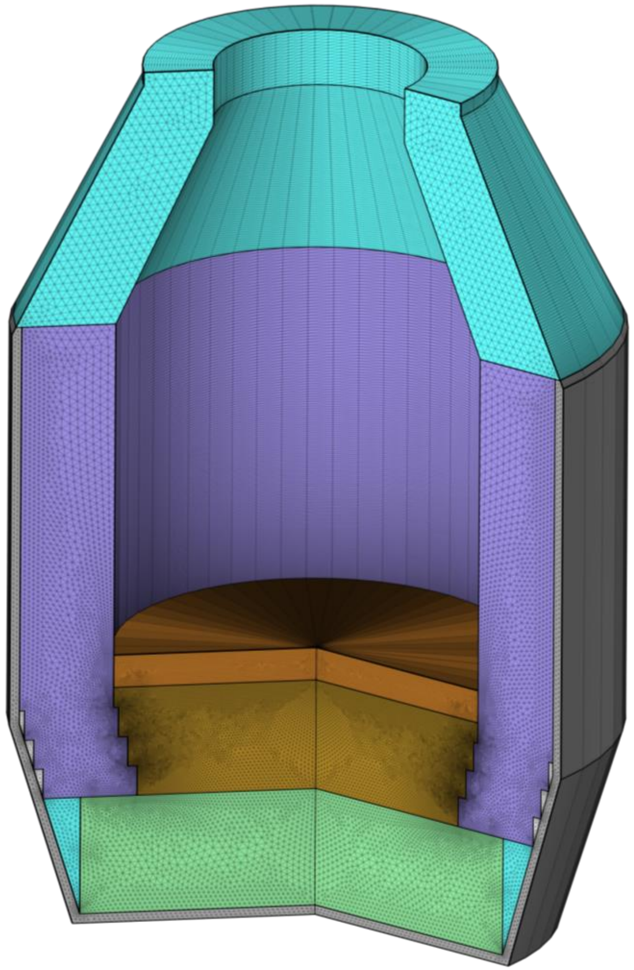
Meshing

2D axisymmetric

- ► 27 600 finite elements
- ► 220 700 degrees of freedom



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III. Main Results

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TBRC preheating

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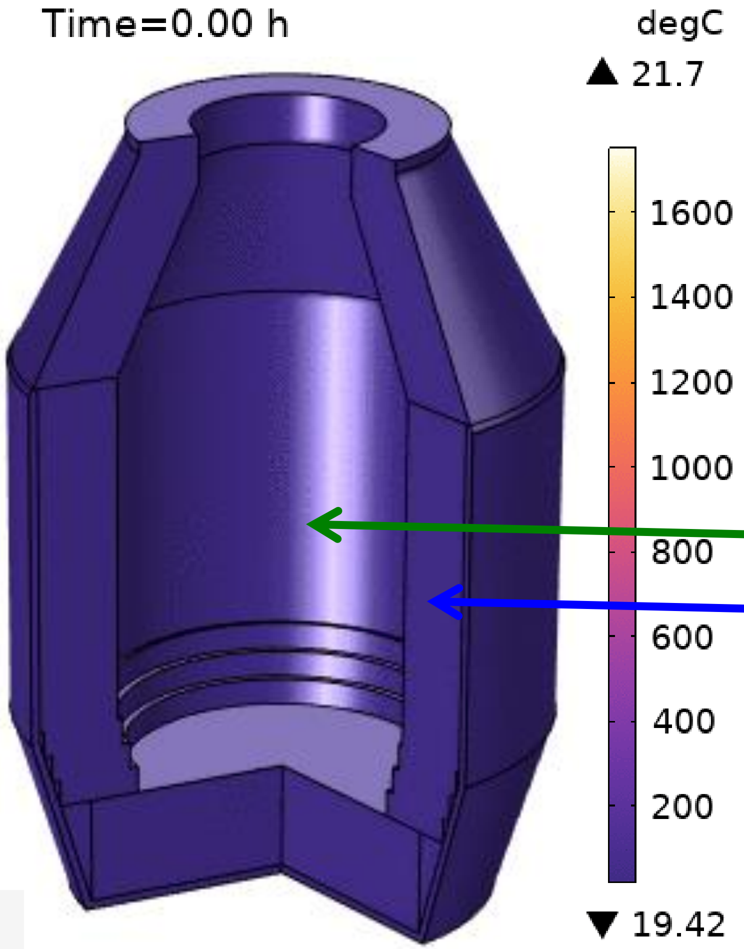
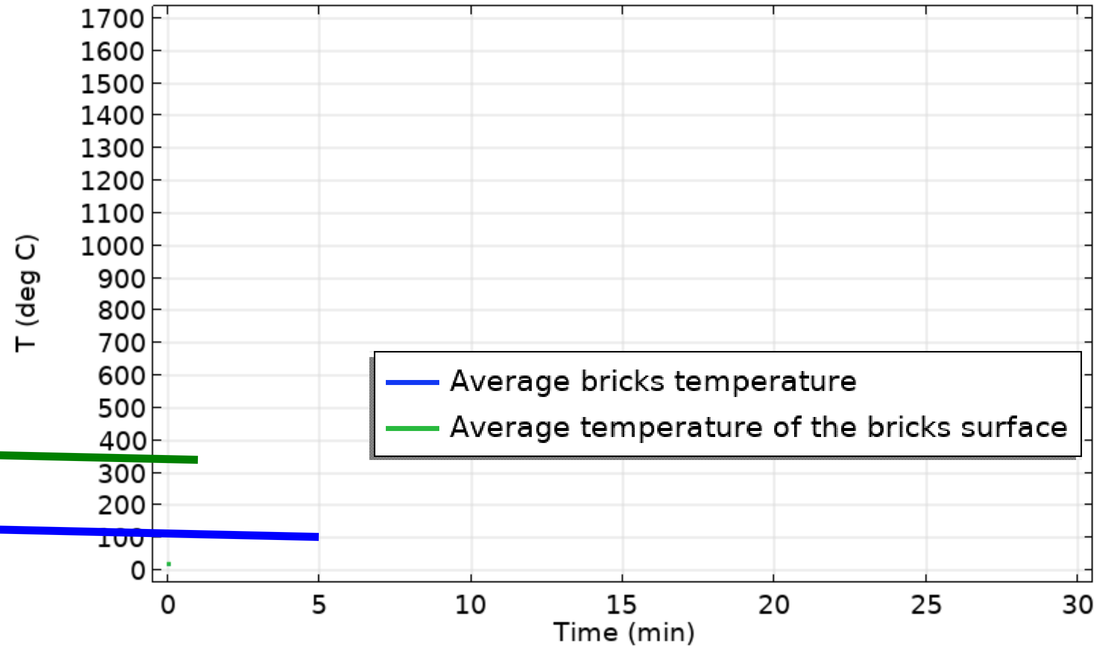
TBRC preheating

Temperature field (first 30 min)



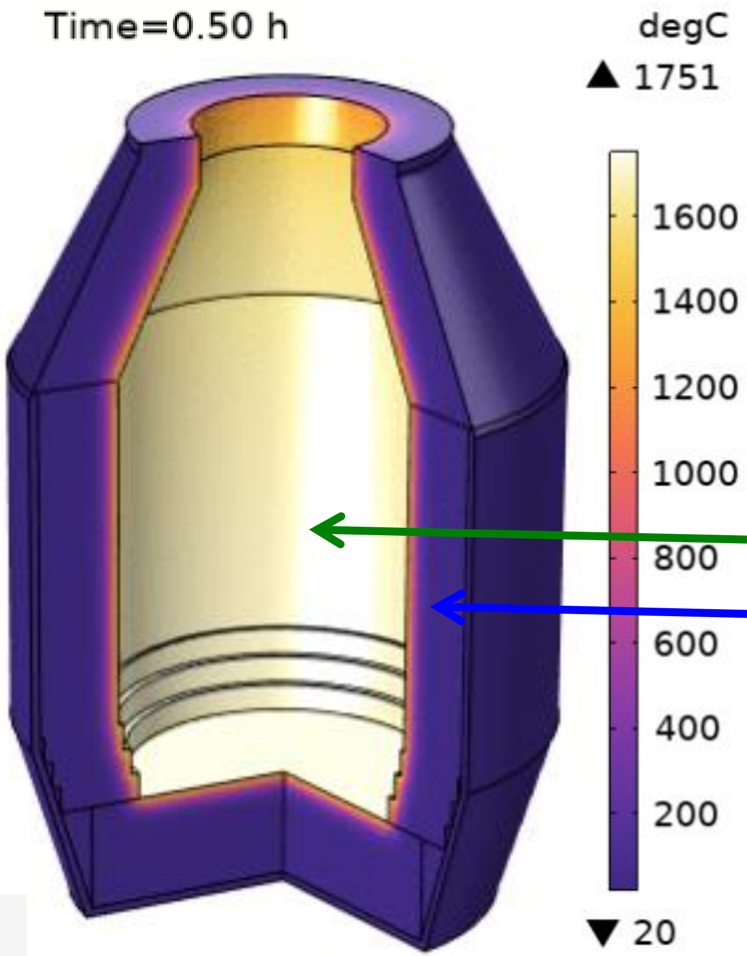
Average temperatures (first 30 min)



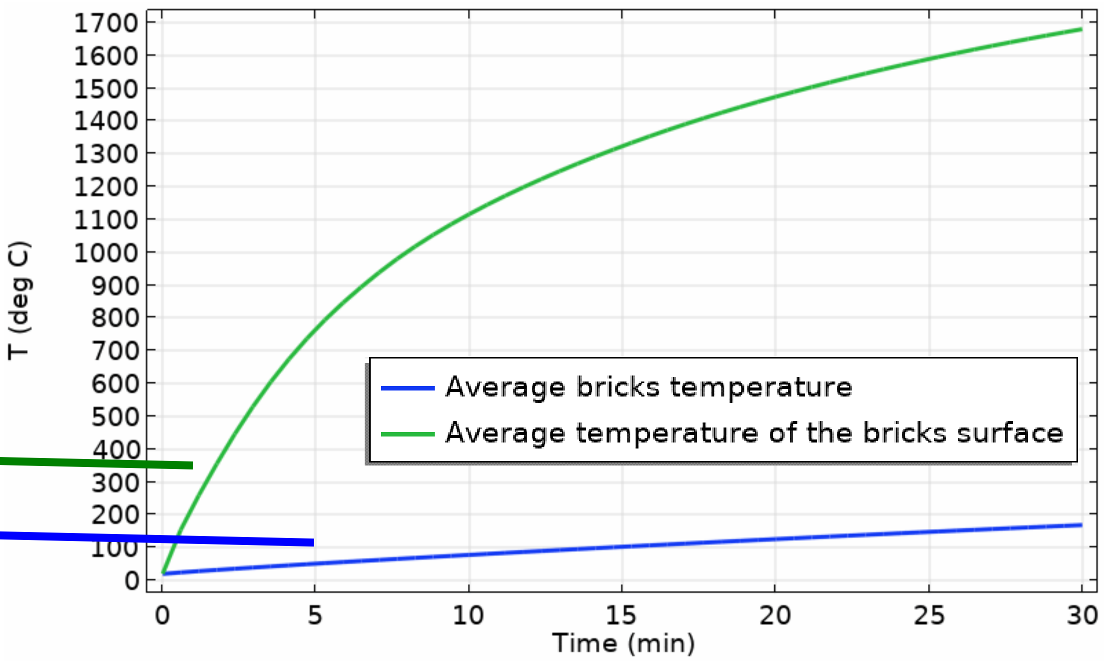
→ Input power : 600 kW

TBRC preheating

Temperature field



Average temperatures (first 30 min)



→ Input power : 600 kW

→ TBRC preheating up to 1650°C is possible in less than 30 min

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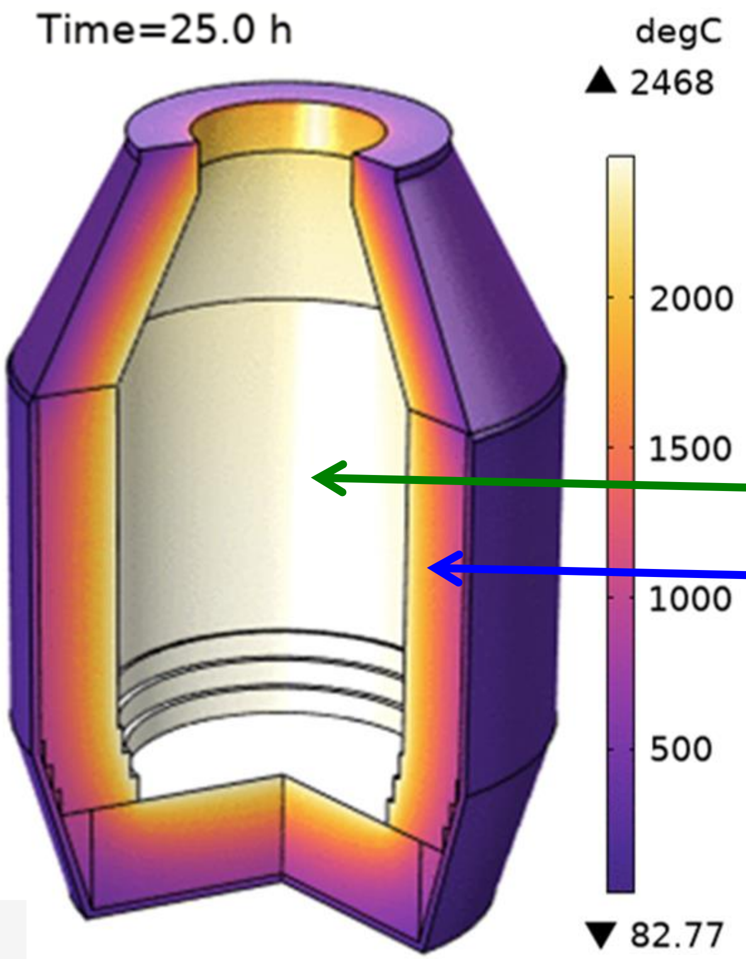
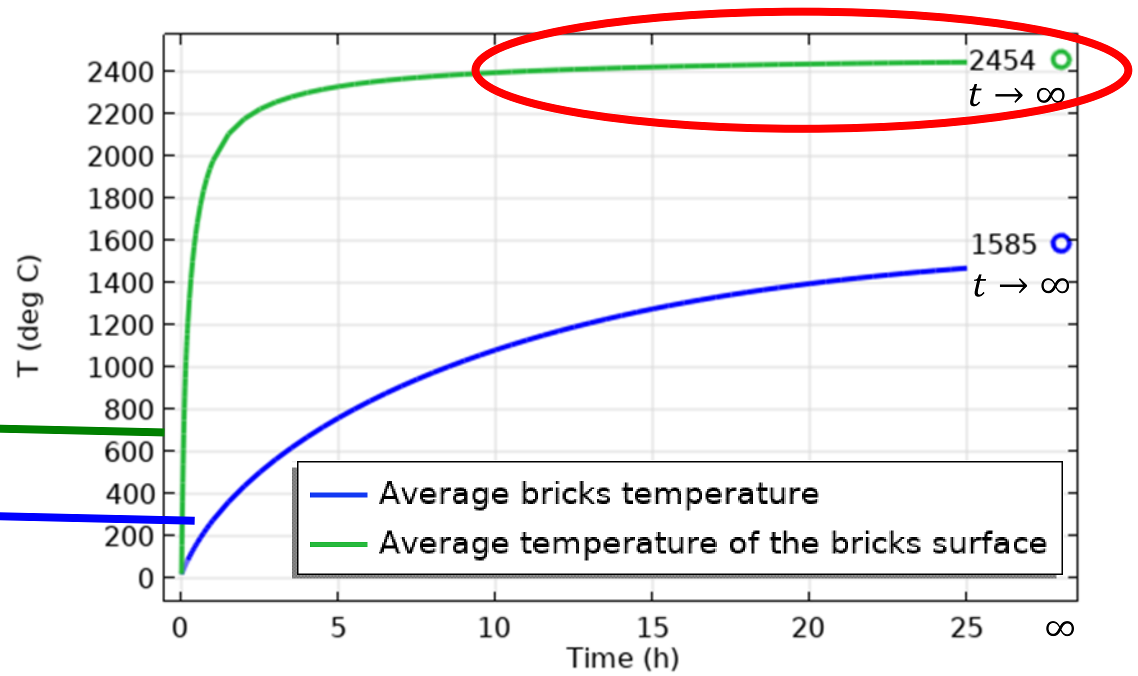
TBRC preheating

Temperature field



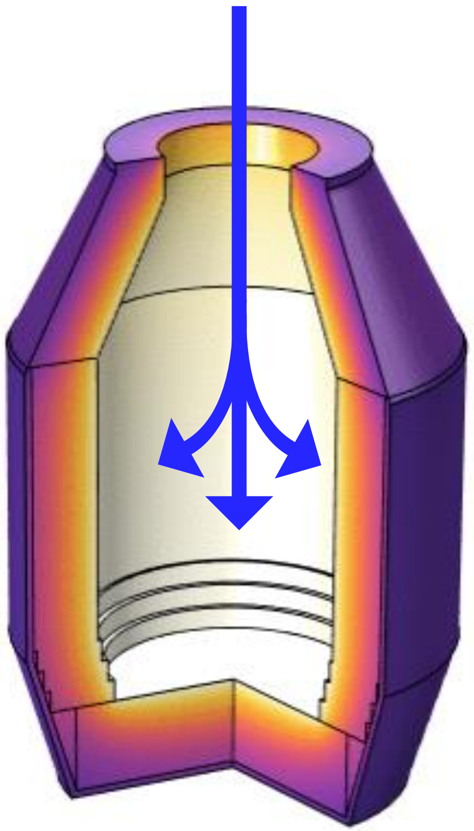
Average temperatures (first 25 h)

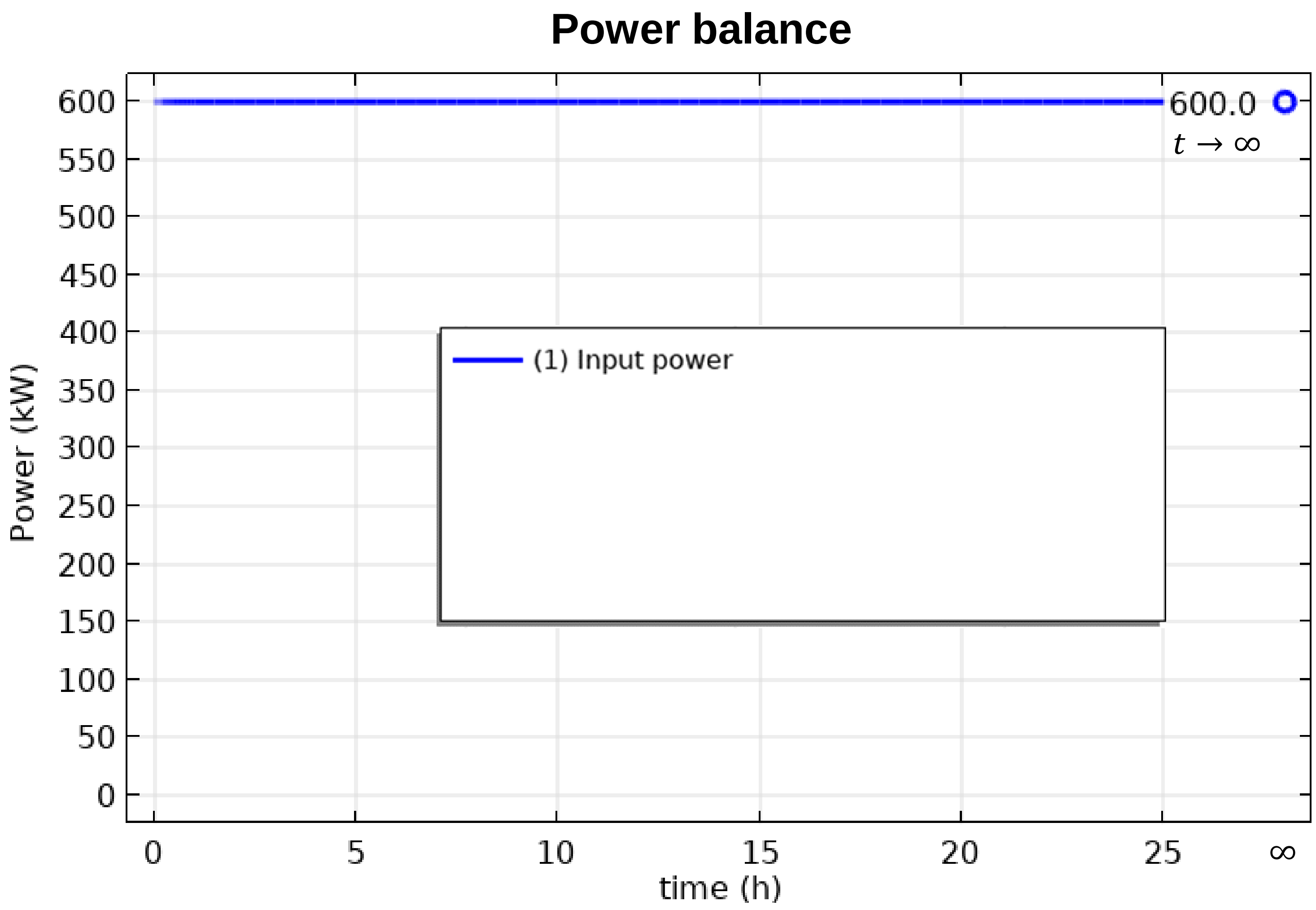


→ Input power : 600 kW

→ The average temperature of the bricks surface is almost constant after ≈ 12 h of preheating

TBRC preheating





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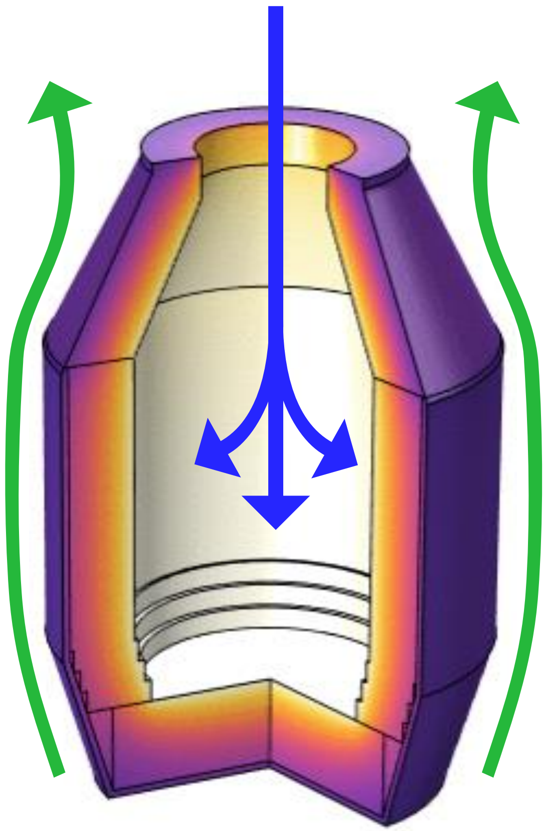
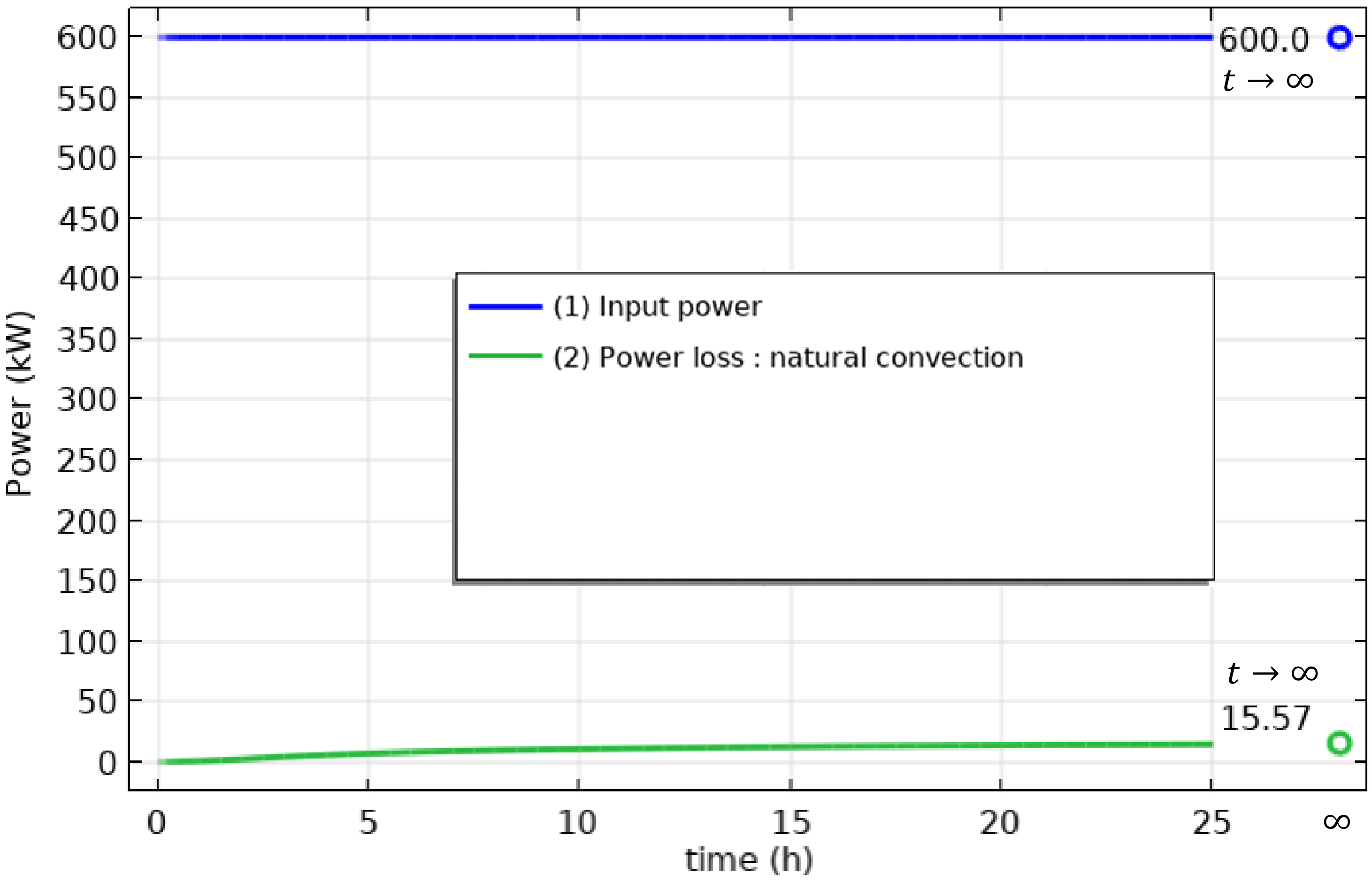
TBRC preheating



Power balance



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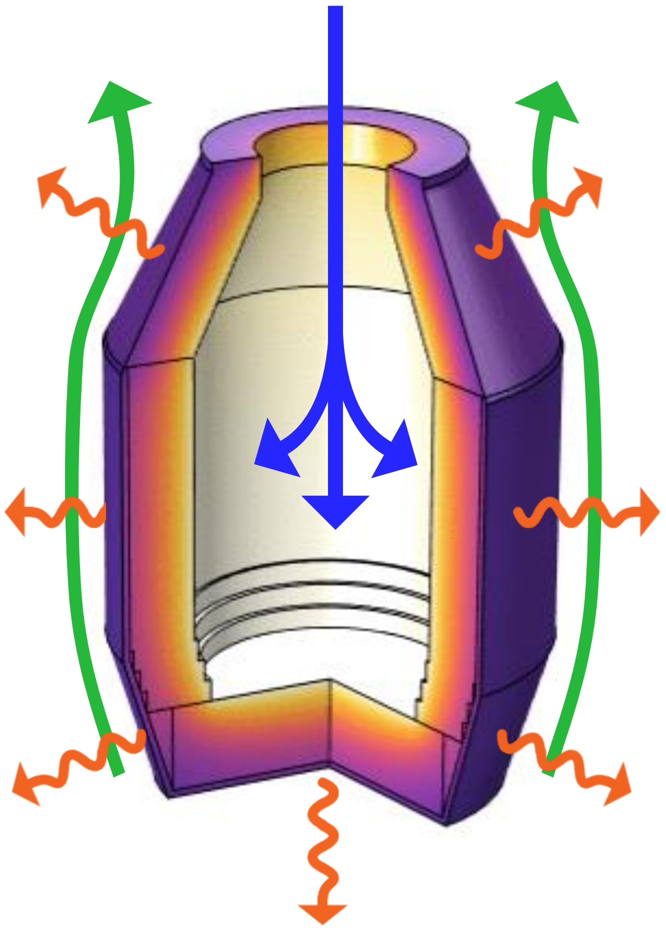

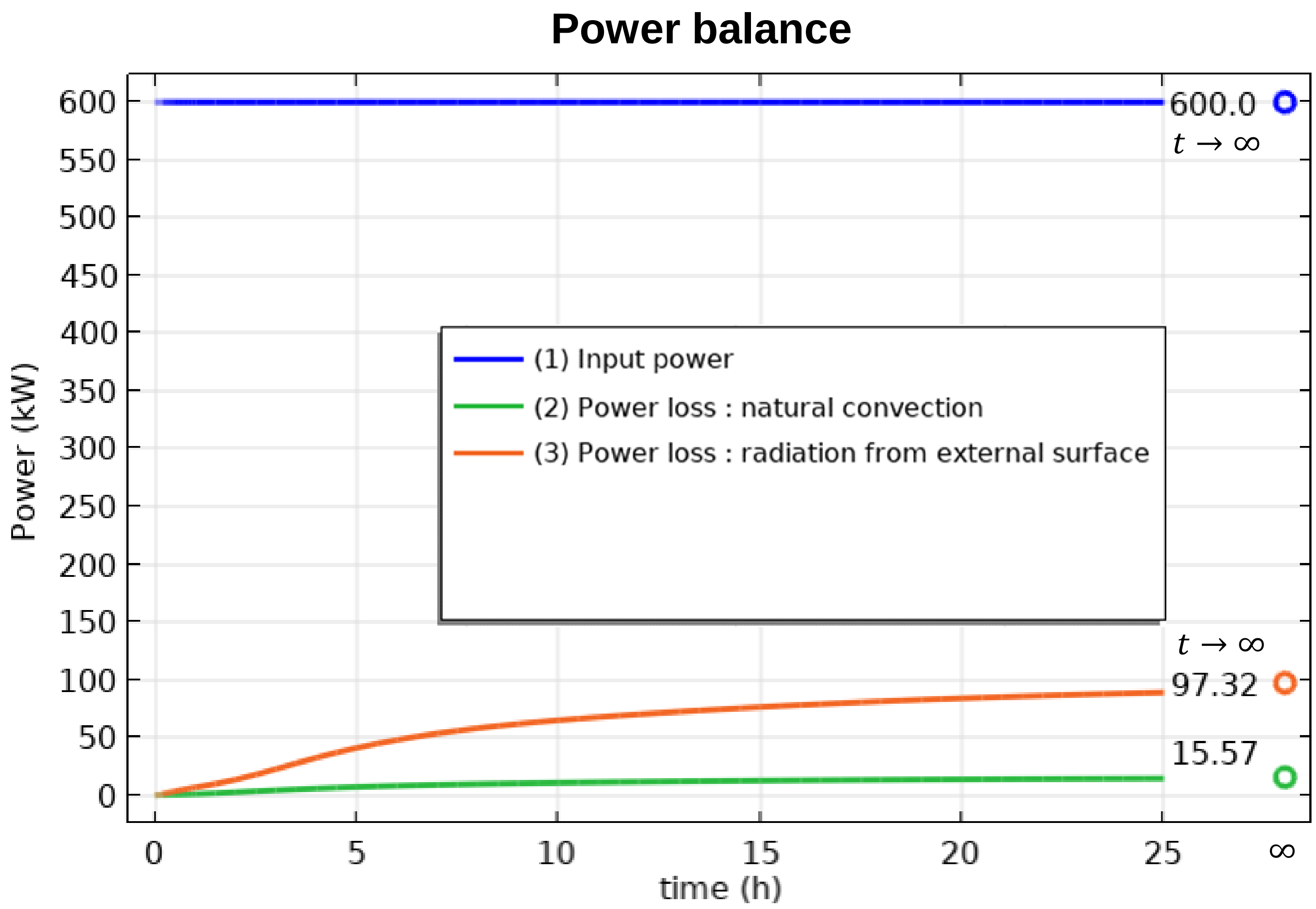

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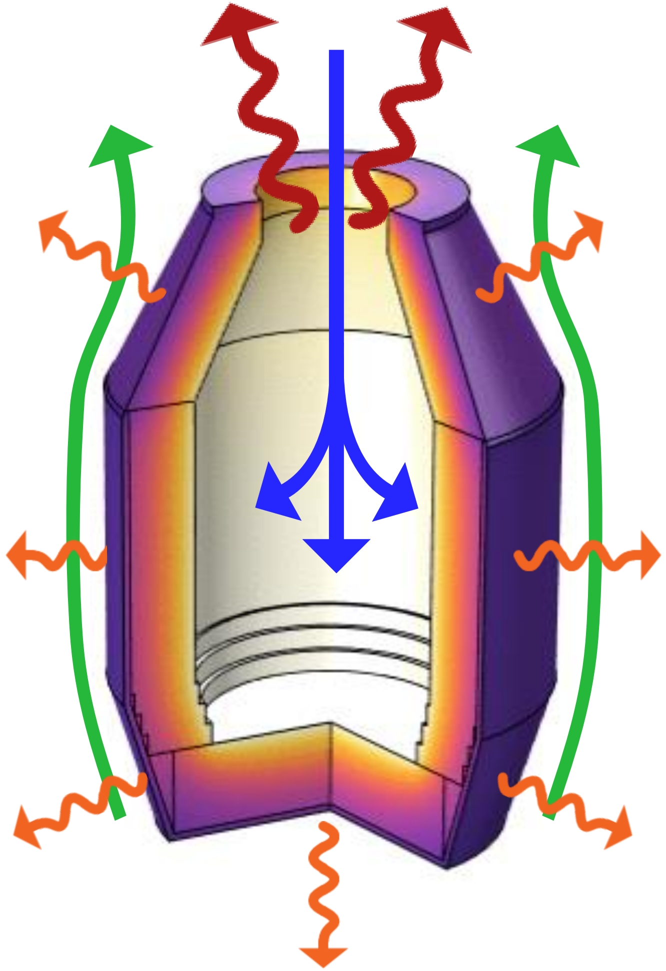
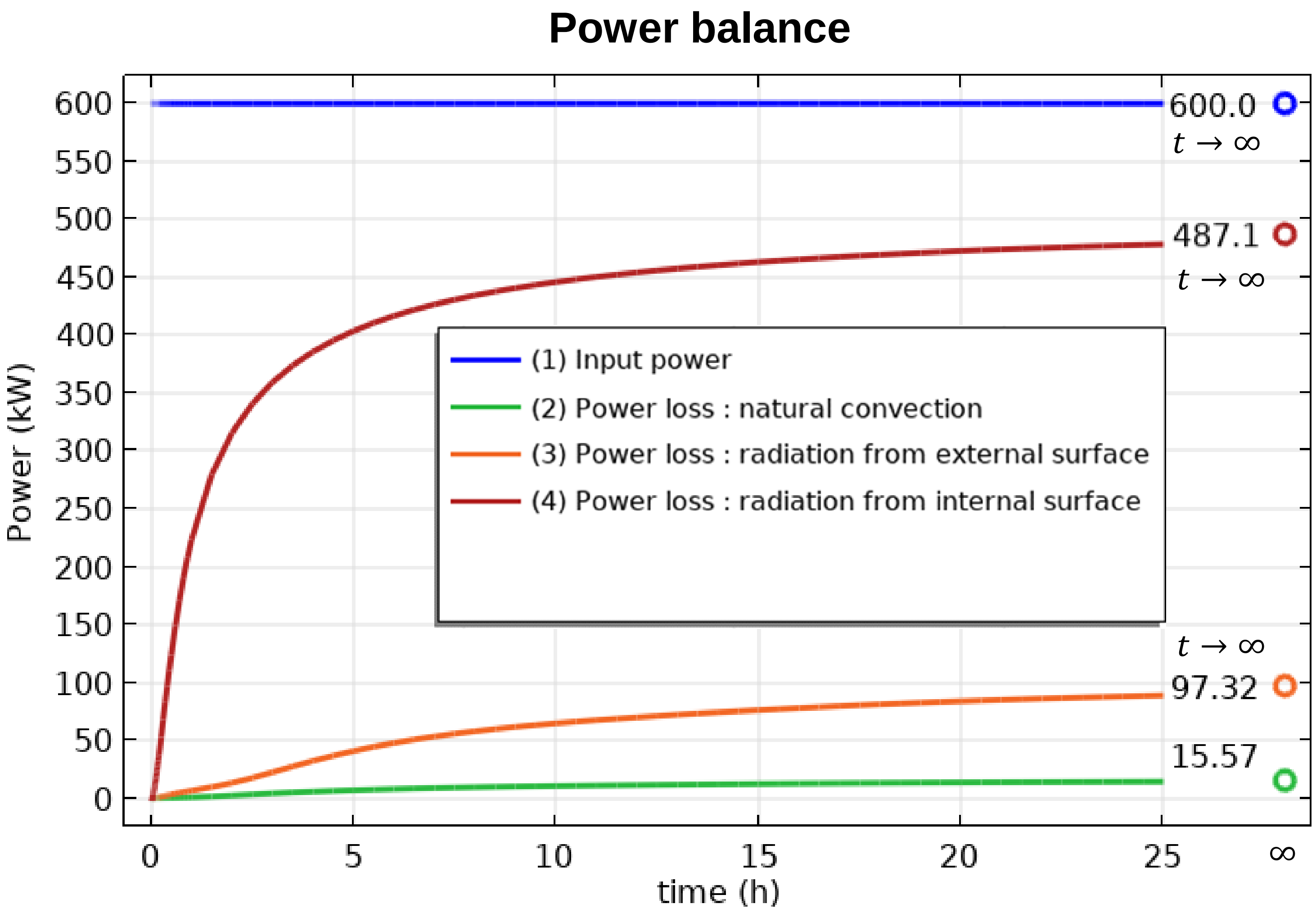
TBRC preheating





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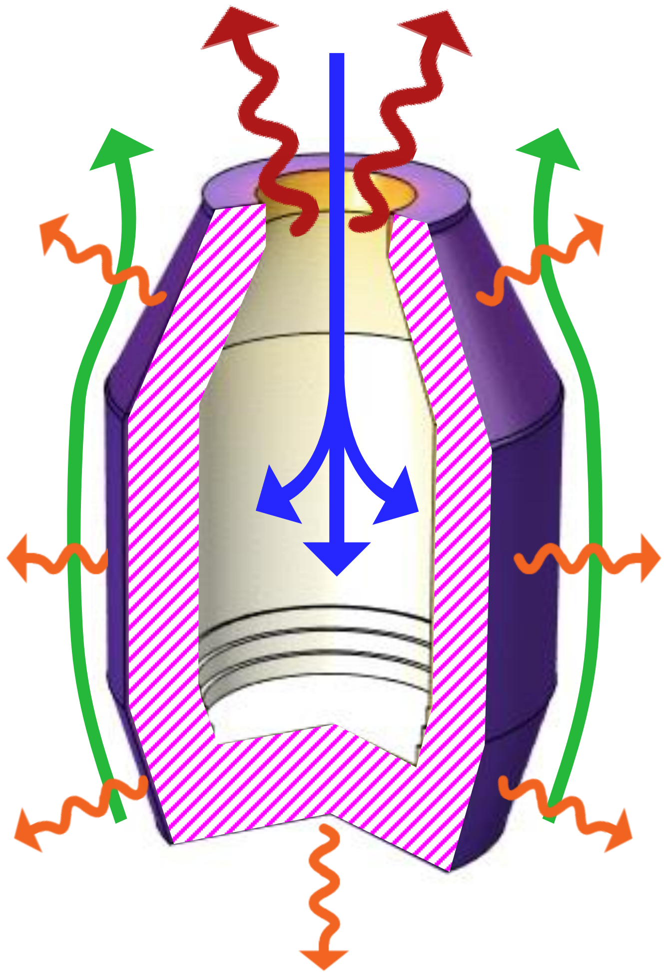

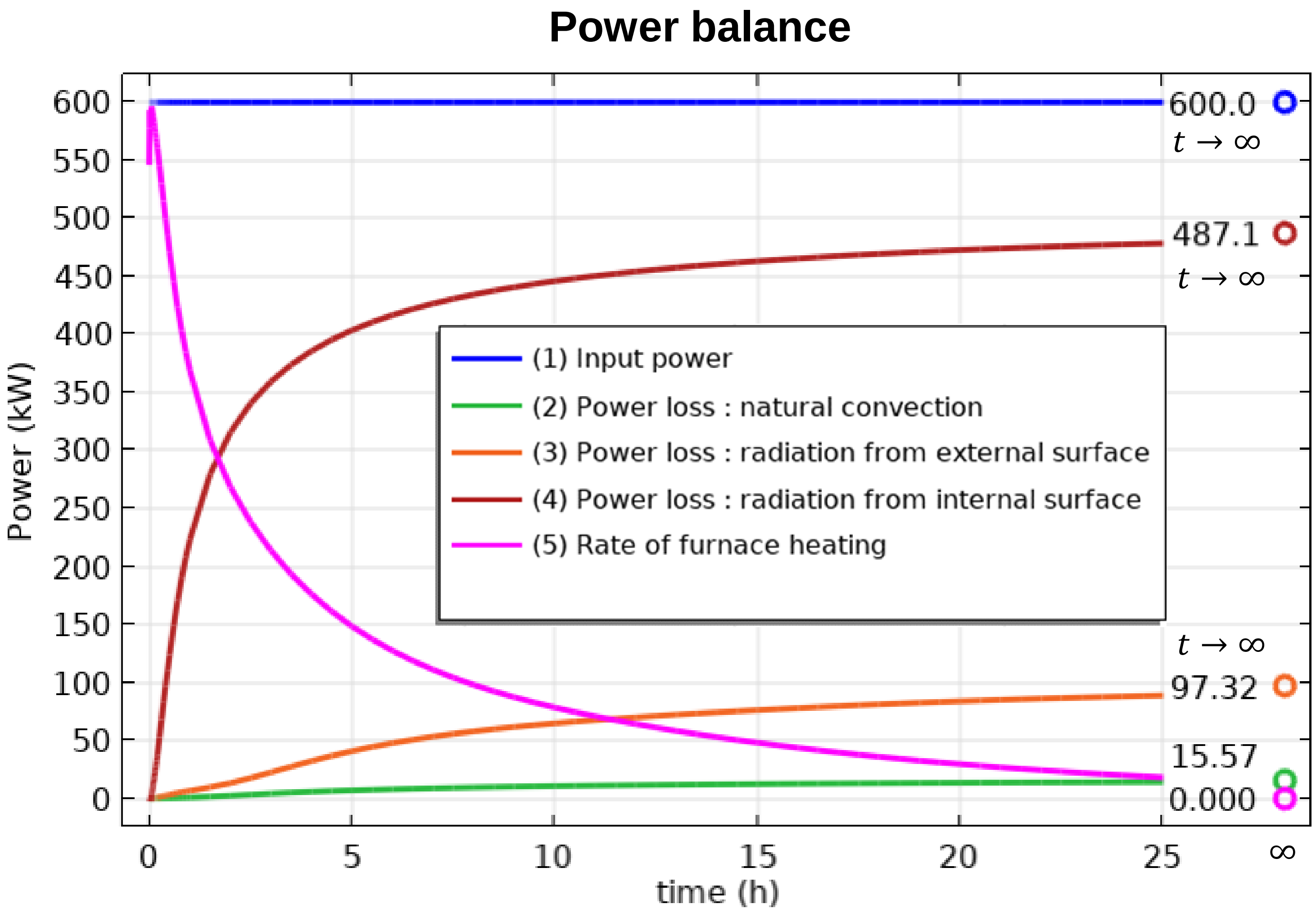

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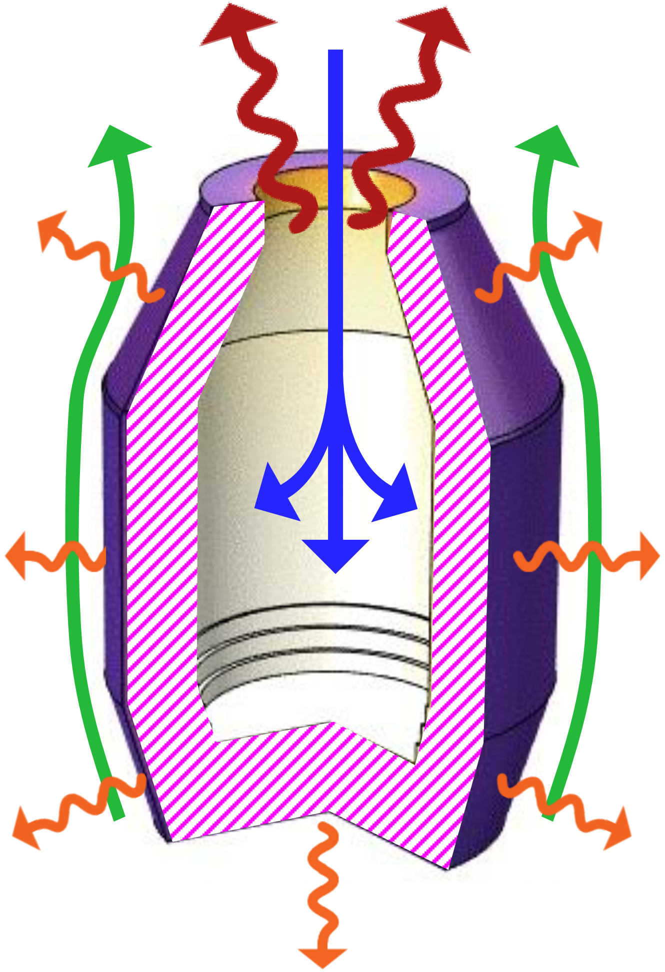

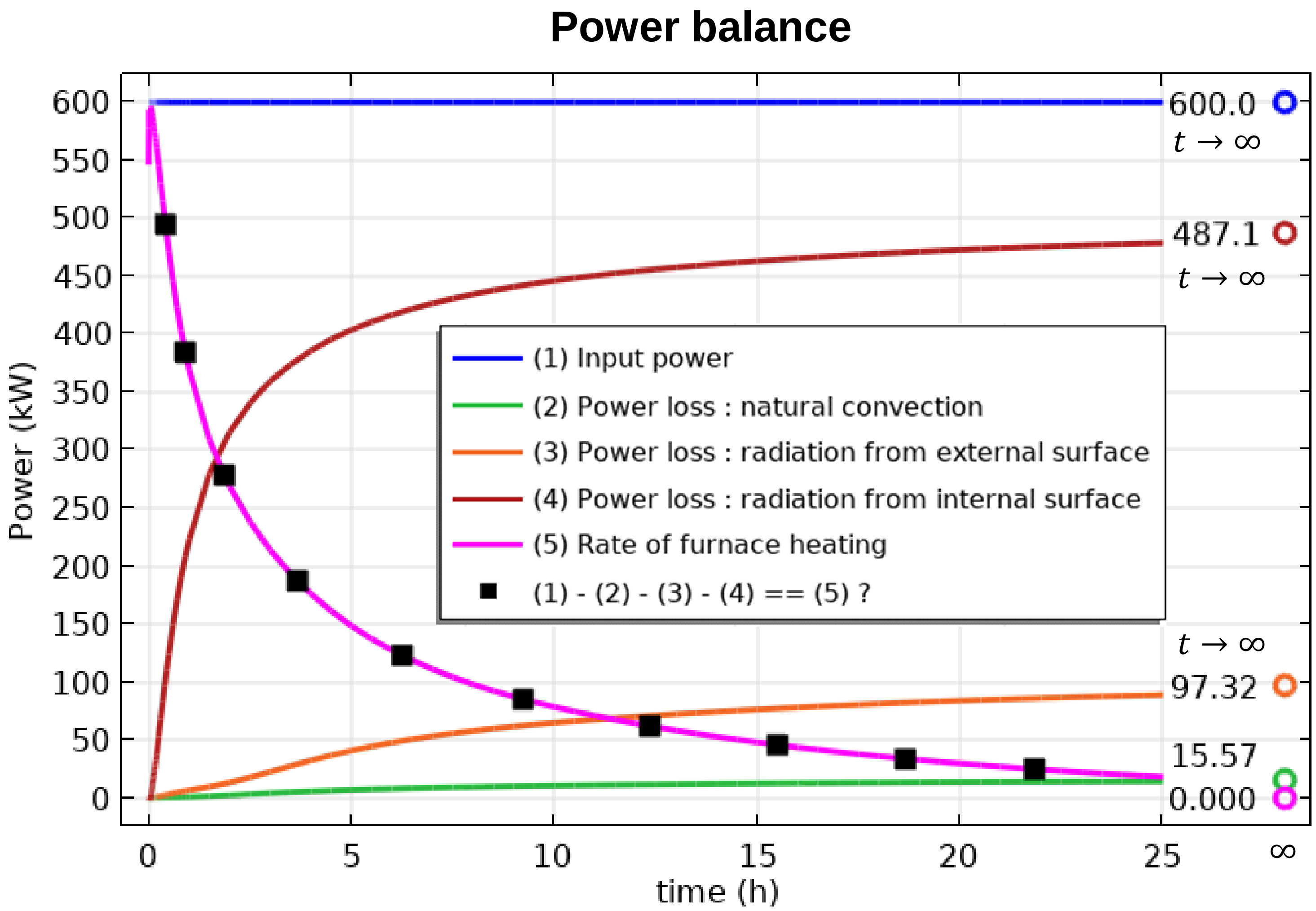

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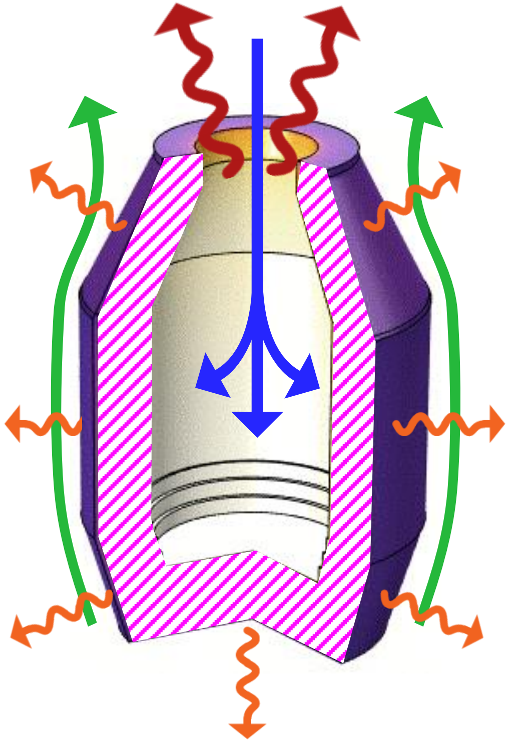
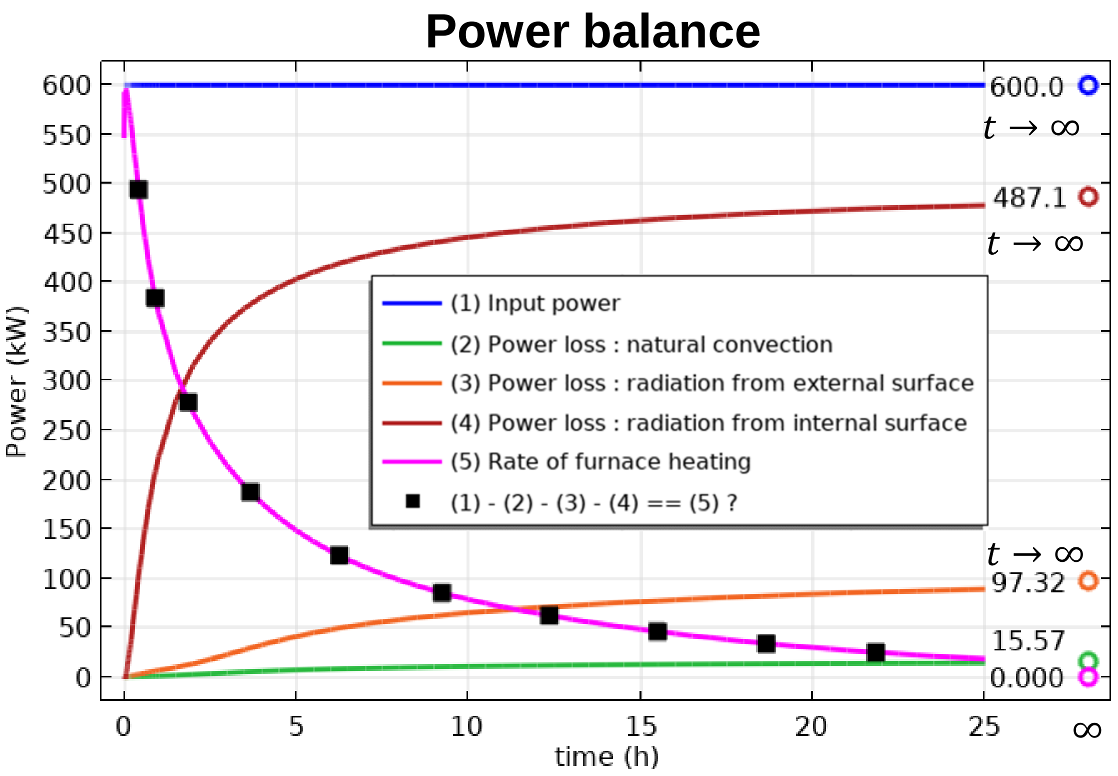
TBRC preheating





→ Perfect power balance

→ Most of the power is lost in form of thermal radiation from the internal surface of TBRC towards ambient environment through the opening at the top of the furnace

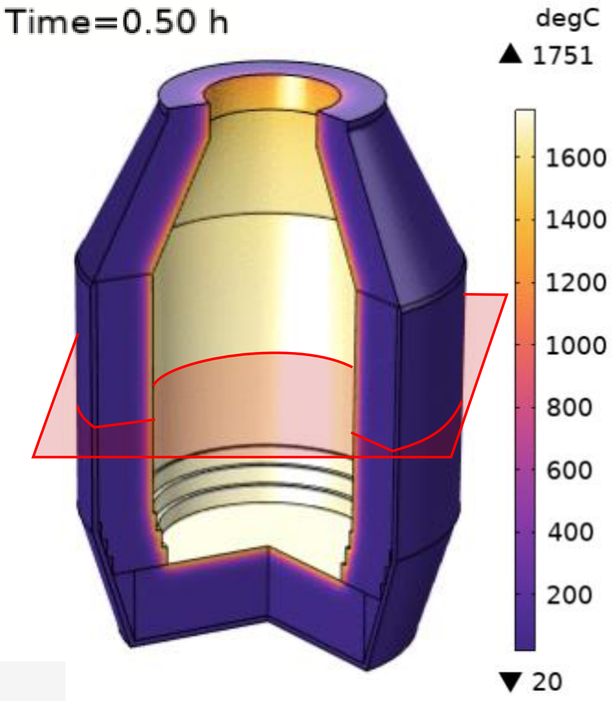
TBRC preheating

Initial condition for further computations with slag and metal

→ The TBRC state after 30 min of preheating at 600 kW serves as initial condition for further computations

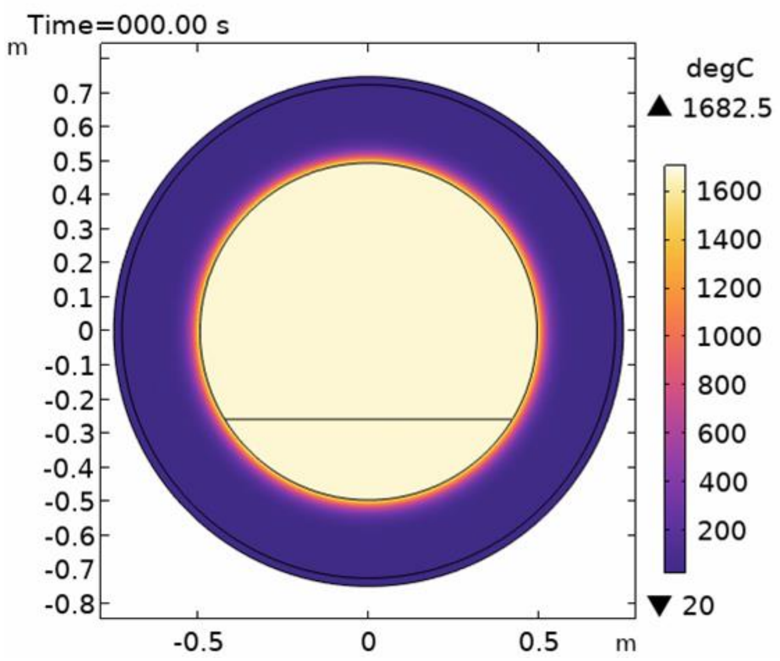
→ Initial condition for TBRC in a vertical position

2D axisymmetric model



→ Initial condition for TBRC in a horizontal position

2D plane model



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Influence of the rotation frequency

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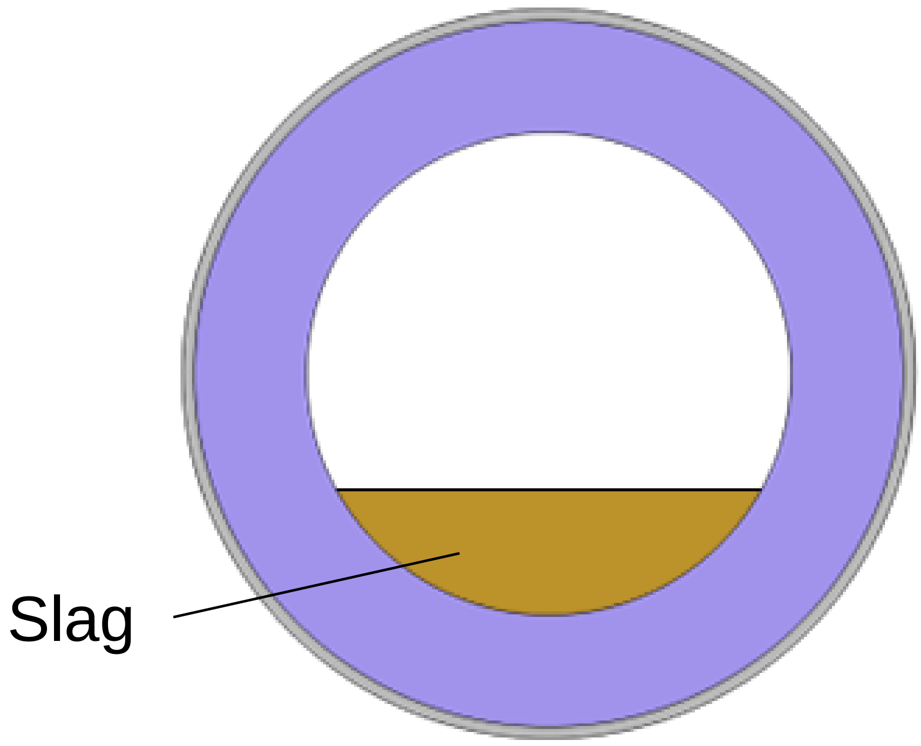
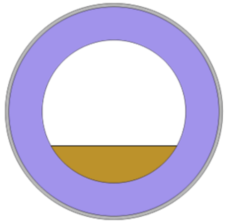
Influence of the rotation frequency

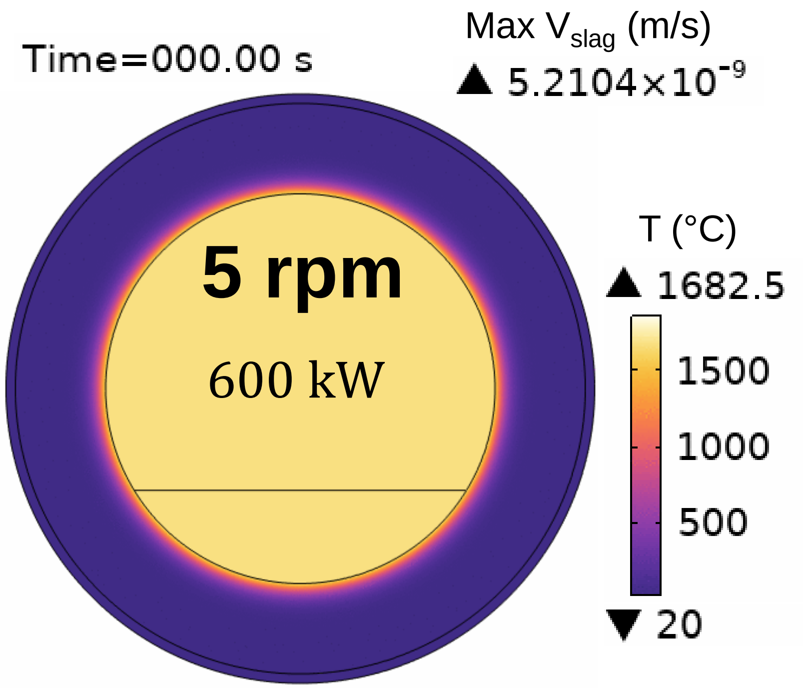


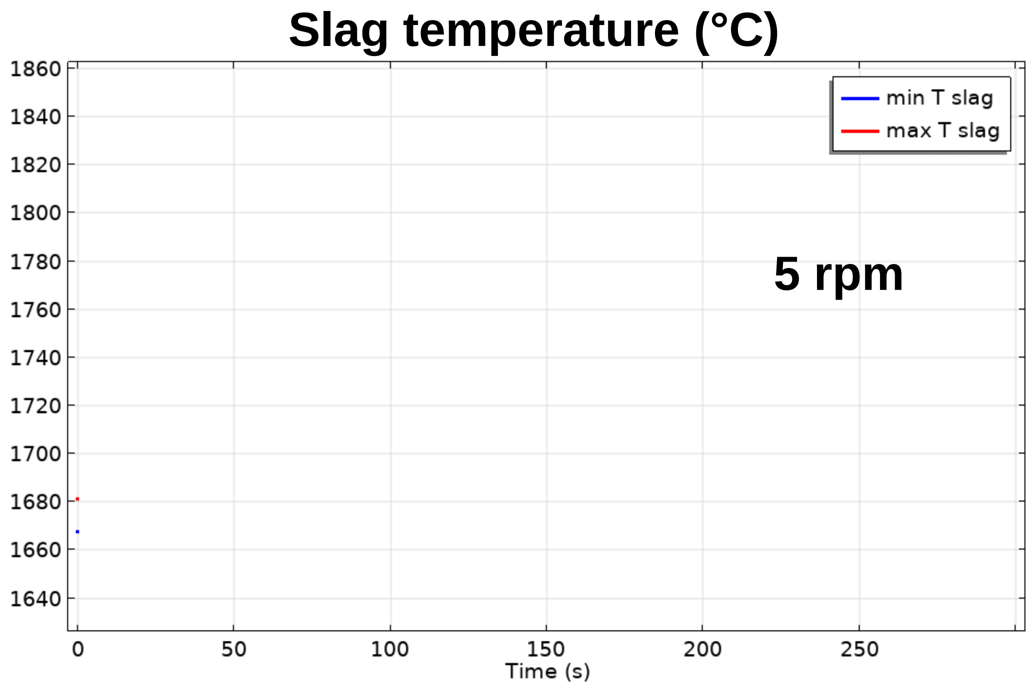
2D plane model

Influence of the rotation frequency

- $P = P_{max}$ (600 kW)
  - 5 RPM







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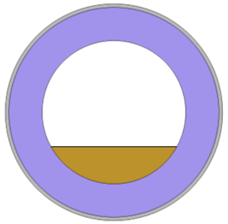
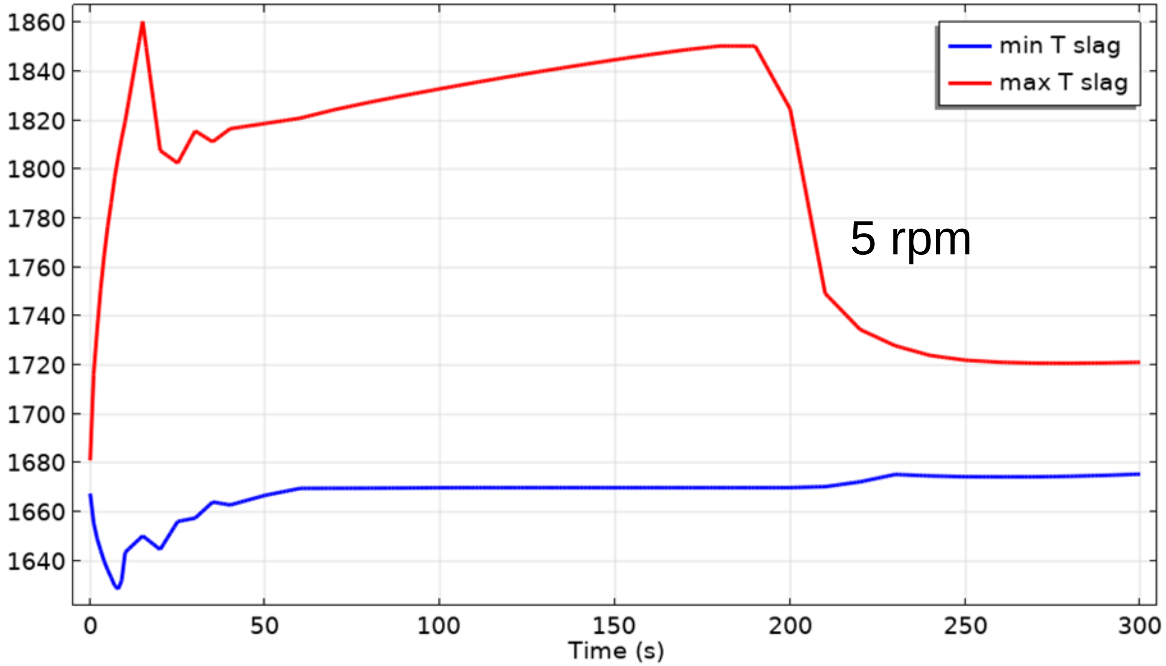
Influence of the rotation frequency

- $P = P_{max}$ (600 kW)
  - 5 RPM



Slag temperature (°C)



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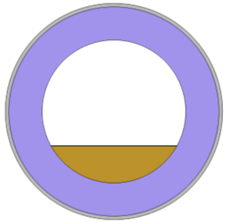
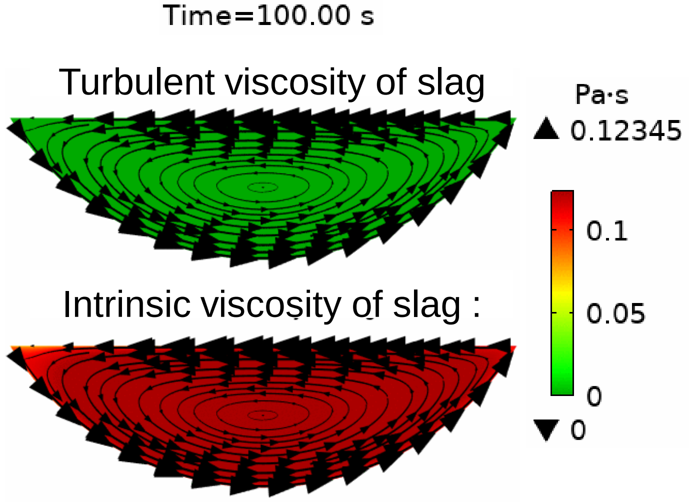
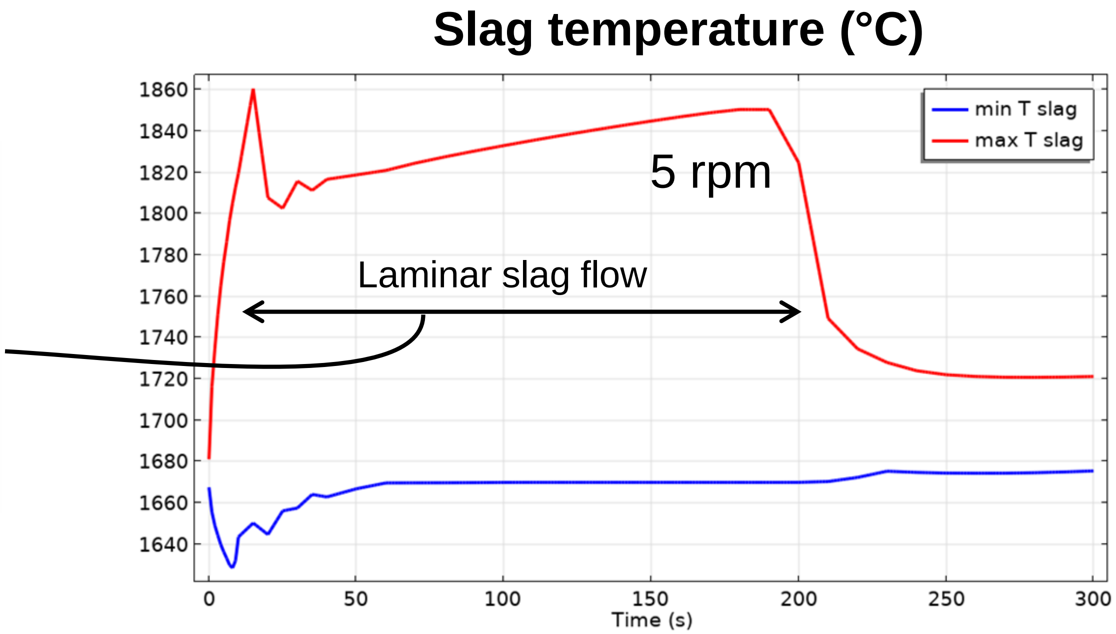
Influence of the rotation frequency

- $P = P_{max}$ (600 kW)
  - 5 RPM

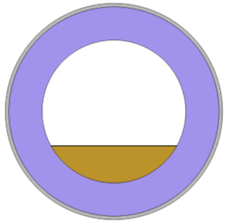




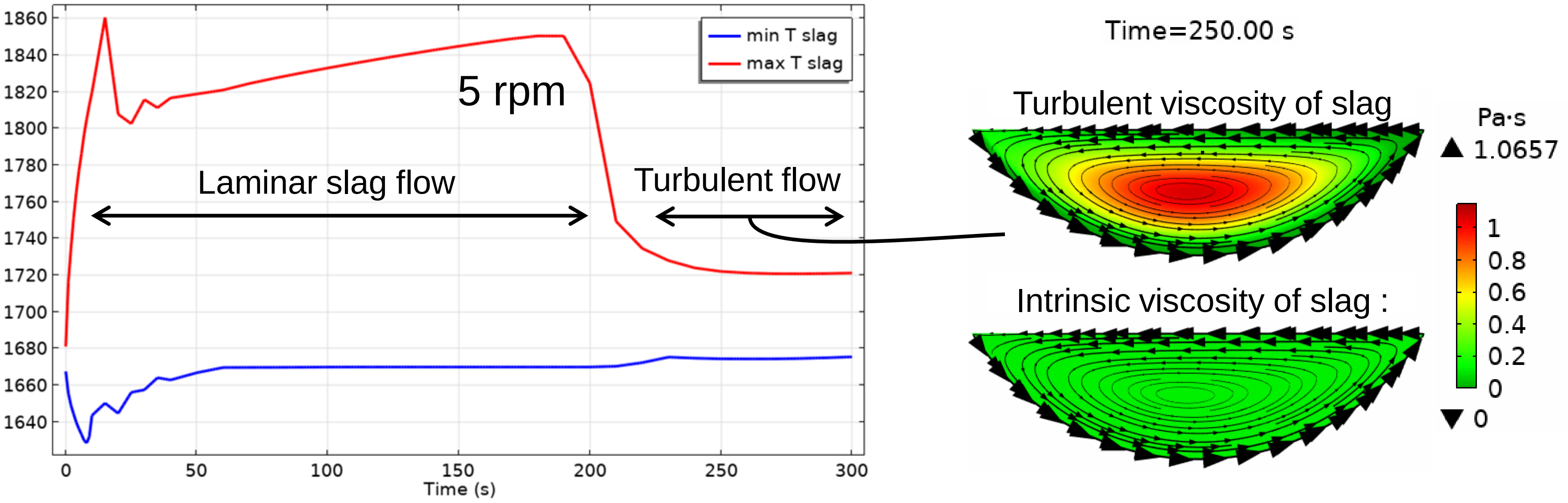


Influence of the rotation frequency

- $P = P_{max}$ (600 kW)
  - 5 RPM



Slag temperature (°C)



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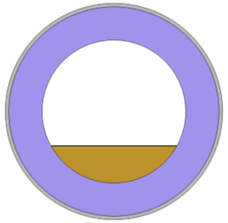
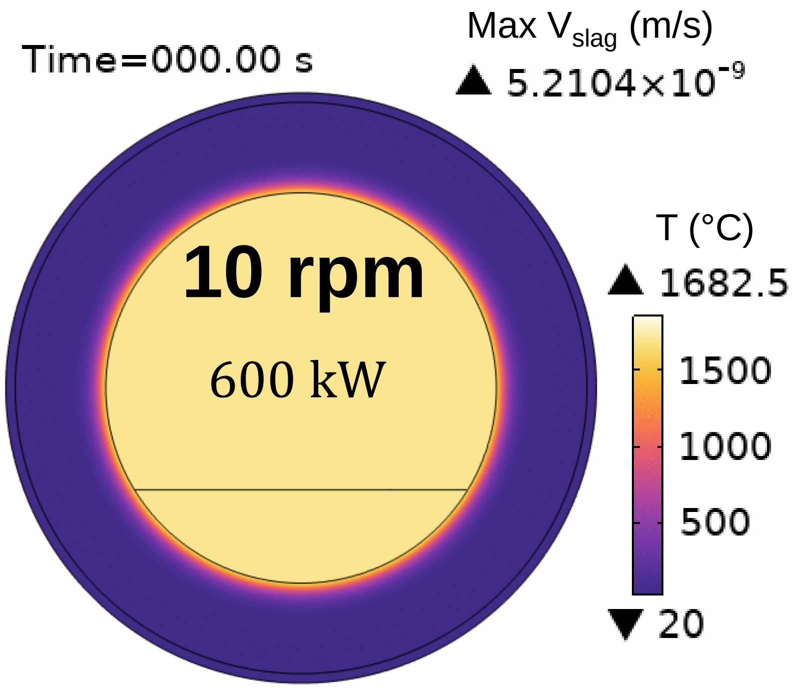
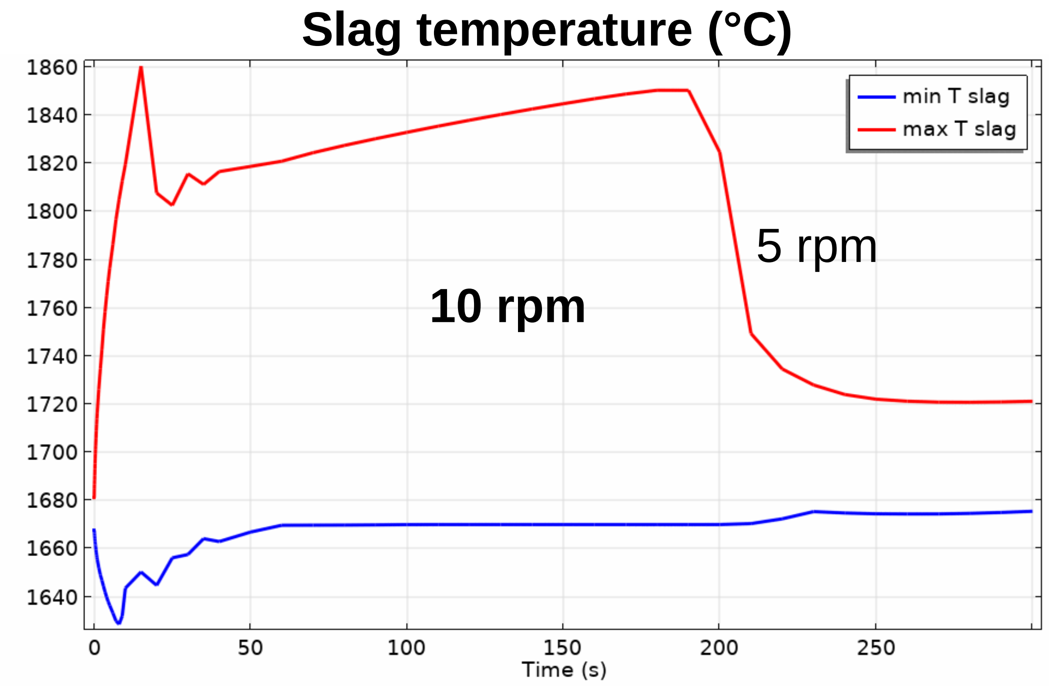
Influence of the rotation frequency

- $P = P_{max}$ (600 kW)
  - 10 RPM







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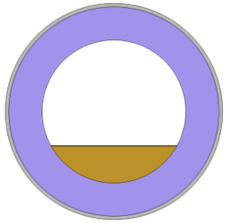
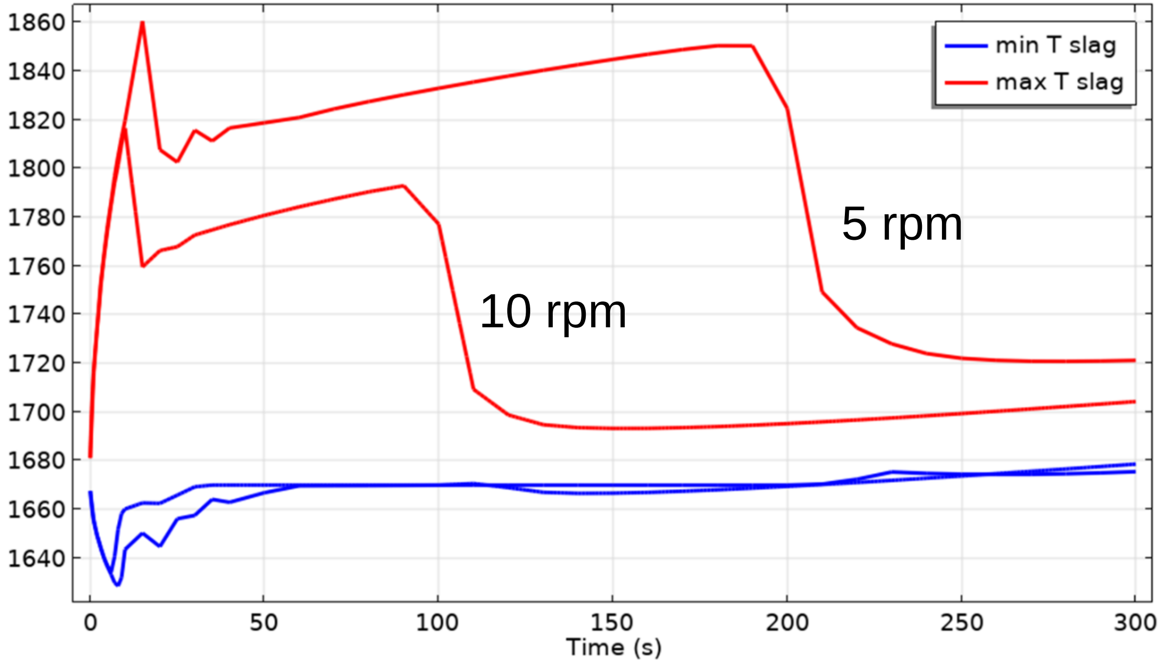
Influence of the rotation frequency

- $P = P_{max}$ (600 kW)
  - 5, 10 RPM



Slag temperature (°C)



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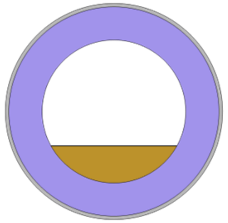
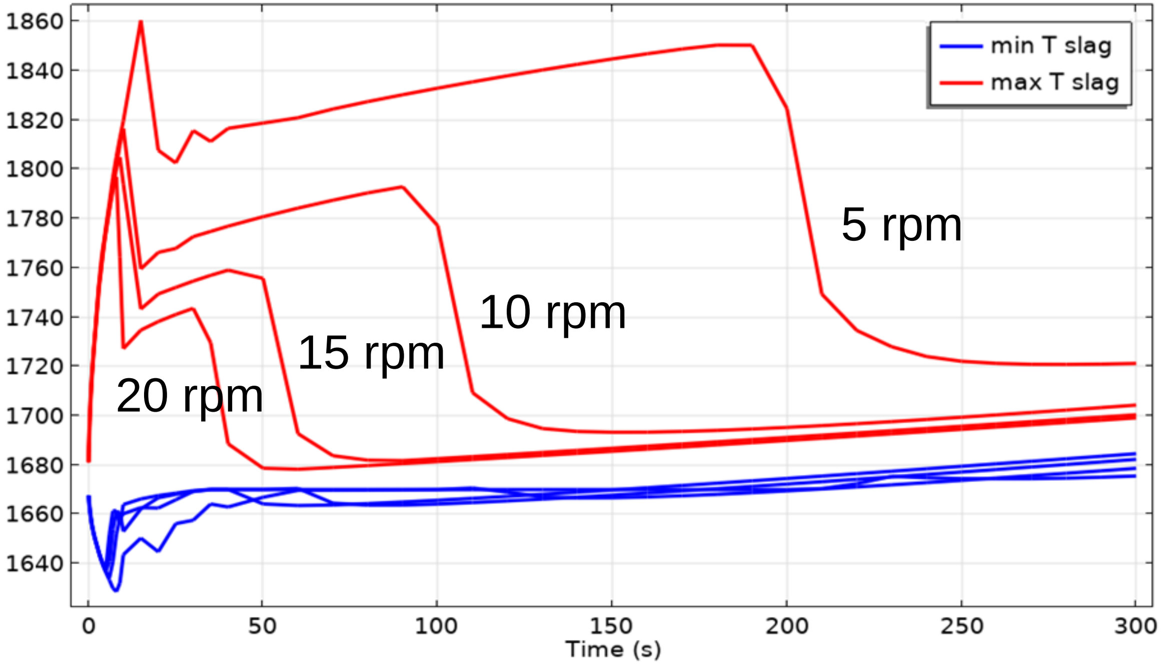
Influence of the rotation frequency

- $P = P_{max}$ (600 kW)
  - 5, 10, 15, 20 RPM



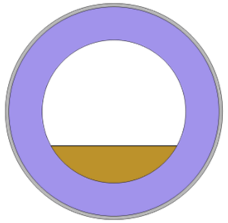
Slag temperature (°C)

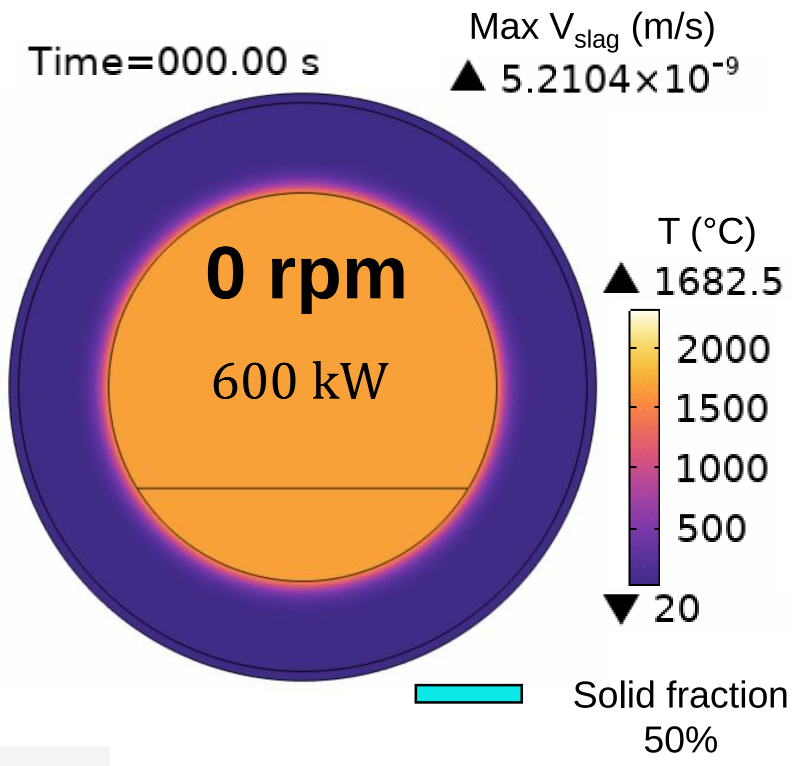


The project has received funding from the European Union's Horizon 2020 research and innovation program under Grant Agreement N°869268.

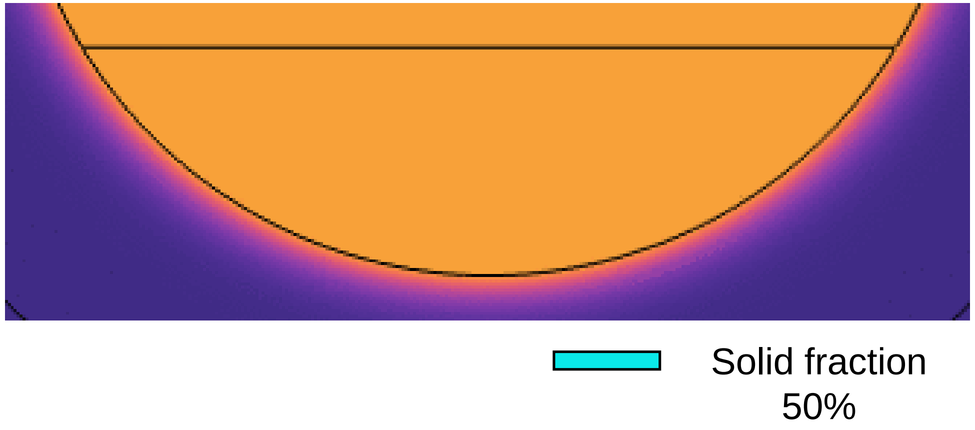
Influence of the rotation frequency

- $P = P_{max}$ (600 kW)
  - 0 RPM





Zoom



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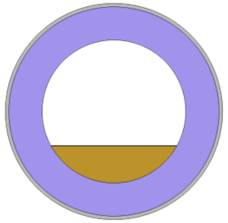
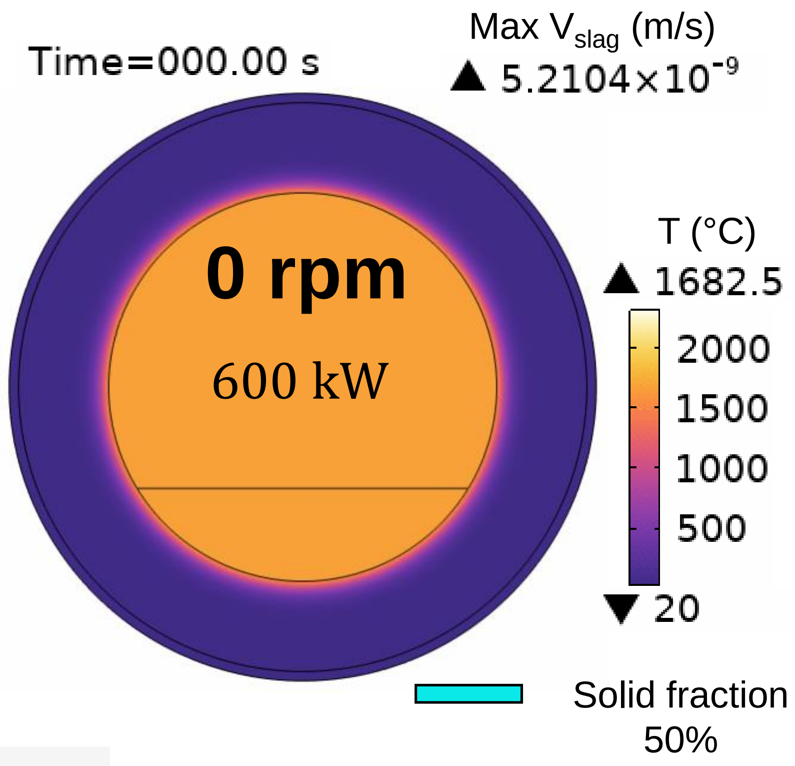
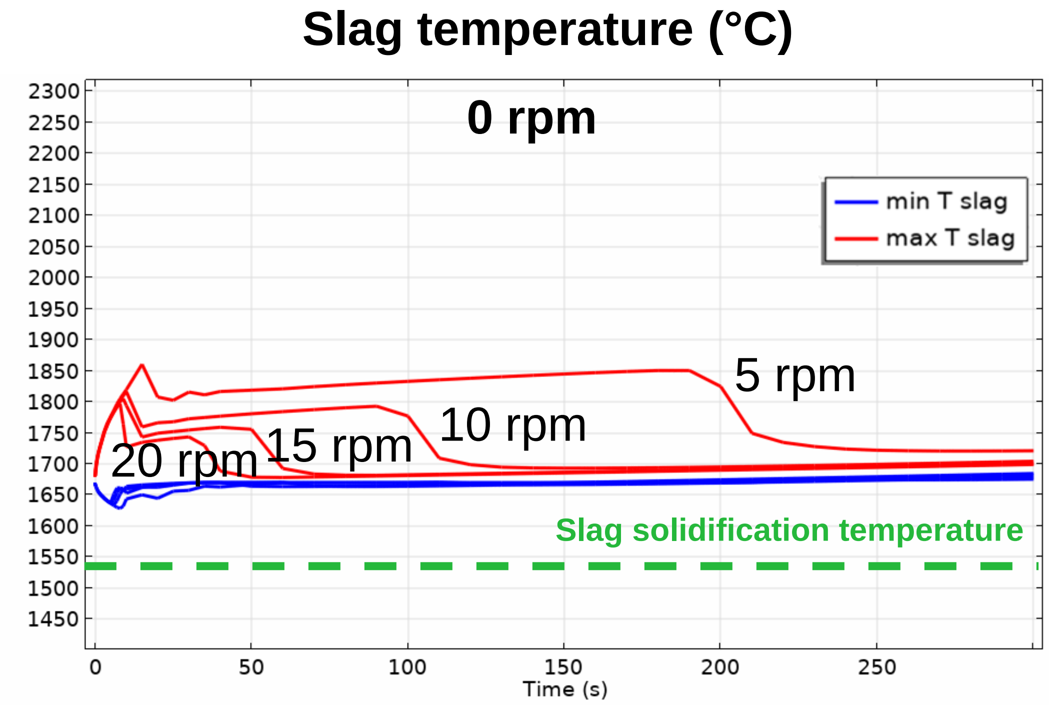
Influence of the rotation frequency

- $P = P_{max}$ (600 kW)
  - 0 RPM







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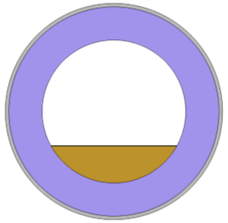
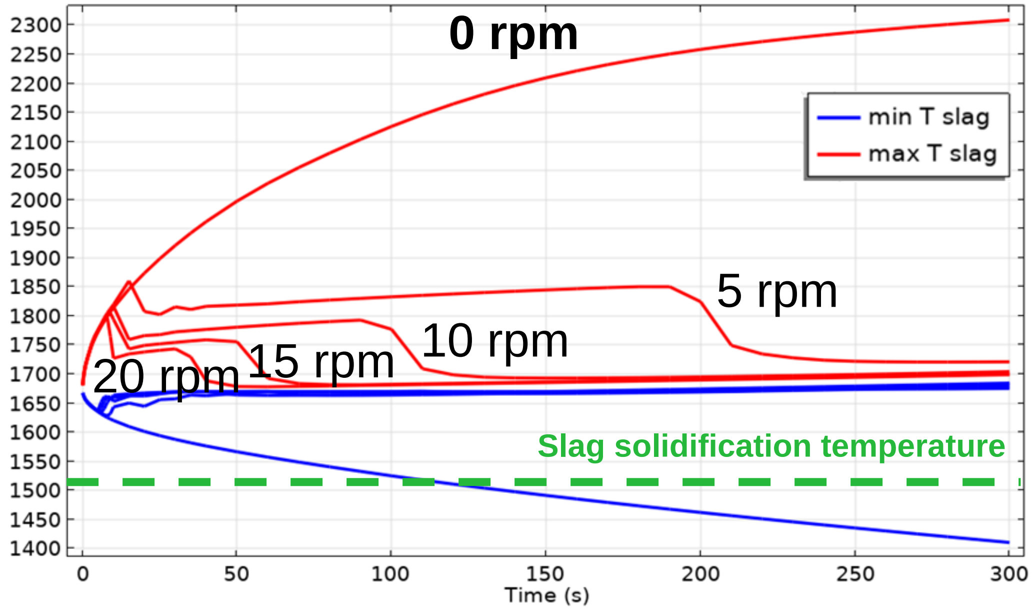
Influence of the rotation frequency



- $P = P_{max}$ (600 kW)
  - 0, 5, 10, 15, 20 RPM

Slag temperature (°C)



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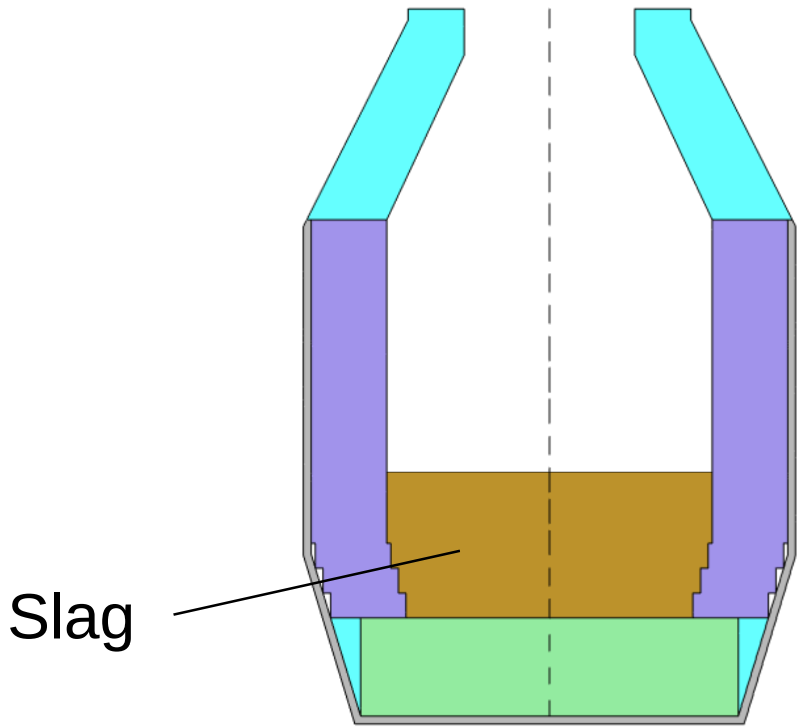
Influence of the rotation frequency



2D axisymmetric model

SisAl Pilot

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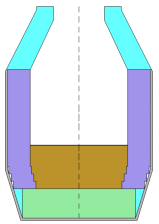
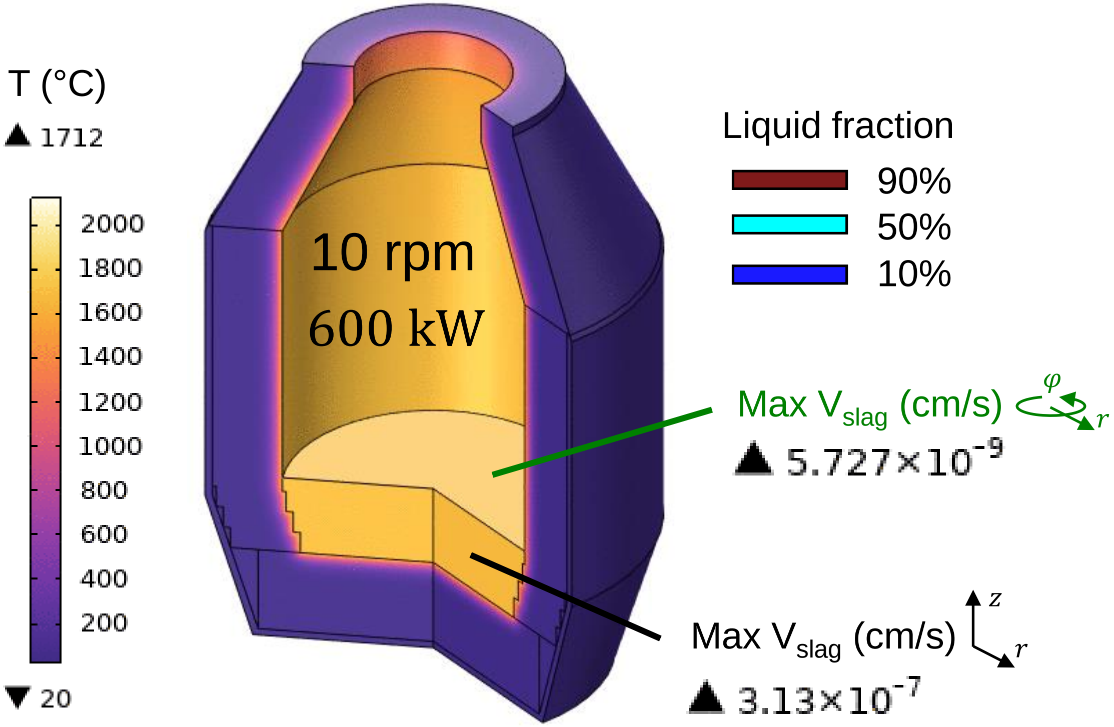
SIMTEC

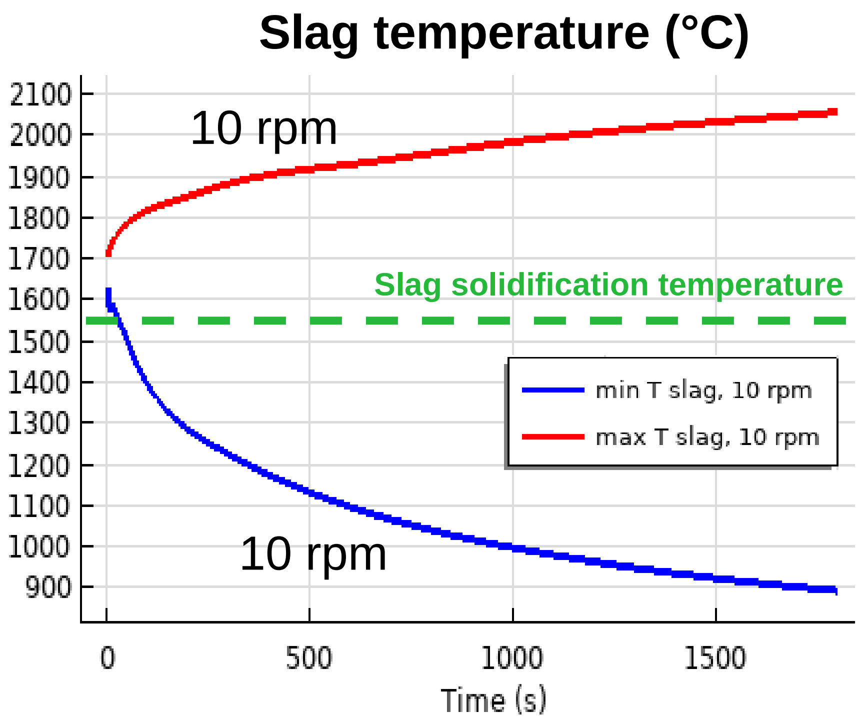
Influence of the rotation frequency

- $P = P_{max}$ (600 kW)
  - 10 RPM



Time=0000 s





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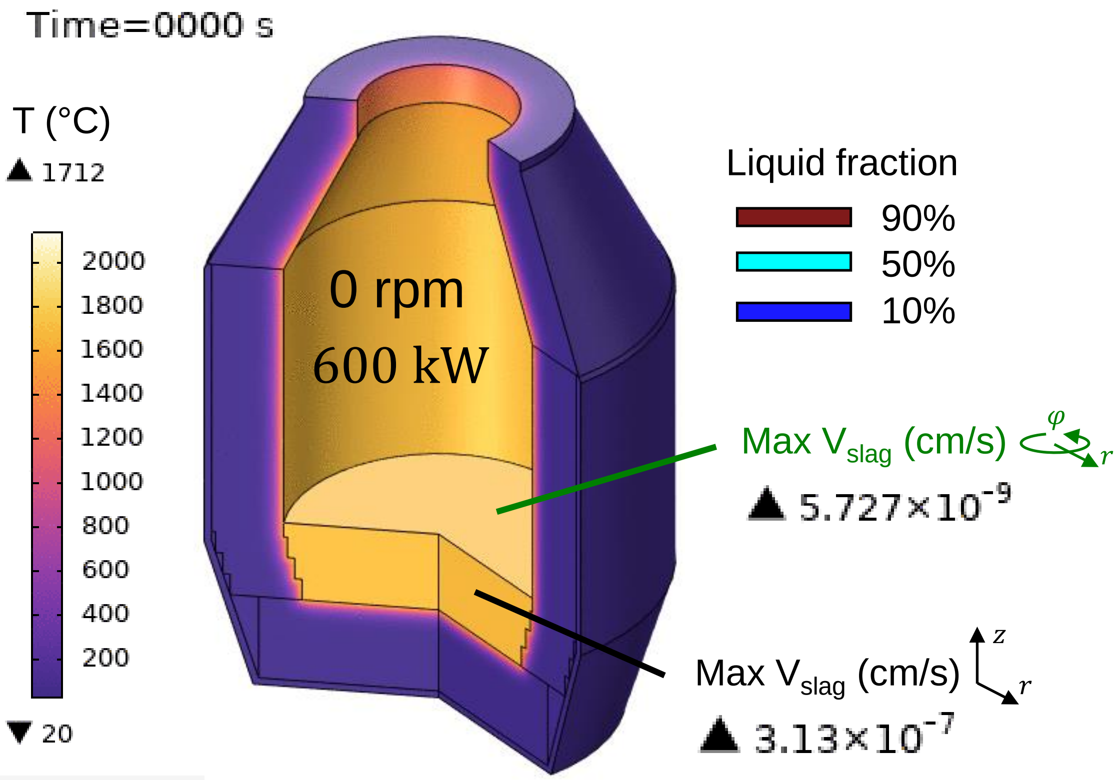
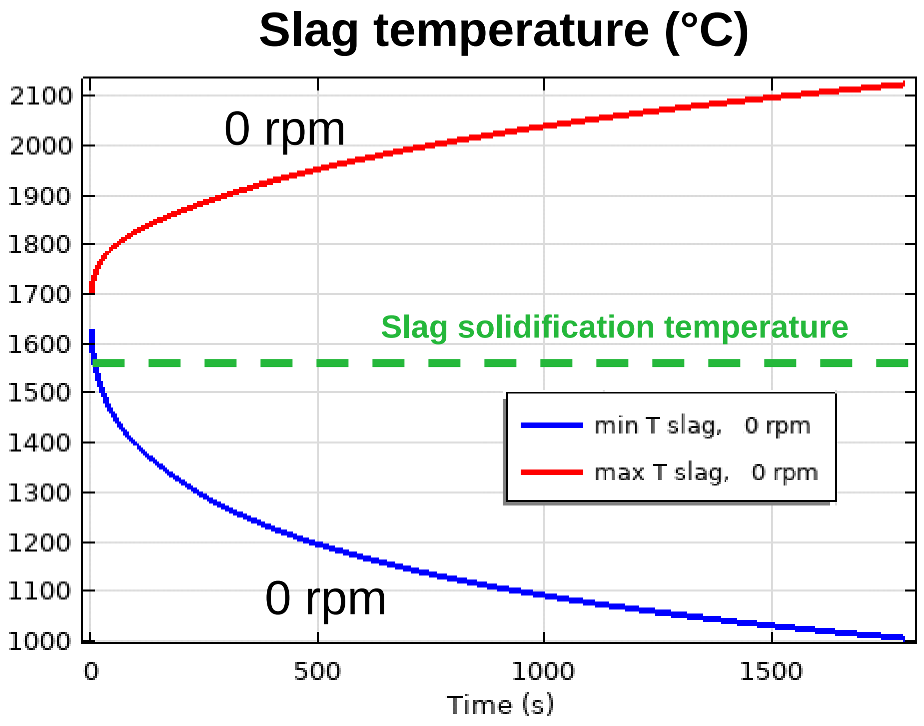
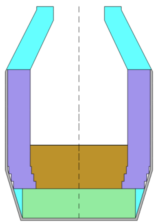
Influence of the rotation frequency

- $P = P_{max}$ (600 kW)
  - 0 RPM







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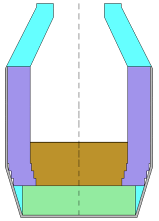
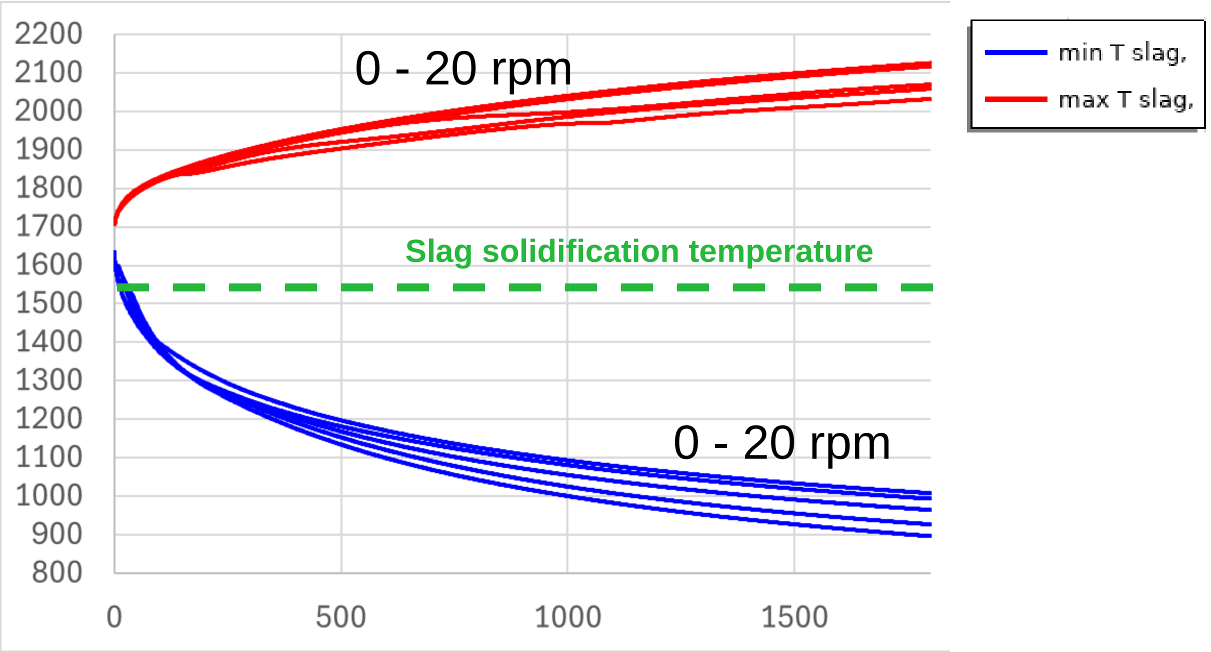
Influence of the rotation frequency

- $P = P_{max}$ (600 kW)
  - 0, 5, 10, 15, 20 RPM



Slag temperature (°C)



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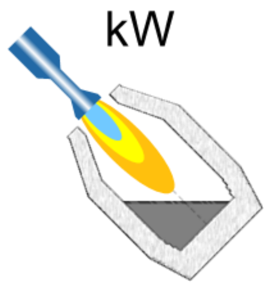
Influence of the burner power and angle

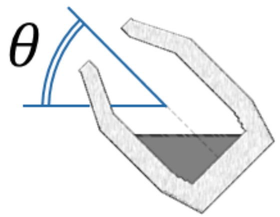
Influence of the burner power and angle

- For the Slag + Metal configuration, determination of the state of the system (stays liquid or not?)…

→ … depending on the burner power



→ … depending on the TBRC inclination angle



at 10 RPM

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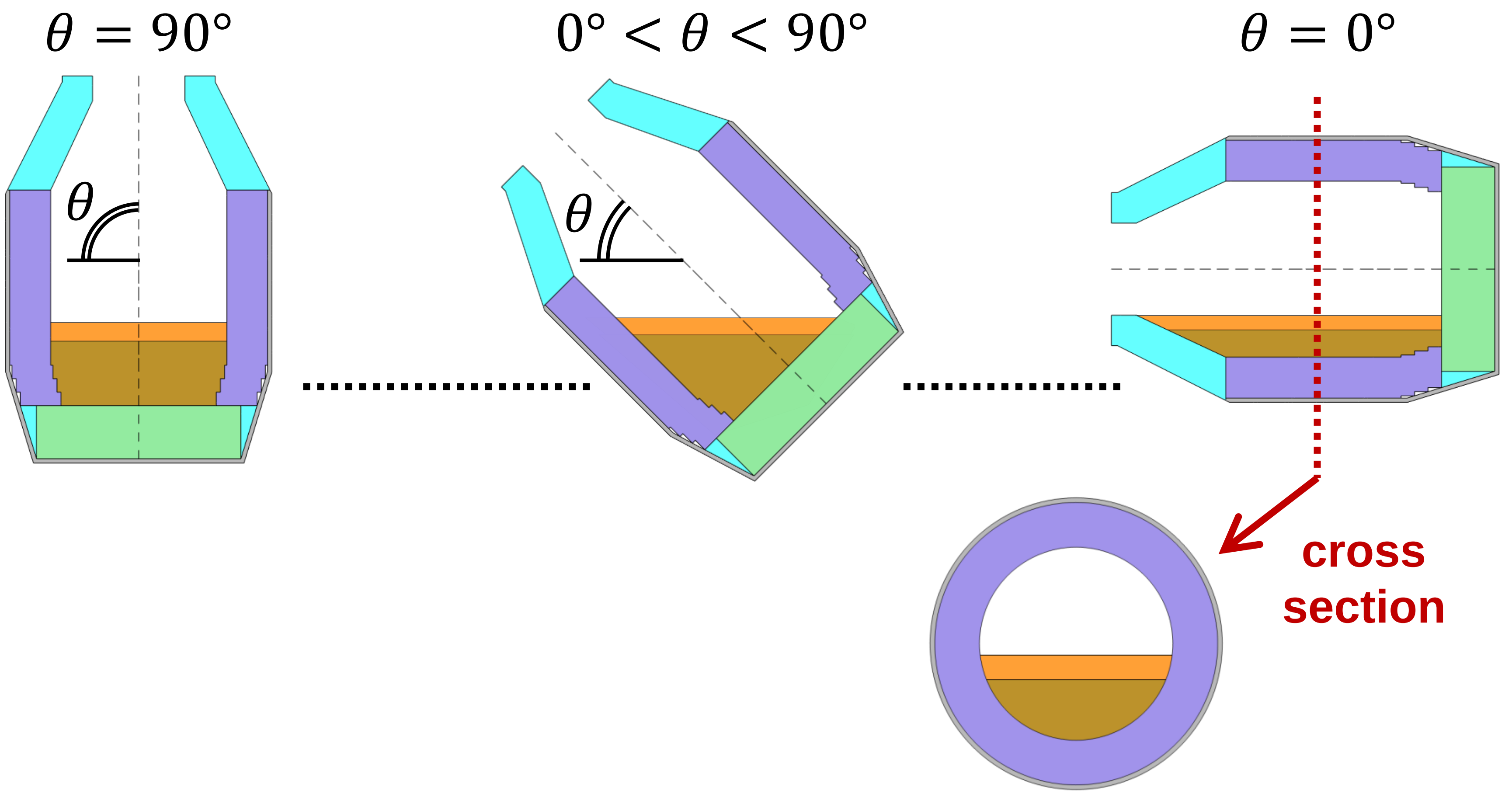
Influence of the burner power and angle

→ Consider all possible inclination angles of TBRC



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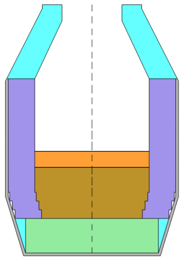
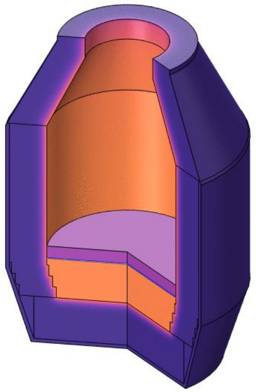
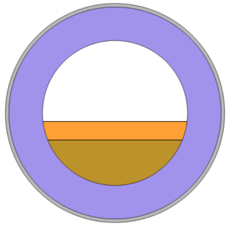
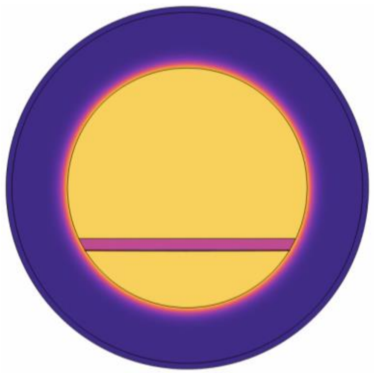
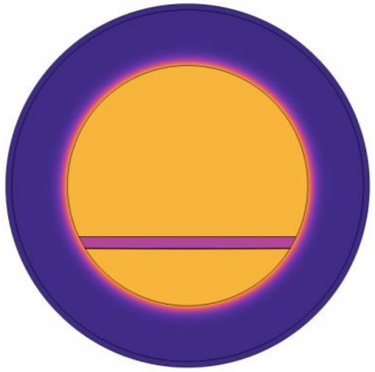
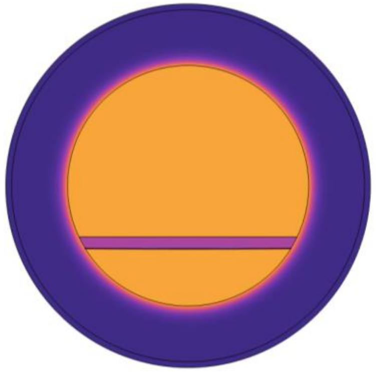
Influence of the burner power and angle

The case of both slag and metal charged into TBRC

	$P = 0$	$P = P_{adjusted}$ (164 kW)	$P = P_{max}$ (600 kW)
Vertical 	✗ Risk of slag solidification	✗ Risk of slag solidification	 ✗ Risk of slag solidification
Horizontal 	 ✗ Risk of slag solidification after chemical reaction is finished	 ✓ Slag is liquid	 ✓ Slag is liquid

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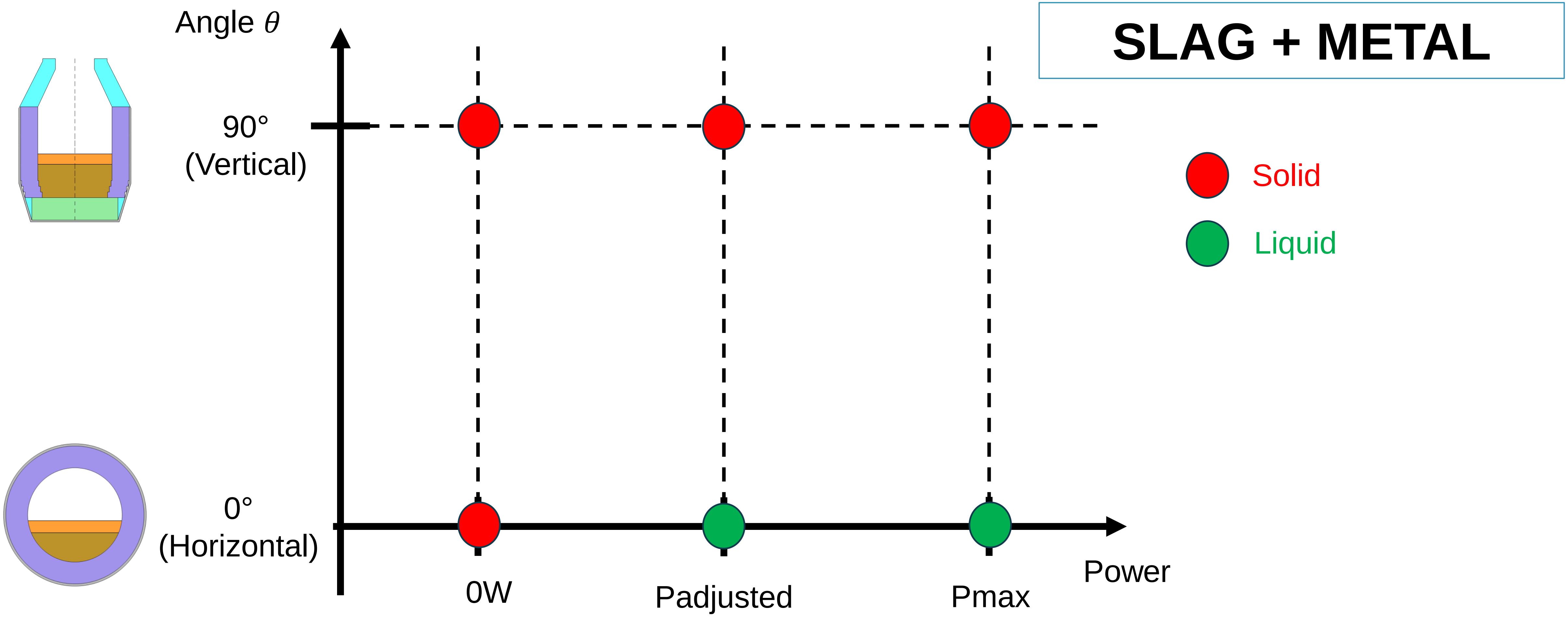
Influence of the burner power and angle



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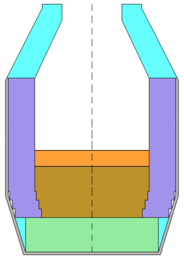
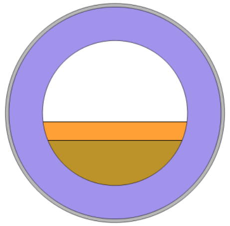
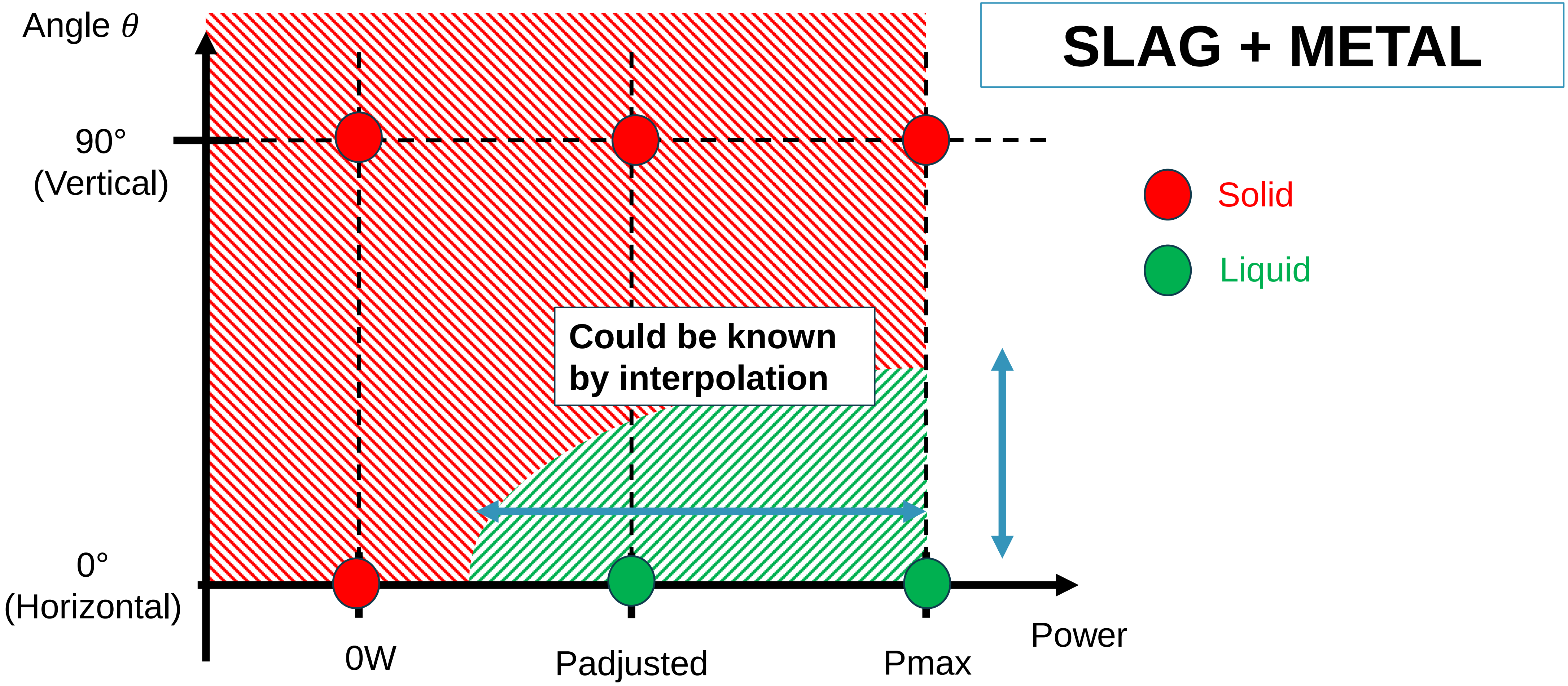
Influence of the burner power and angle







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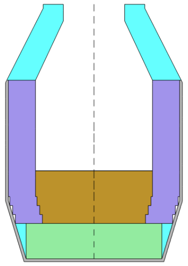
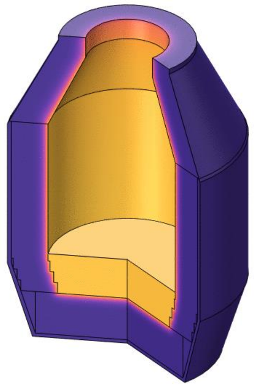
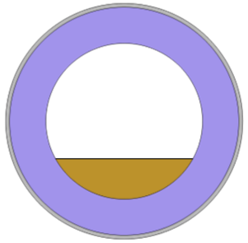
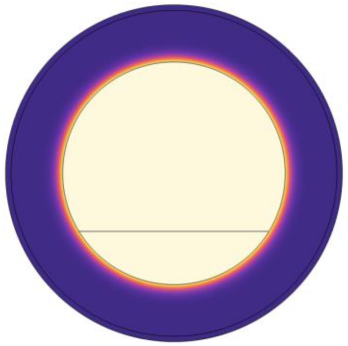
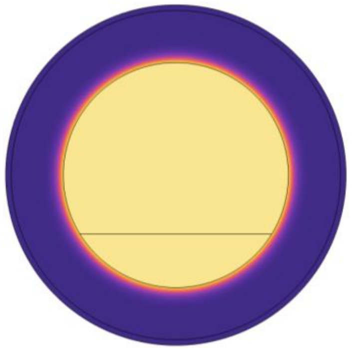
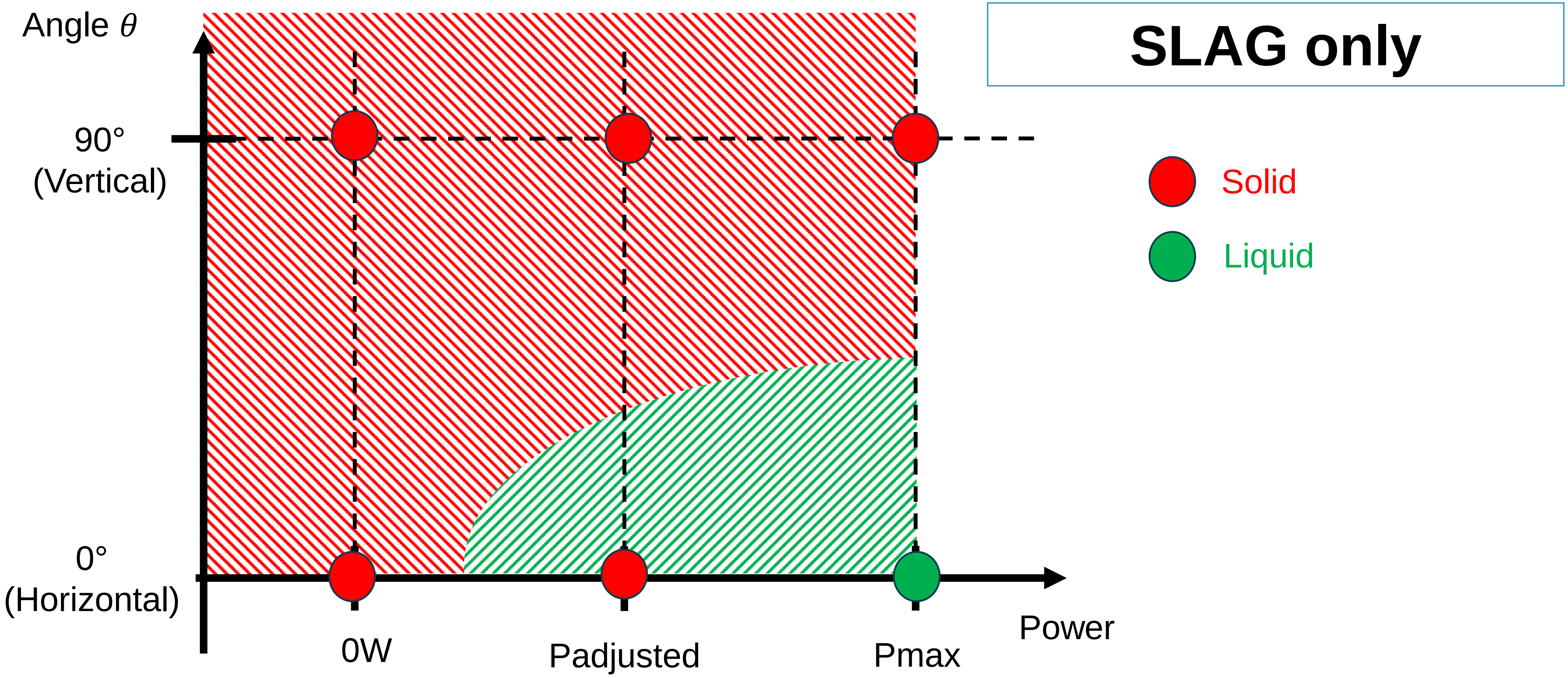
Influence of the burner power and angle

The case of only slag charged into TBRC

	$P = P_{adjusted}$ (164 kW)	$P = P_{max}$ (600 kW)
Vertical 	✗ Risk of slag solidification	 ✗ Risk of slag solidification
Horizontal 	 ✗ Risk of slag solidification	 ✓ Slag is liquid

Influence of the burner power and angle



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IV. Conclusions

The project has received funding from the European Union’s Horizon 2020 research and innovation program under Grant Agreement N°869268.

Conclusions

- Aim: Numerical testing of a new design of TBRC
- Creation of an efficient decision-making tool to:

→ Determine the best angle ✓

→ Compute the necessary power ✓

→ Optimise the rotation speed ✓

The project has received funding from the European Union's Horizon 2020 research and innovation program under Grant Agreement N°869268.

To finish…

Thank you!

Q&A?

Our question: What about a coffee to discuss your topic? ☺

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patrick.namy@simtecsolution.fr

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