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STEELSIM 2011

4th International Conference on Modelling and Simulation of Metallurgical Processes in Steelmaking

STEEL SIM

Stahl

Transient simulation temperature field for continuous casting steel billet and slab

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26.06.2011

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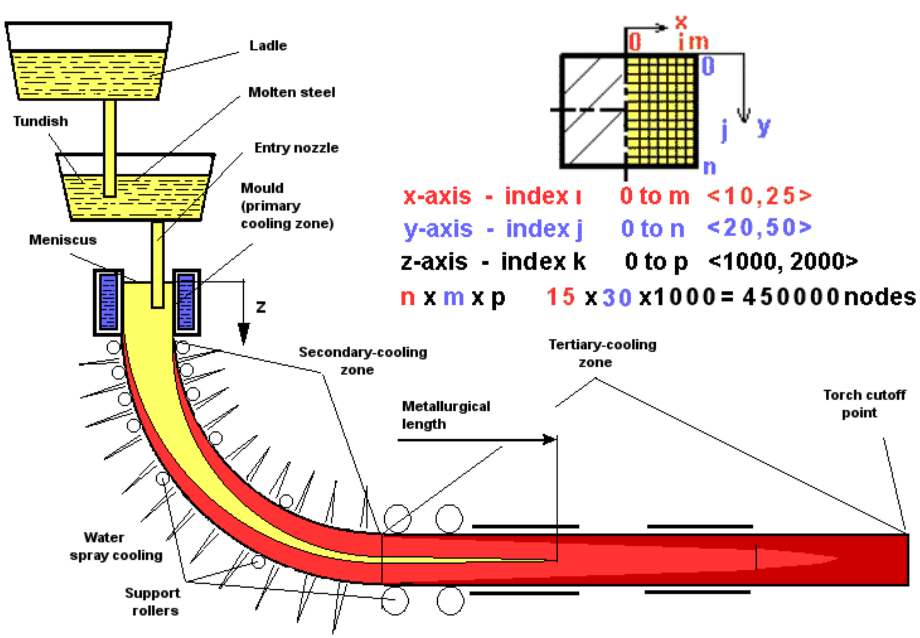
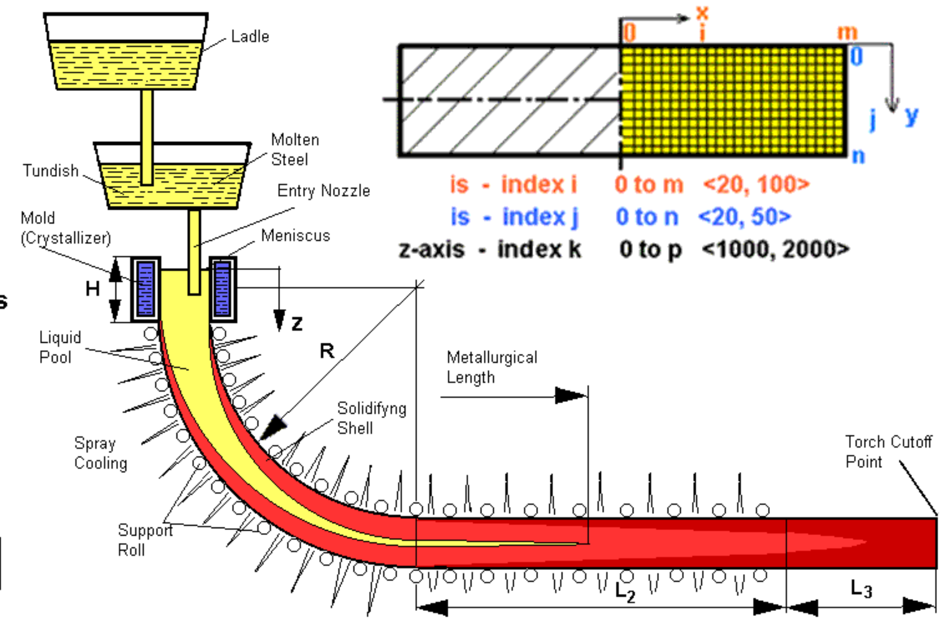
FACULTY OF MECHANICAL ENGINEERING

MODELS OF RADIAL BILLET AND SLAB CASTER



BILLET CASTER



SLAB CASTER

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FOURIER-KIRCHHOFF'S EQUATION

$$\frac{\partial T}{\partial \tau} = \frac{k}{\rho \cdot c}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + \left(w_x \frac{\partial T}{\partial x} + w_y \frac{\partial T}{\partial y} + w_z \frac{\partial T}{\partial z}\right) + \frac{Q_{SOURCE}}{\rho \cdot c}$$

IF $$w_x \frac{\partial T}{\partial x} = w_y \frac{\partial T}{\partial y} = 0$$

THEN $$\frac{\partial T}{\partial \tau} = \frac{k}{\rho \cdot c}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + \left(w_z \frac{\partial T}{\partial z}\right) + \frac{Q_{SOURCE}}{\rho \cdot c}$$

T	temperature	[K]
τ	time	[s]
k	heat conductivity	$[W.\ m^{-1}.K^{-1}]$
w	velocity	$[m\ s^{-1}]$
ρ	density	$[kg\ m^{-3}]$
c	specific heat capacity	$[J\ kg^{-1}K^{-1}]$
x,y,z	coordinates	[m]
Q_{SOURCE}	heat flow/internal source	$[W\ m^{-3}]$

Boundary conditions:

1st $$T = T_{pour}$$

3rd $$-k\frac{\partial T}{\partial n} = HTC\,(T_{surf} - T_{mould})$$

2nd $$-k\frac{\partial T}{\partial n} = 0$$

4th $$-k\frac{\partial T}{\partial n} = HTC\,(T_{surf} - T_{amb}) + \sigma\varepsilon\left(T_{surf}^4 - T_{amb}^4\right)$$

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ENTHALPY AS A FUNCTION OF TEMPERATURE

$$\frac{\partial H_v}{\partial \tau} + \frac{\partial}{\partial z}\left(w_z . H_v\right) = k\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right)$$

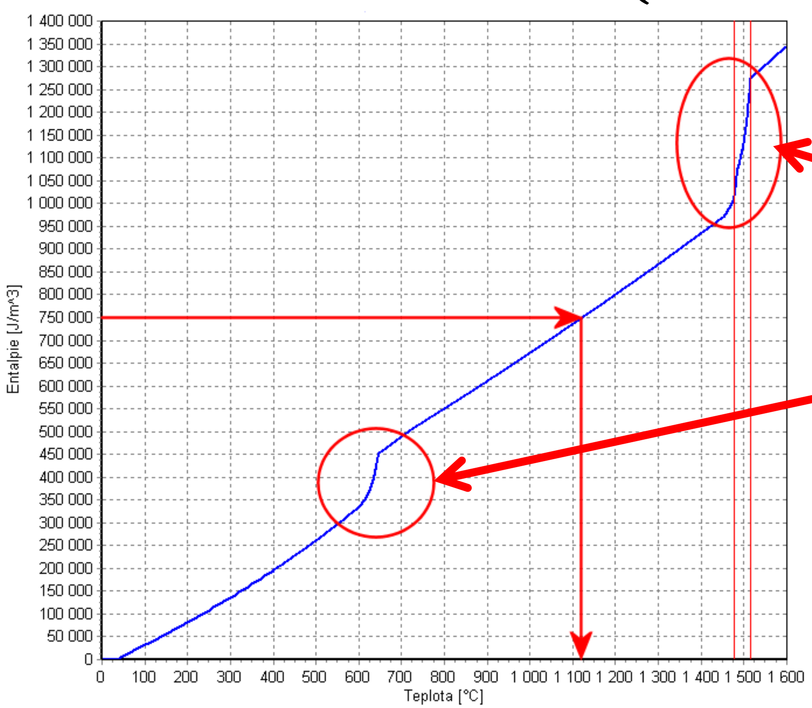
$\rho(t)$ [$kg.m^{-3}$]

$k(t)$ [$W.m^{-1}.K^{-1}$]

$c(t)$ [$J.kg^{-1}.K^{-1}$]

$H_v(t)$ [$J.m^{-3}$]

L [J]



This point can change its phase or structure during the simulated process. The enthalpy function contains the latent or structural heat of each change.

This function must be known for the relevant steel

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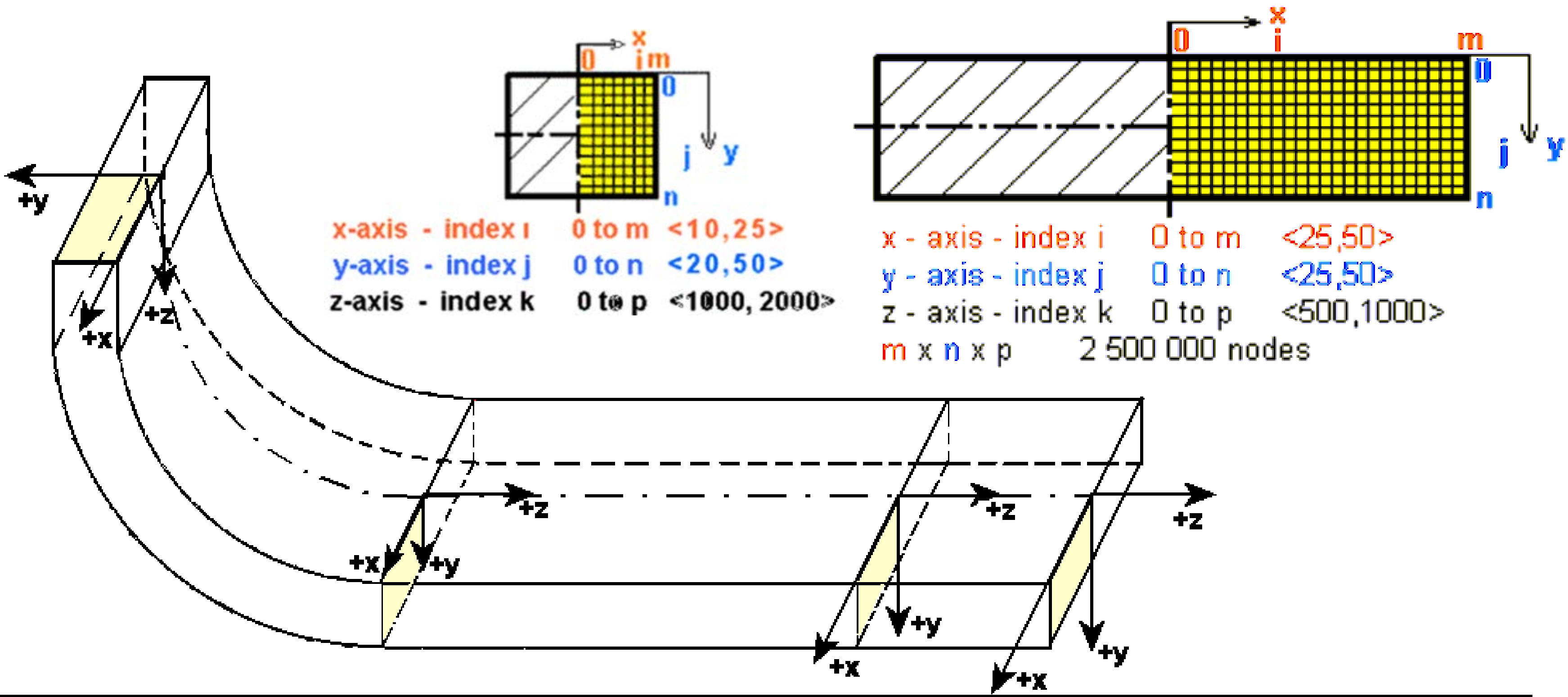
COMPUTING NETWORK



The entire length of the slab/billet in the z-direction - from the level in the mould, down to the cutting torch, is approximately 24-27 meters.

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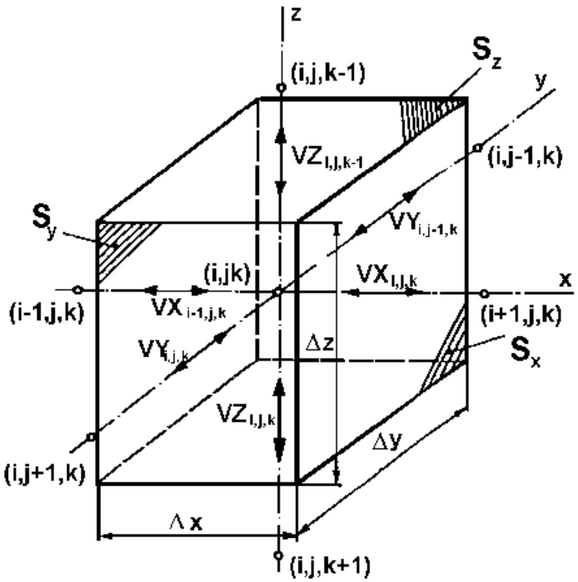
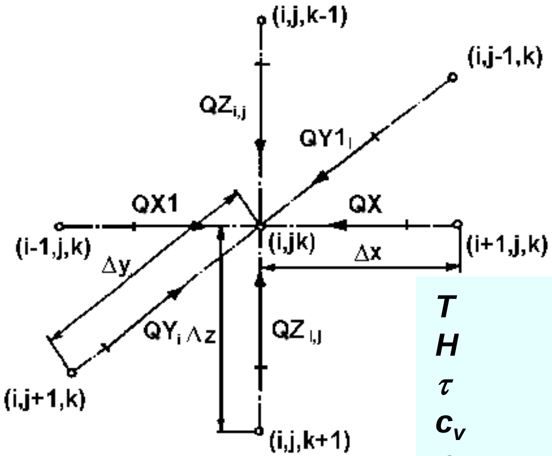
3D TEMPERATURE FIELD ELEMENT





T	temperature	[K]
H	specific volume enthalpy	[$W.m^{-3}$]
τ	time	[s]
c_v	specific volume heat capacity	[$J.m^{-3}.K^{-1}$]
ρ	density	[kg m^{-3}]
x,y,z	axis in given direction	
QX,QY,QZ	heat flow in given direction	[W]
VX,VY,VZ	conductivity in given direction	[$W.K^{-1}$]

$$T_{i,j,k}^{(\tau+\Delta\tau)} = T_{i,j,k}^{(\tau)} + (QZ1_{i,j} + QZ_{i,j} + QY1_i + QY_i + QX1 + QX)\frac{\Delta\tau}{c_v \cdot \Delta x \cdot \Delta y \cdot \Delta z \cdot \rho}$$

$$H_{i,j,k}^{(\tau+\Delta\tau)} = H_{i,j,k}^{(\tau)} + (QZ1_{i,j} + QZ_{i,j} + QY1_i + QY_i + QX1 + QX)\frac{\Delta\tau}{\Delta x \cdot \Delta y \cdot \Delta z}$$

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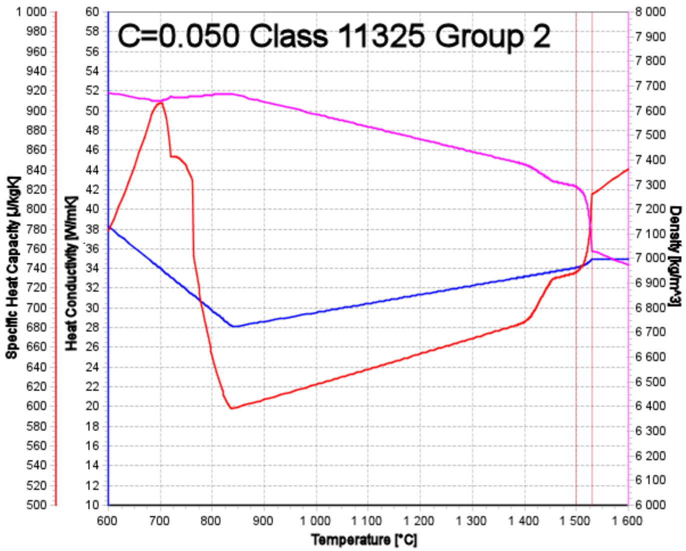
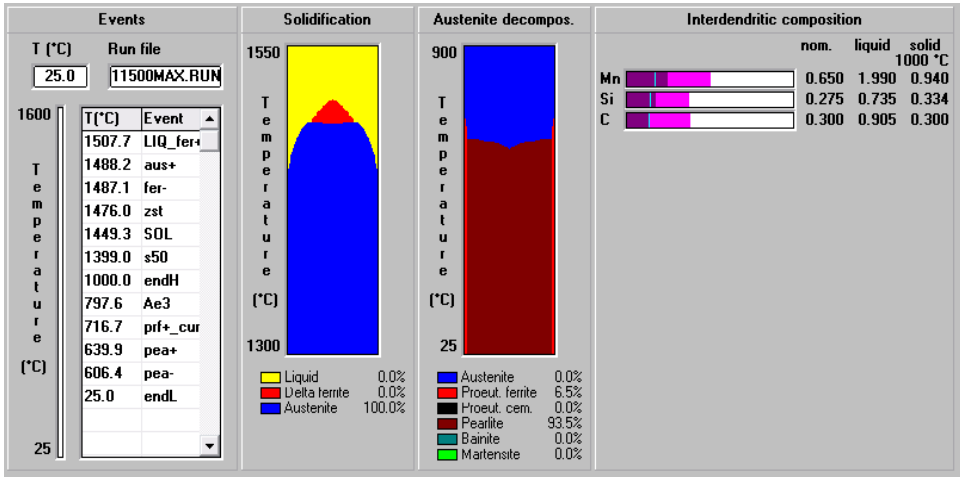
THERMOPHYSICAL PROPERTIES OF STEEL



ρ(T) [kg.m^{-3}]	- Density
k (T) [W.m^{-1}.K^{-1}]	- Heat Conductivity
c(T) [J.kg^{-1}.K^{-1}]	- Specific Heat Capacity

IDS software



We use a solidification analysis package for steels IDS. IDS calculates thermophysical material properties from liquid state to room temperature.

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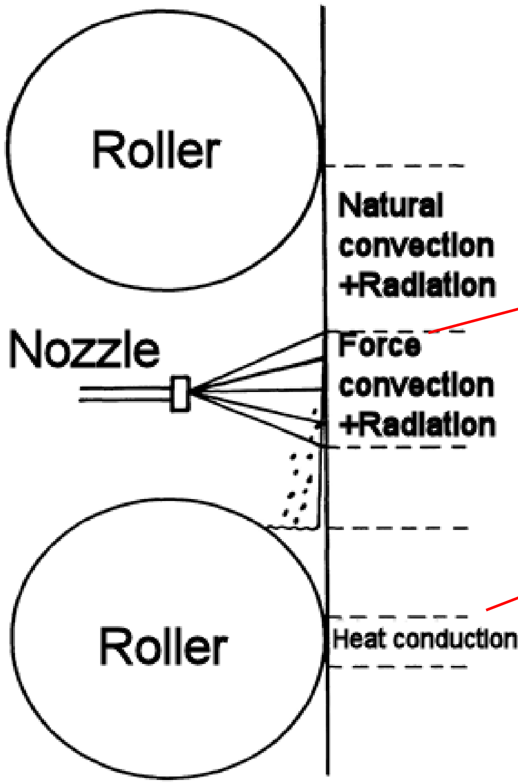
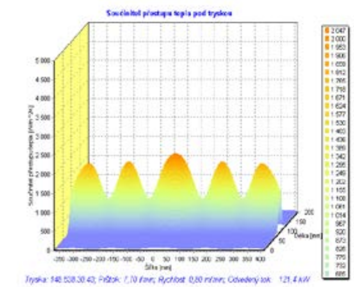
BOUNDARY CONDITIONS



Experiment for each nozzles



$$\dot{Q}_{rol} = htc_{rol} \cdot \pi \cdot \frac{l}{2} \cdot d \cdot (T_{rol} - T_{amb})$$

$$htc_{rol} = htc_{rolnat} + \varepsilon_{rol} \cdot \sigma \cdot (T_{rol}^2 + T_{amb}^2) \cdot (T_{rol} + T_{amb})$$

Natural convection

$$htc_{nat} = 0{,}84 \cdot \sqrt{(T_{surface} - T_{amb})}$$

Radiation

$$htc_r = \varepsilon \cdot \sigma \cdot (T_{surface}^2 + T_{amb}^2) \cdot (T_{surface} + T_{amb})$$

$$\varepsilon = 0{,}78828571429 + 0{,}0003375 \cdot T_{surface} - 40{,}17857143 \cdot 10^{-6} \cdot T_{surface}^2$$

Q [W] *heat flow* **htc [W.m^{-2}.K^{-1}]** heat transfer coefficient ***l, d [m]*** *roller dimensions*
T [K] *temperature* **ε [-]** emissivity

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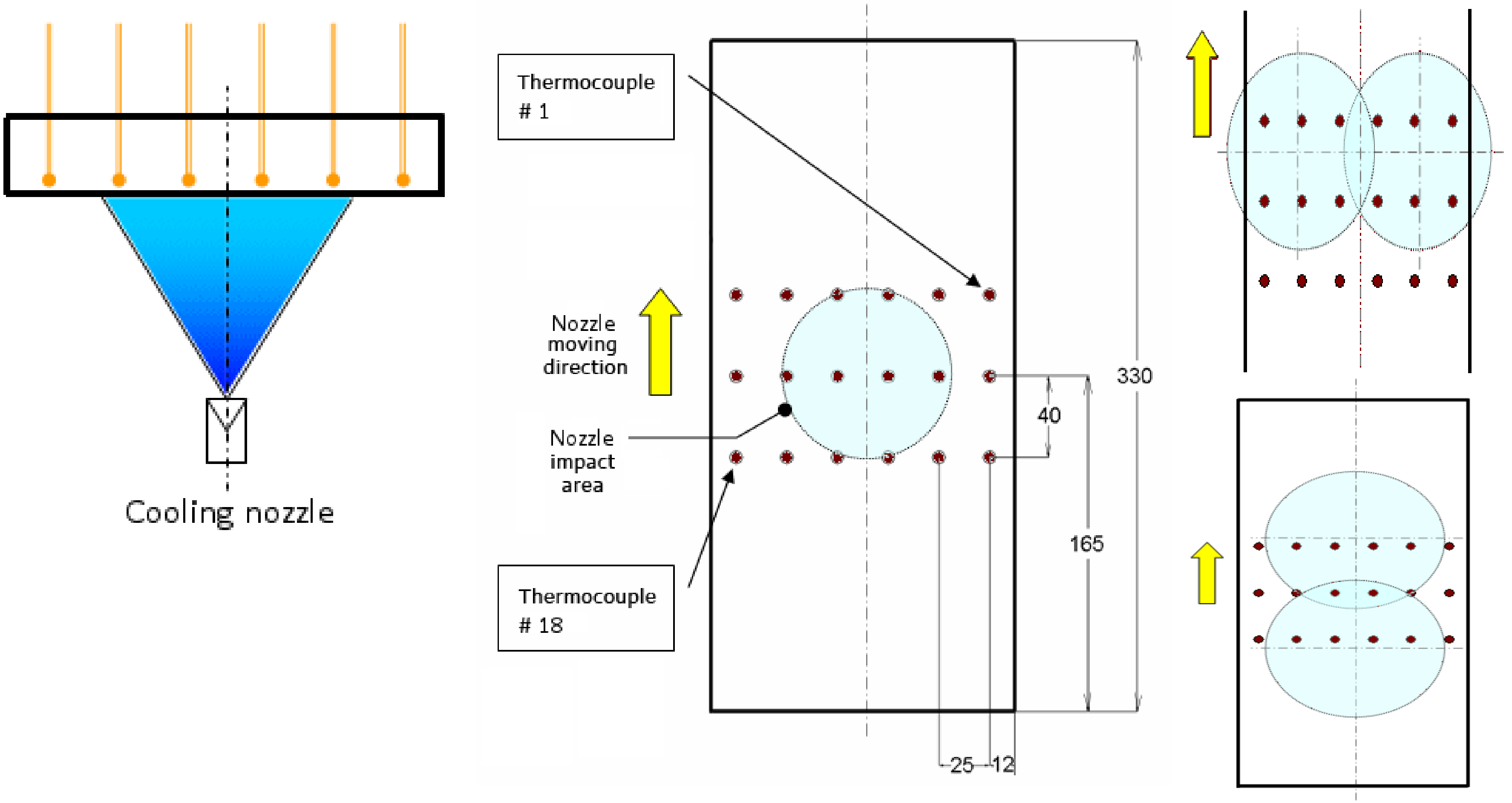
MEASURING THE COOLING EFFECT OF NOZZLES



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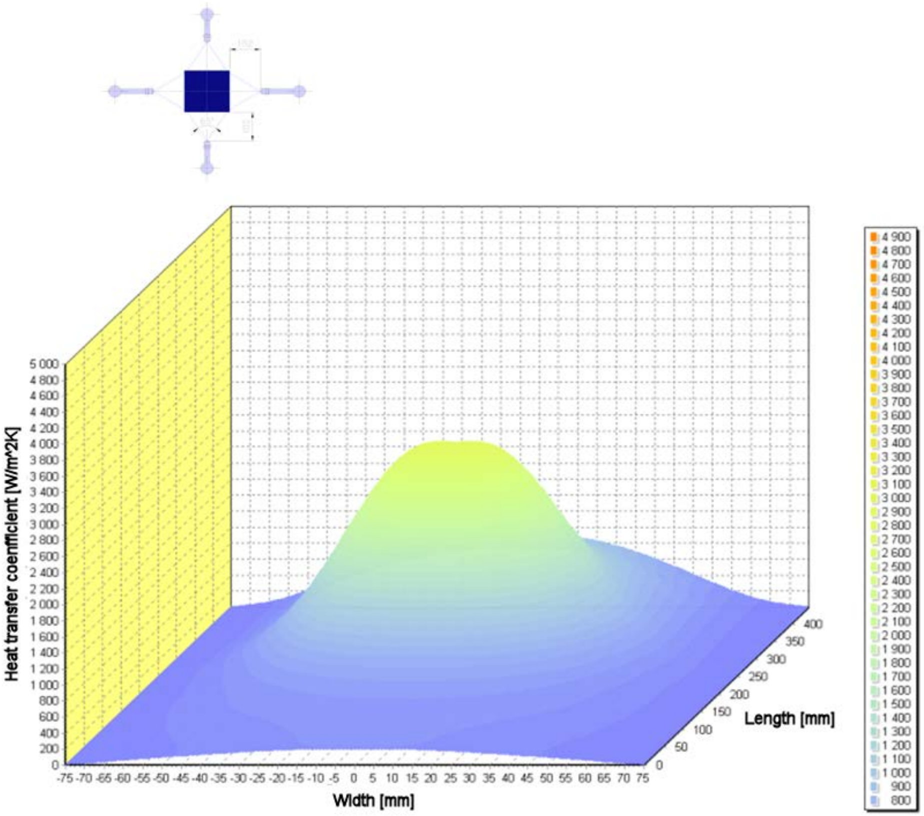
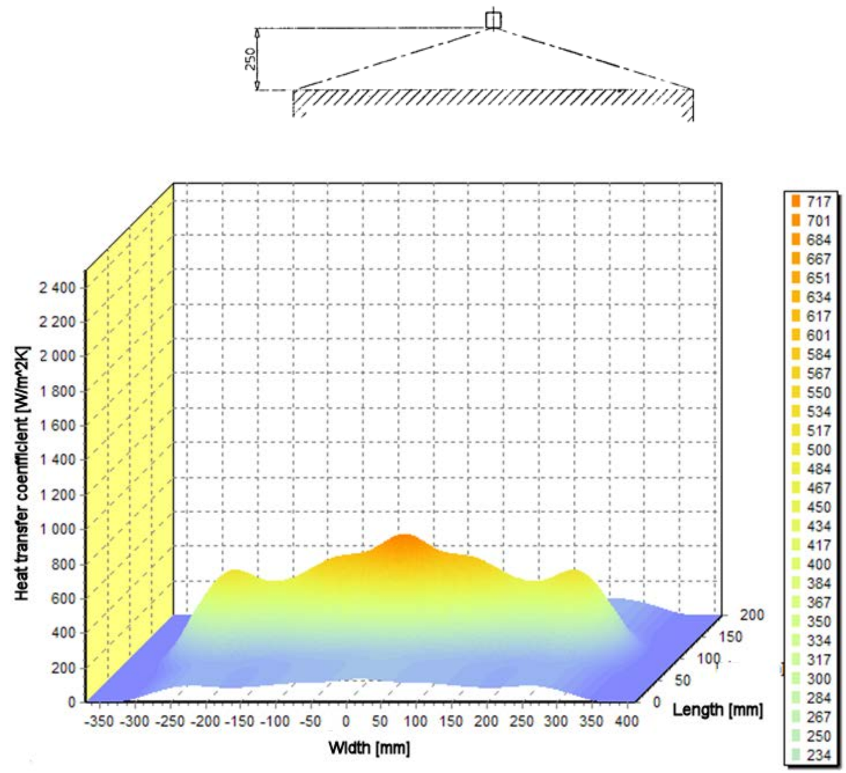
THE HEAT TRANSFER COEFFICIENT UNDER SINGLE AND TWIN FLUID NOZZLES





Water nozzle JATO 4065L
Flow through one nozzle at 4.40 l/min

Water-air nozzle Lechler 100.638.30.24
Flow through one nozzle at 9.2 l/min

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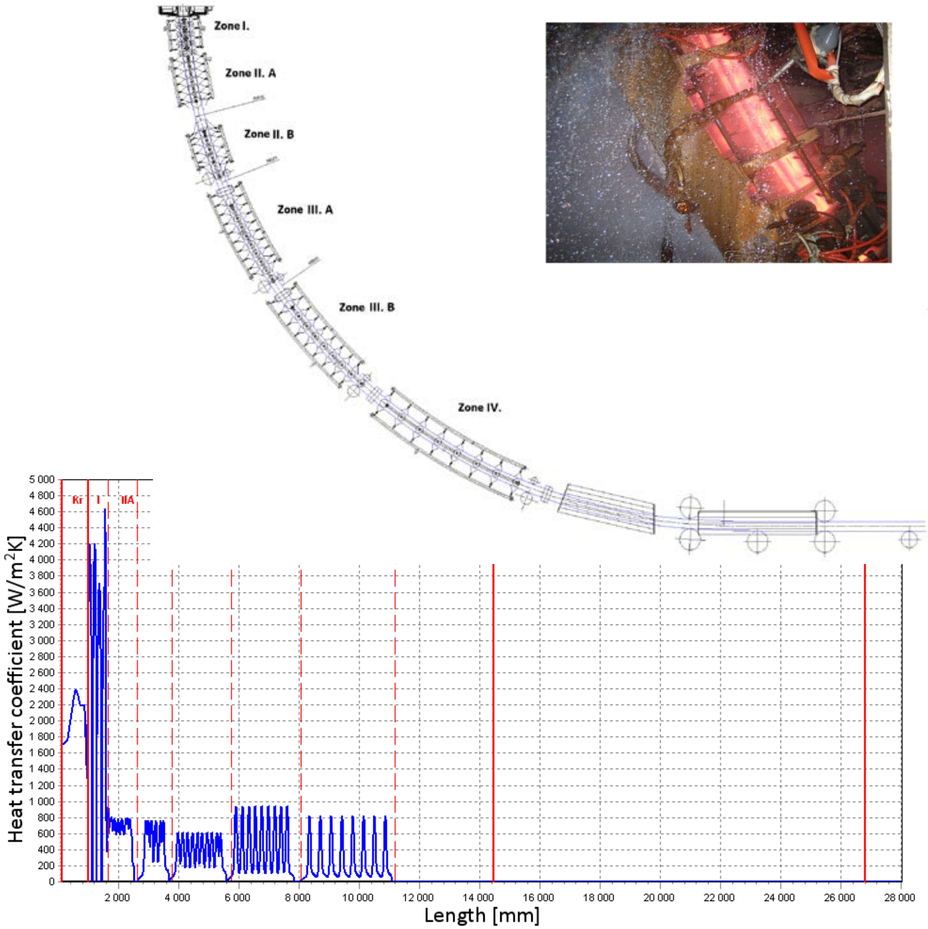
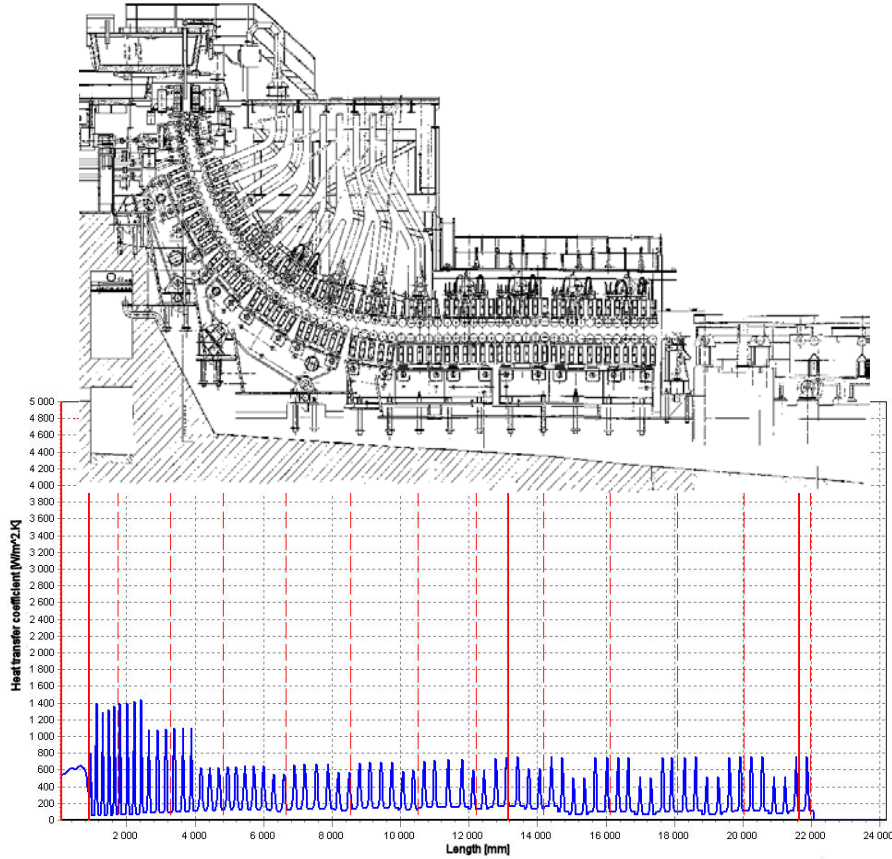
THE HEAT TRANSFER COEFFICIENT ALONG THE ENTIRE CASTER





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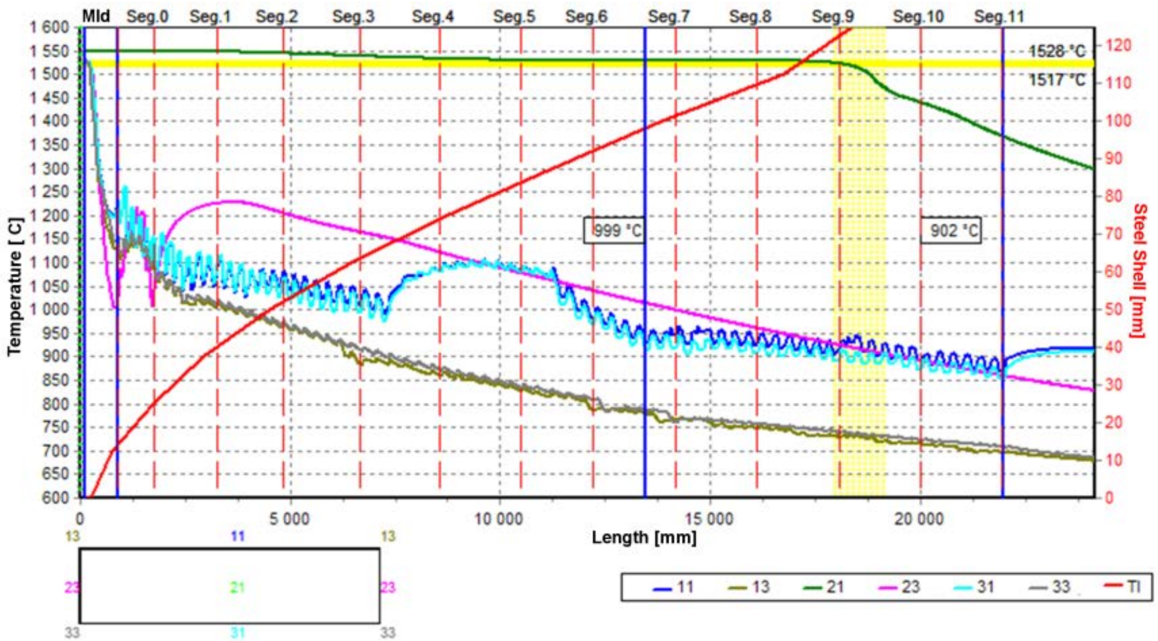
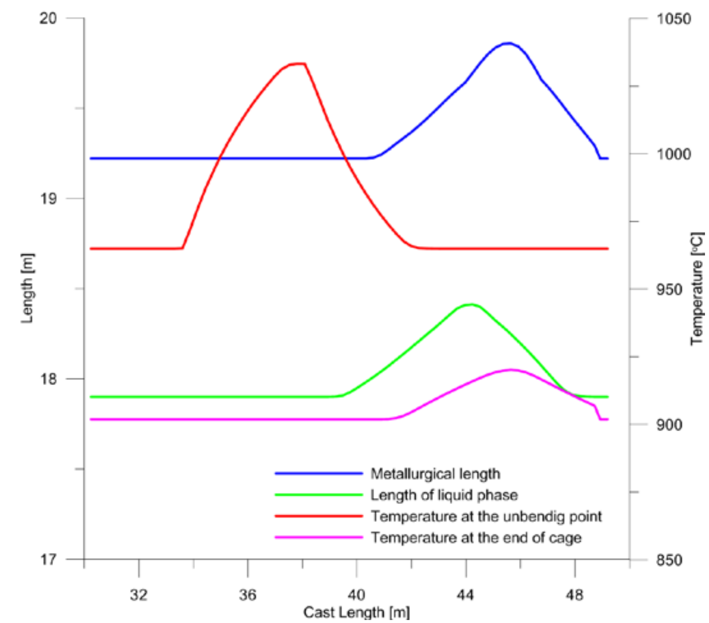
SIMULATION OF FAILURE OF COOLING CIRCUITS





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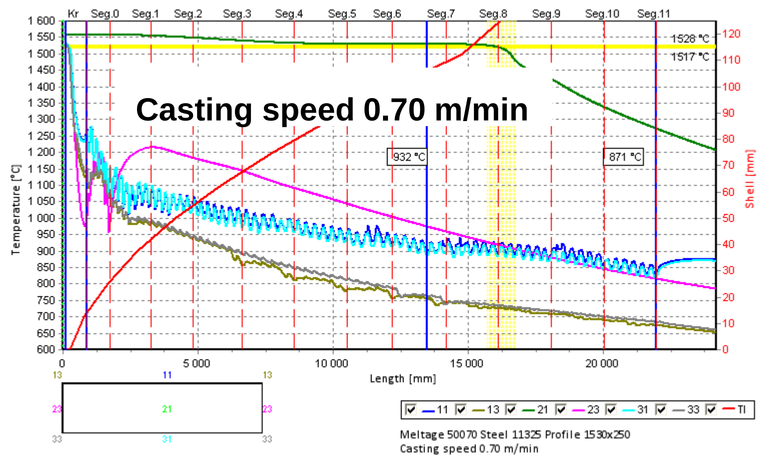
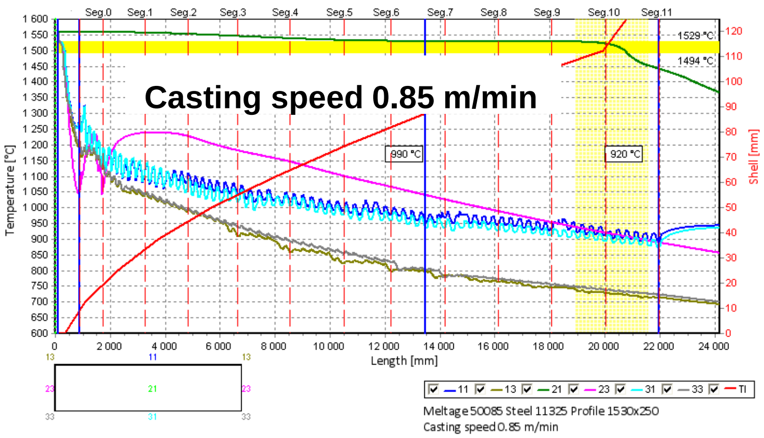
SIMULATION OF INFLUENCE OF CASTING SPEED ON TEMPERATURE FIELD





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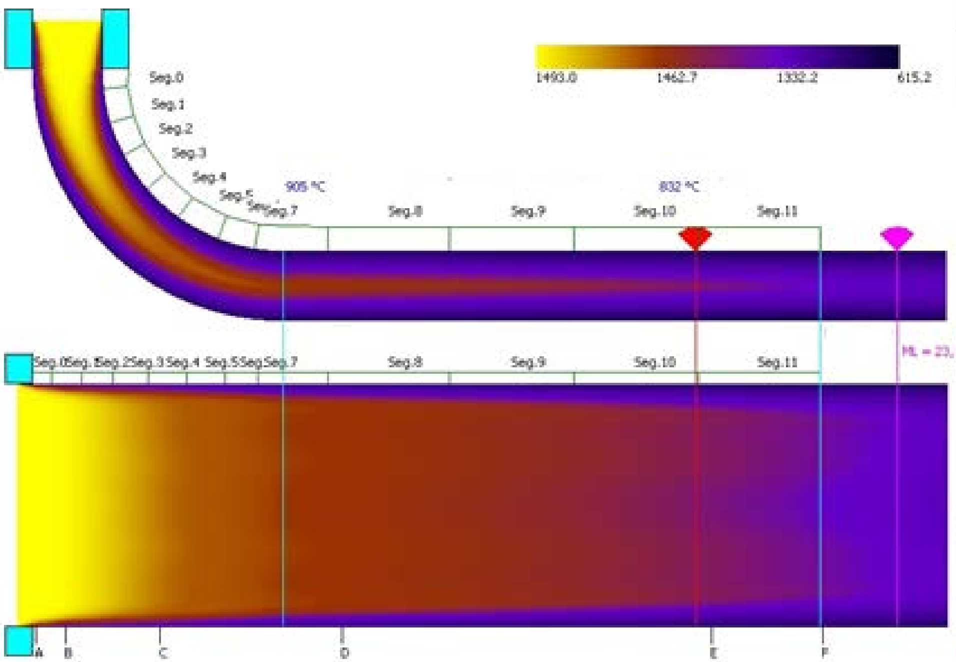
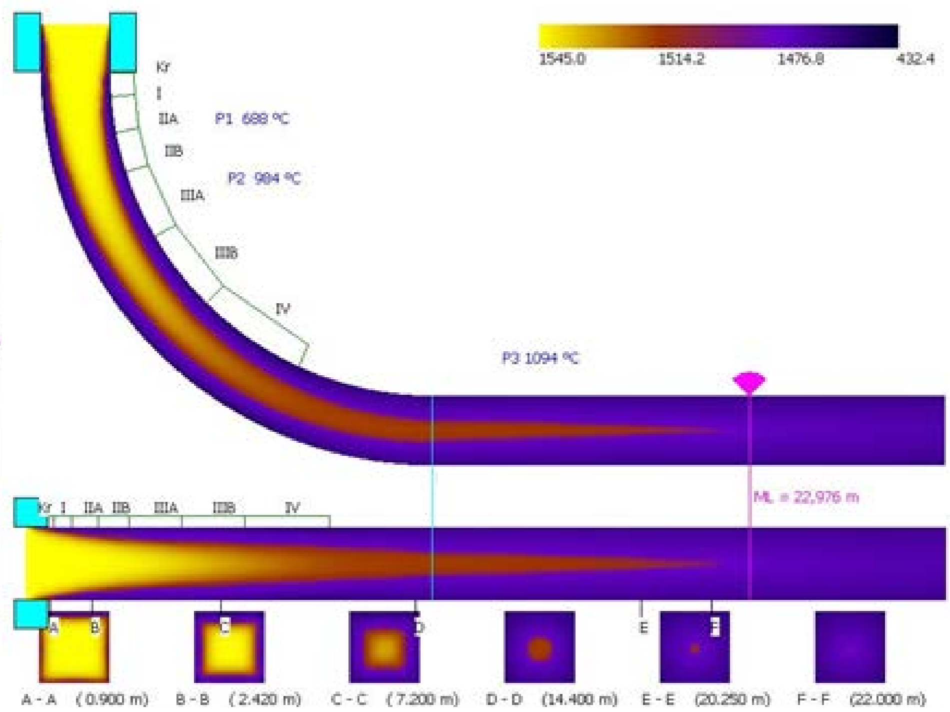
TEMPERATURE FIELD OF SLAB AND BILLET





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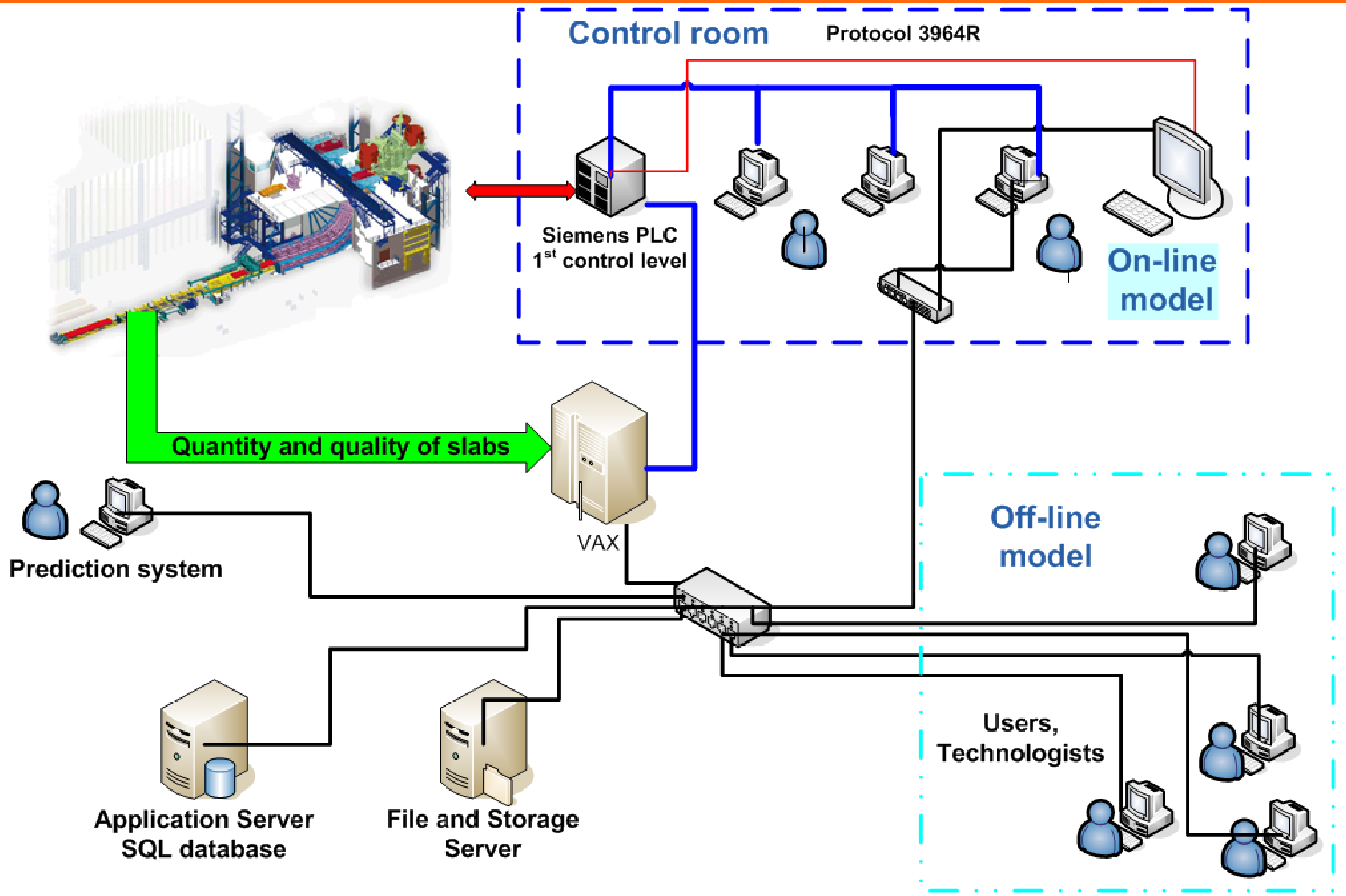
THE CASTING TECHNOLOGY CONTROL SYSTEM



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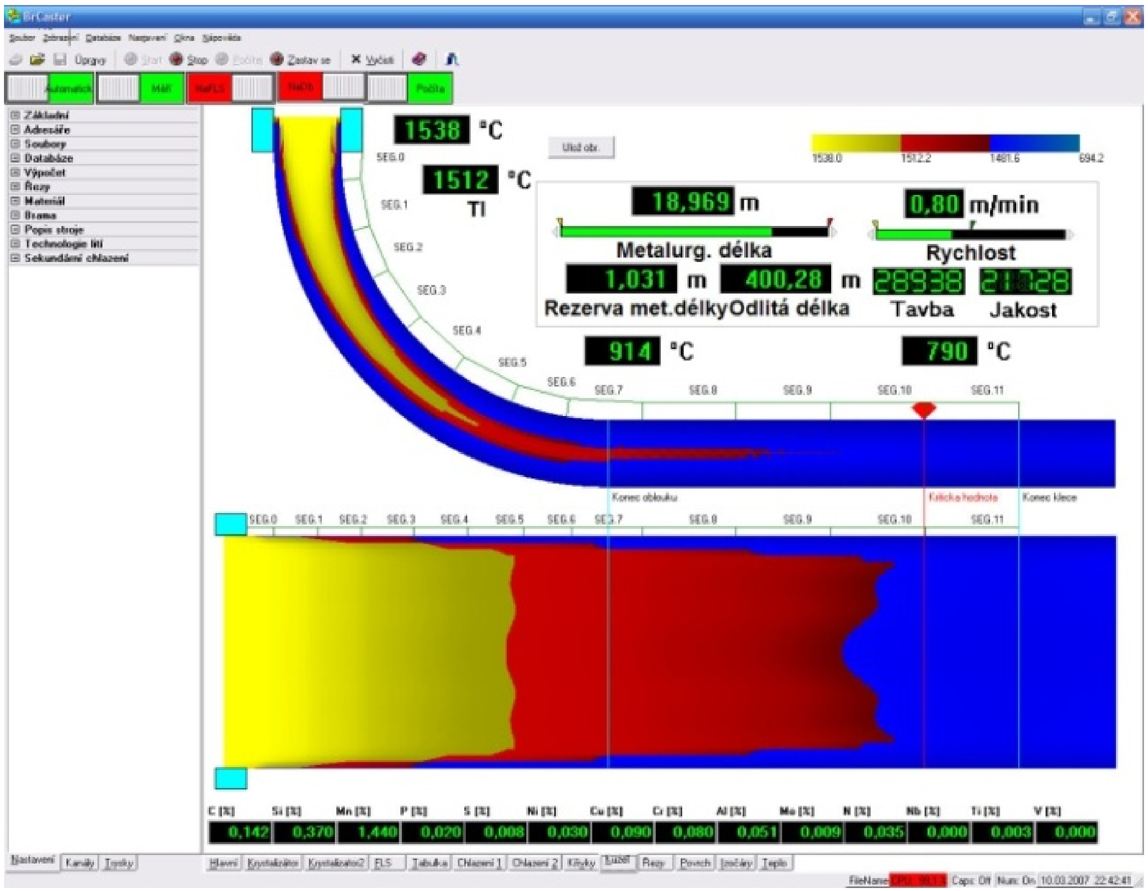
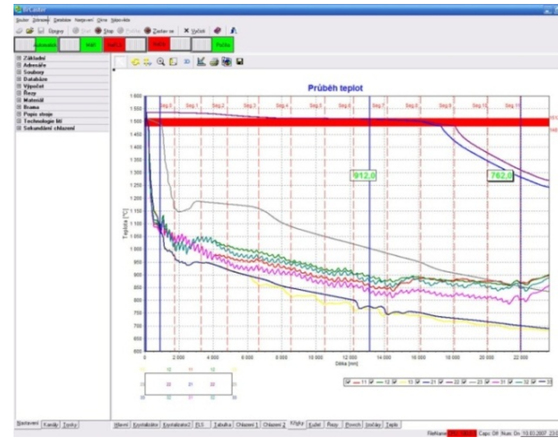
ON-LINE MODEL IN THE CONTROL ROOM





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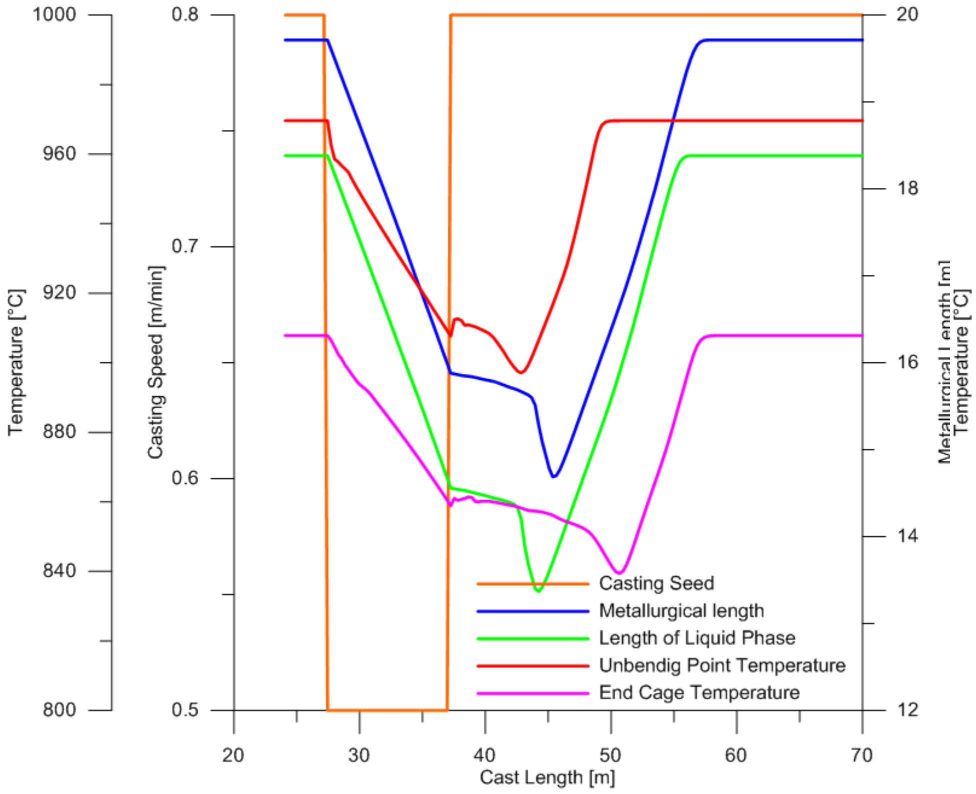
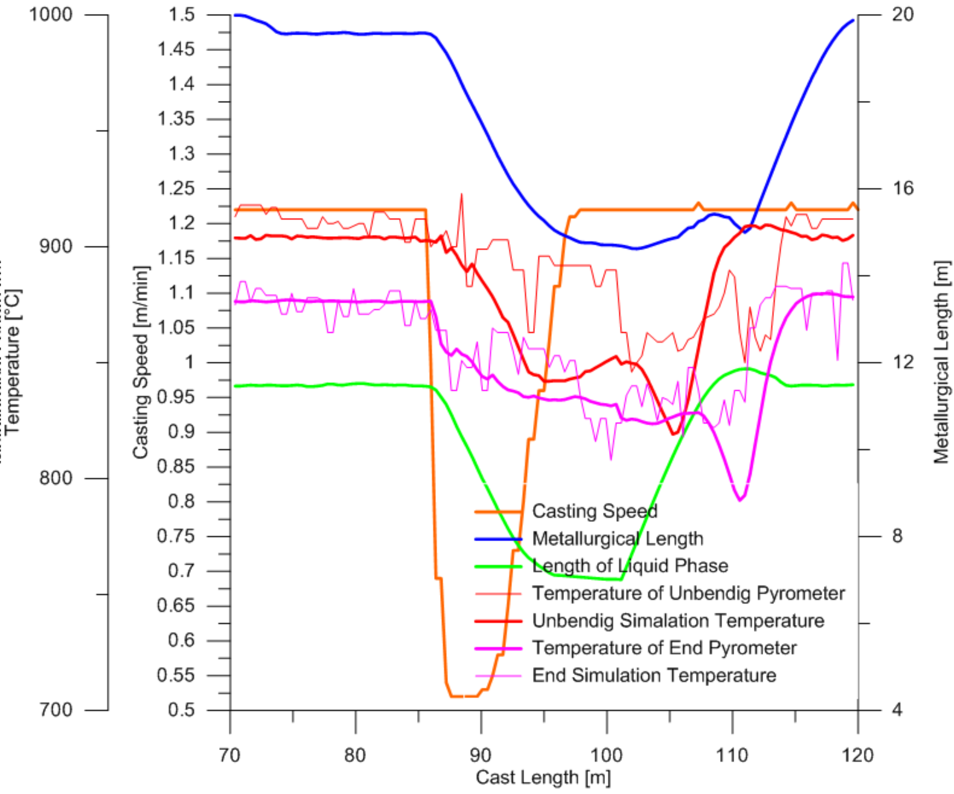
DYNAMIC RESPONSE MODEL TO CHANGES IN CASTING SPEED





TRANSIENT VALUE – OFF LINE MODEL

TRANSIENT VALUE – ON LINE MODEL

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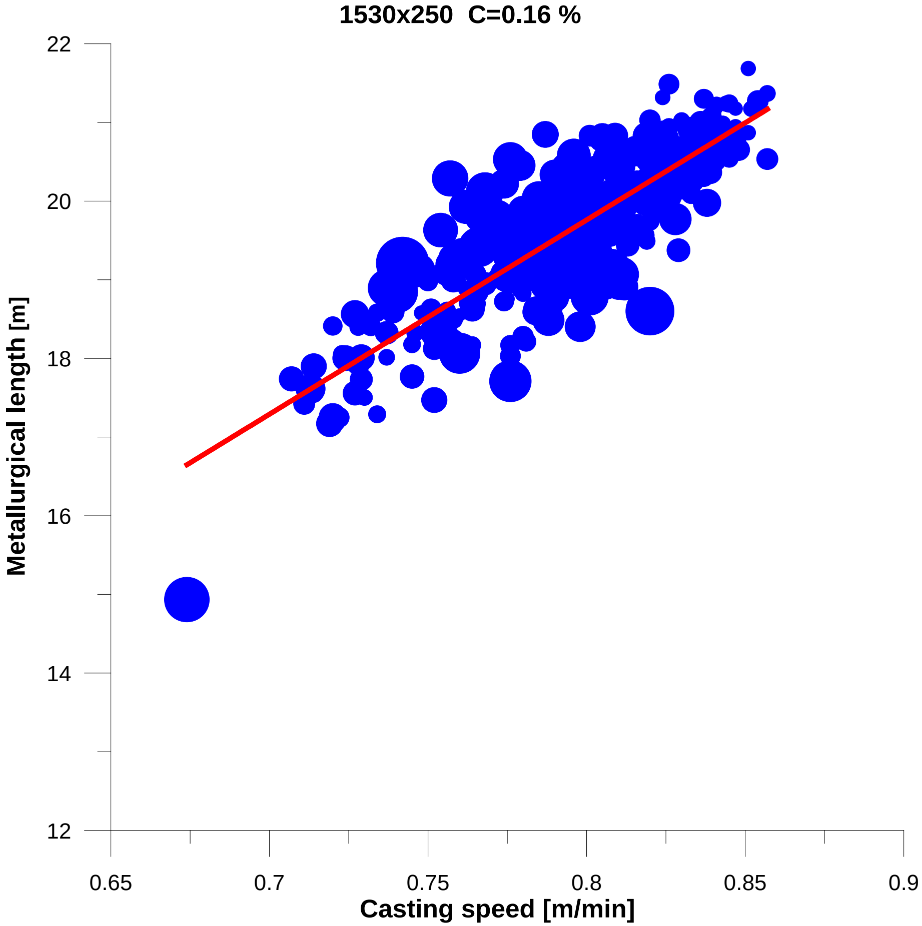
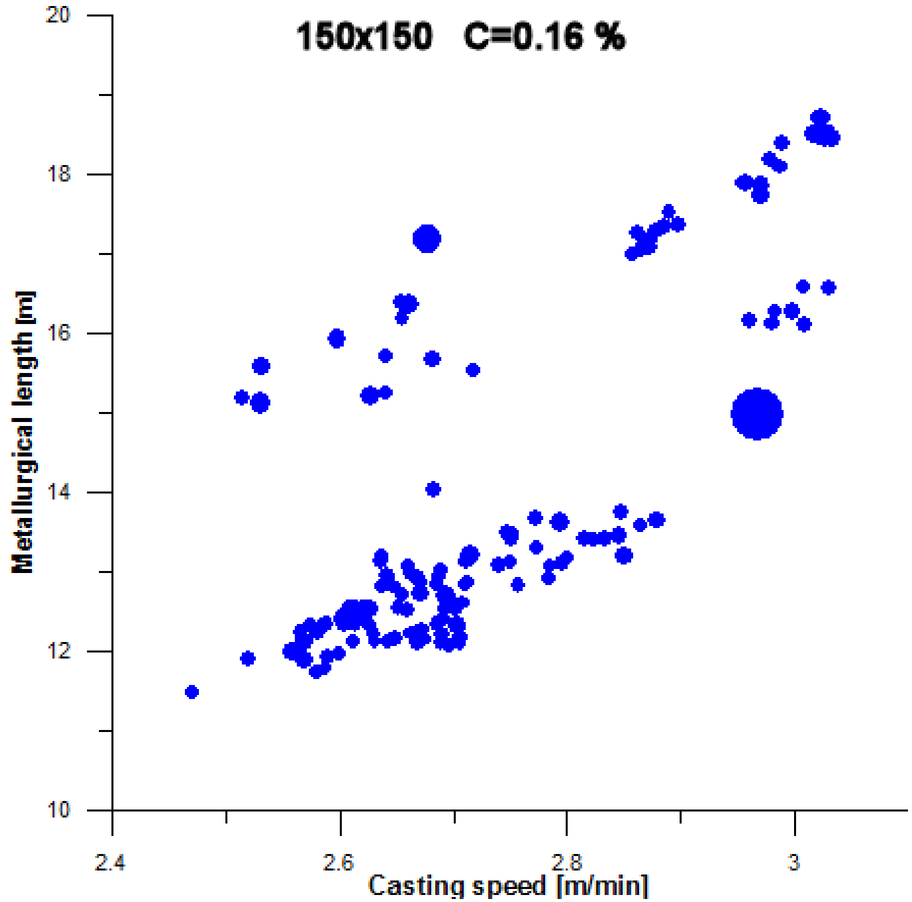
METALLURGICAL LENGTH - CASTING SPEED FOR SLAB 1530x250 AND BILLET 150x150





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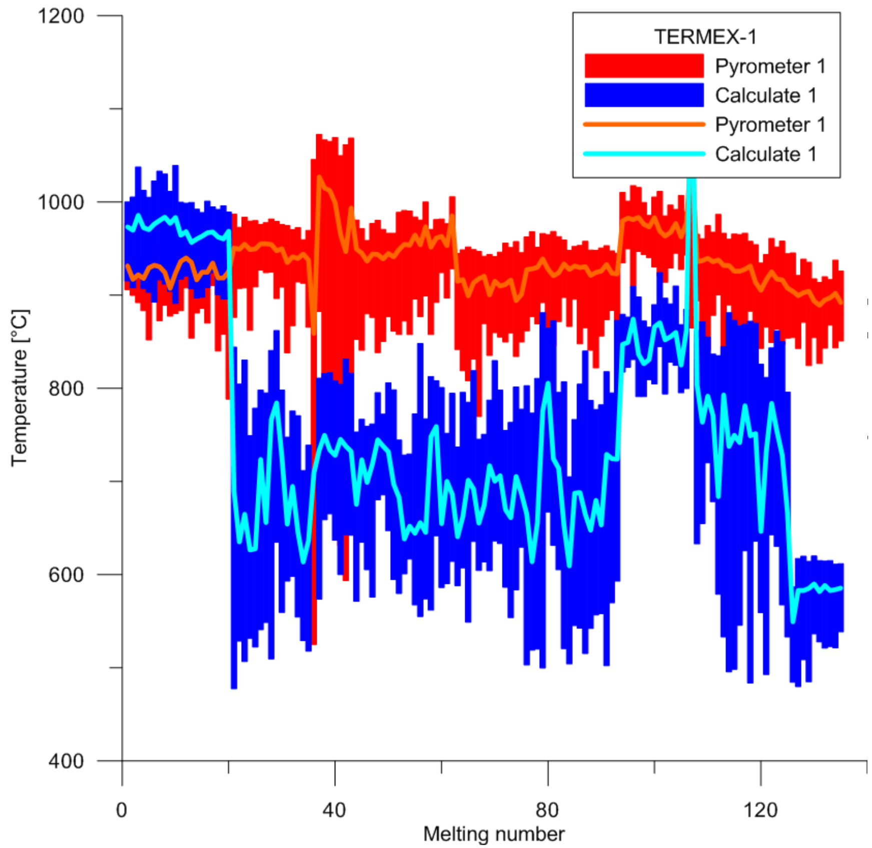
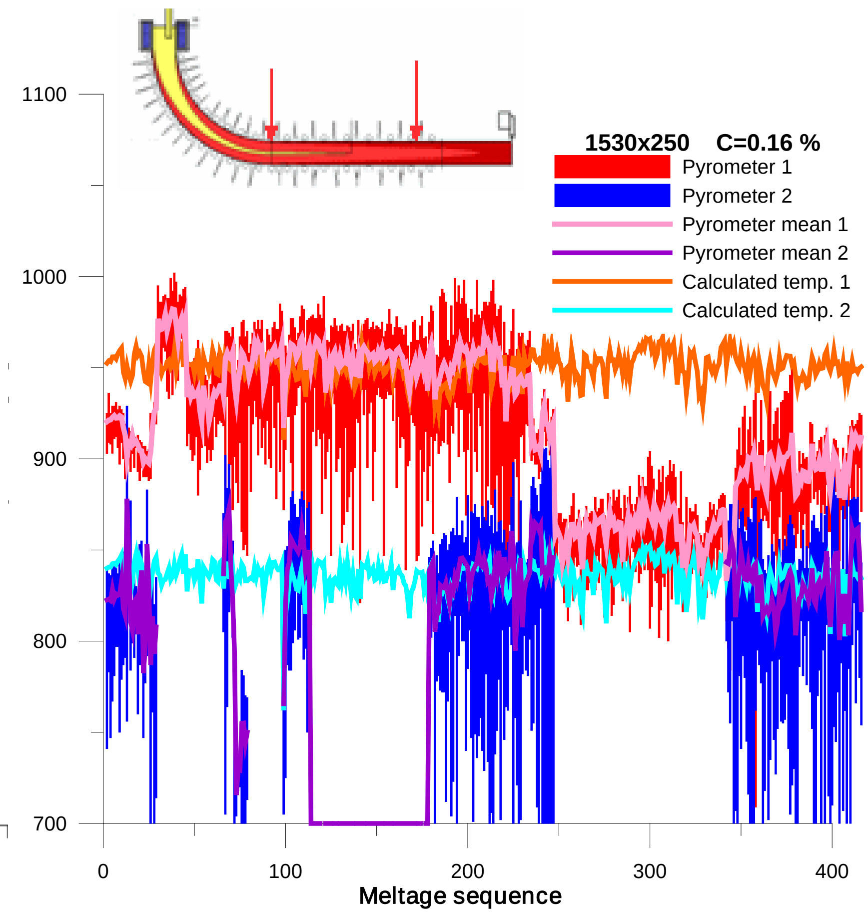
CALCULATED AND MEASURED SURFACE TEMPERATURE OF SLAB AND BILLET





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CONCLUSIONS

- 3D numerical model of the temperature field for concasting of steel in the form of in-house software
- The software has been implemented:
  - EVRAZ VITKOVICE STEEL
  - TRINECKE ZELEZARNY
- Three ways of utilizing the results of the dynamic model:
  - Simulate/Monitor the current temperature field
  - Simulate/Monitor the quantities in the form of trends
  - Simulate/Monitor the statistical quantities from individual melts

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THANK YOU
FOR YOUR ATTENTION

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