Pilot scale simulator based on liquid metal to study flow related issues on continuous casting

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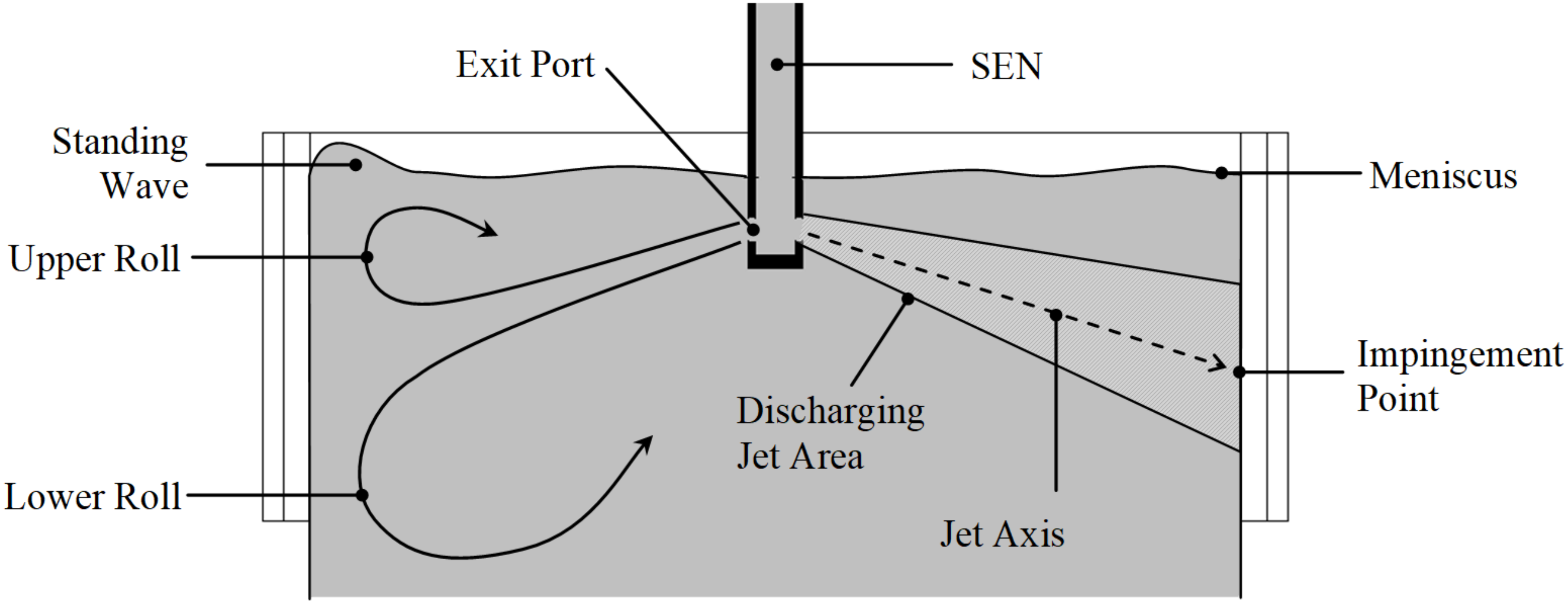
European Commission
Research Fund for Coal & Steel

Flow pattern in the mould

Definitions

The molten metal flow pattern inside the mould is one of the main factors controlling the casting process. This pattern is produced by the molten steel exiting the nozzle ports, which creates a variety of flow structures within the mould such as discharging jets, standing waves, rolls and biased flows.



Flow instabilities = cracking & defects

Defects in CC

DEFECT	CAUSE
Longitudinal cracking and longitudinal corner cracking	4% difference in thermal shrinkage coefficient between γ and δ-ferrite causes stresses in the shell, which can only be relieved by cracking. Particularly severe in MC grades. Nozzle misalignment, biased flows and immersion depth changes.
Star cracking	Irregular heat transfer at bottom of mould due to breaking of slag film
Deep Oscillation Marks	decreases with increasing , stroke, slag rim thickness, superheat and frequency.
Transverse and corner cracks	Associated with large ’s. Particular problem in ULC, where small γ to δ-Ferrite shrinkage causes: Excessive taper and low powder consumption. Sometimes related to deep Oscillation Marks
Sticker breakouts	Lack of lubrication. Formation of low-melting shell through C contamination, which does not heal in (particularly HC grades). Often involves blockage of liquid slag channel. Strong level fluctuations
Slag entrapment	High turbulence and high interfacial velocities between slag and steel
Gas entrapment, “pinholes”, “pencil pipe”	Gas bubbles trapped in meniscus. Prevalent wide slabs of LC and ULC steel. Metal flow takes bubbles too far (bubbles entrapped in the shell). Inclusion attaches to bubble (not welded shut). Foam near flux attaches to the SEN
“sliver”	Al_2O_3 particles freed from SEN trapped by shell; prevalent in LC and ULC.
Depressions **a) Longitudinal** **b) Transverse** **c) Off-corner**	a) Associated with large mould level variation- probably due to increased pressure and bending forces on shell as liquid slag enters the rim. b) Mould and starter fluxes mix forming a sinter (“rope”), which forms a template for depressions as mould rises. c) This stops liquid slag flow, the rope melts and is captured by the shell.
Carbon pick-up	Particular problem in LC and ULC grades due to either pick-up from C-rich slag rim or steel poking into powder.
SEN erosion	Erosion of Z band by flux, promoted by low viscosity flux Attack of CaO stabiliser for ZrO_2 by CaF_2 and SiO_2 and high metal flow velocities.

Continuous Casting Simulator (CCS) with liquid metal

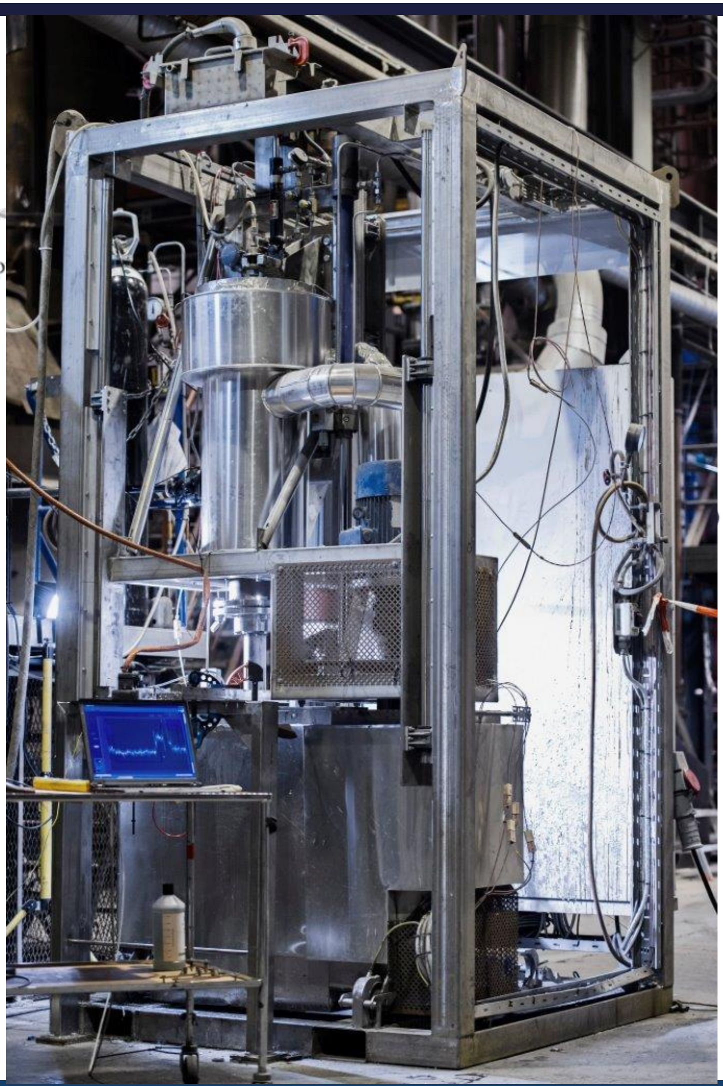
CCS at SWERIM Luleå

• Designed and built between 2004-2007 through RFCS–FLOWVIS project. The model was originally focused in the submerged entre nozzle (SEN).

• Between 2011-2014; RFCS DDT (Direct Defect Toolbox) allowed updating of control and heating systems, solving operational issues with dross and developing probes for velocity and metal level measurements (Vivés, ultrasound, light beam, etc.)

• Results of the revamped Continuous Casting Simulator were used to validate numerical models and expand process knowledge.

• Lately, VINNOVA-FLOWFLEX (2014-2016) focuses on nozzle design allowing installation of new industrial ceramic nozzles and a secondary Argon line.



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Why using Bismuth-Tin alloy ?

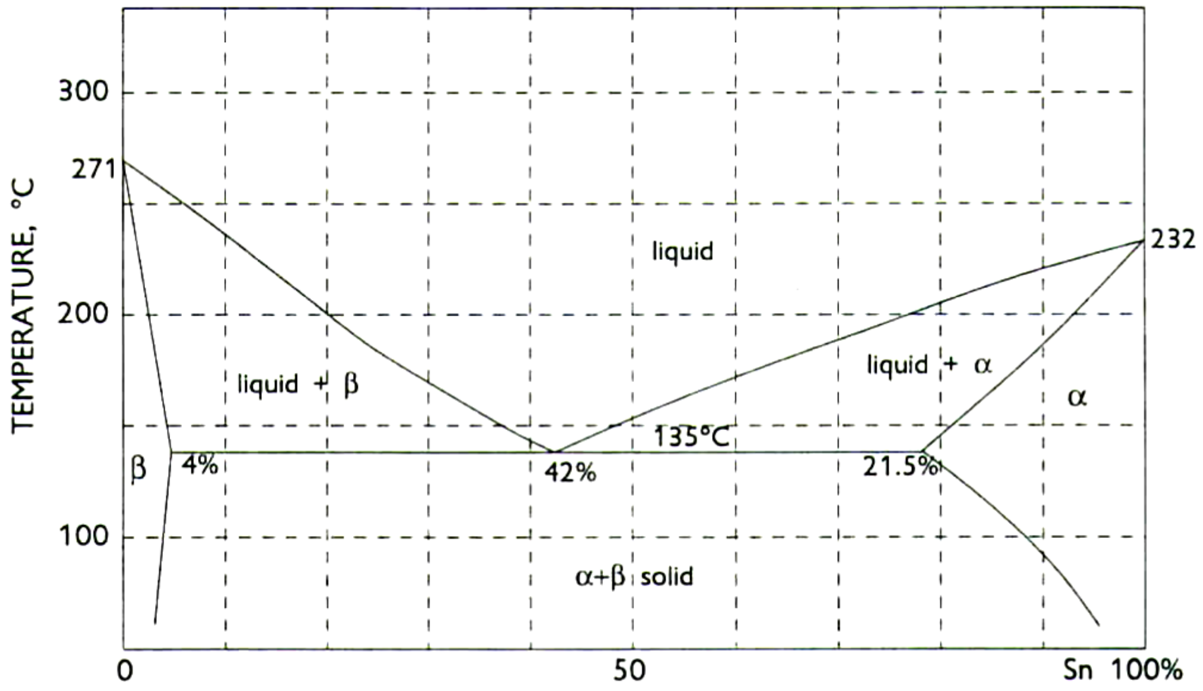
The properties of MCP-137 (Bi 58%-Sn 42%)

Electrical conductivity

	σ (1/Ωm)
MCP-137 (solid)	1.7*10^6
MCP-137 (liquid)	1.0*10^6
Steel (solid)	0.8*10^6
Steel (liquid)	0.7*10^6

Kinematic viscosity

	η[Ns/m^2]x10^{-3}	ρ[kg/m^3]	ν[m^2/s]x10^{-6}
Steel(1600°C)[6]	~6.3	7000	~0.9
MCP-137(150°C)	~10.7	8580	~1.25
MCP-137 (170°C)	~8.6	8580	~1



Continuous Casting Simulator (CCS-1) at SWERIM

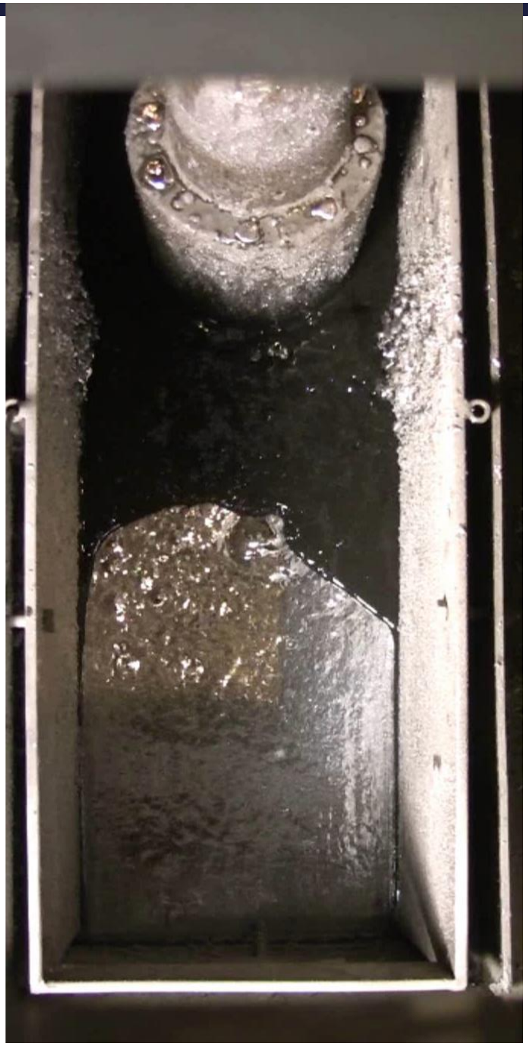
Real refractories in CCS

SENs and stoppers and diverse measurements

All the tests and measurements can be carried out with industrial ceramic nozzles and stoppers.

Measurements include:

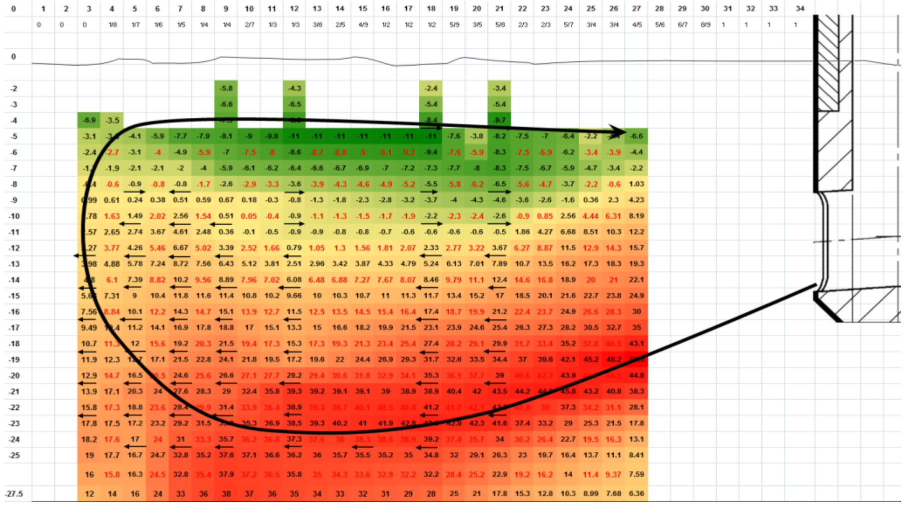
- Velocity just below metal level (electromagnetic Vivés probe)
- Mould Level fluctuations (Light beam)
- High-speed imaging to capture argon bubble size and number released through stopper and SEN porous plugs.

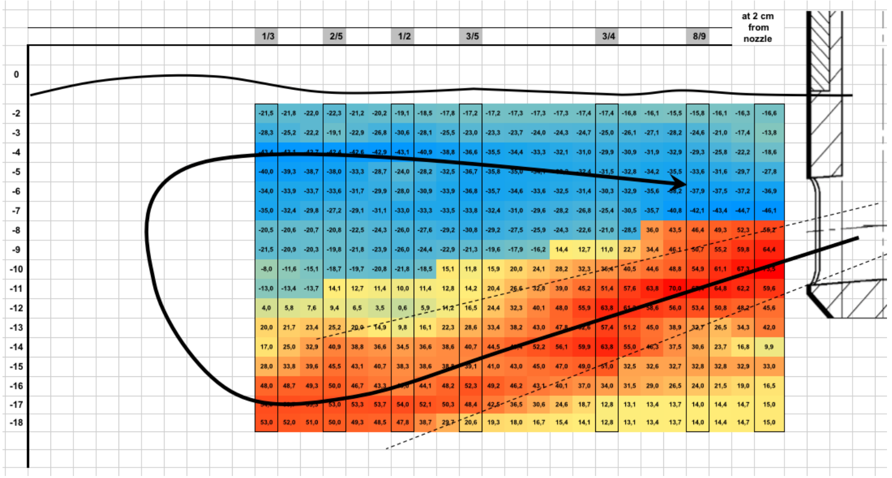


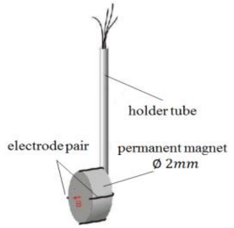
Measurement techniques

Velocity measurements

Electromagnetic (VIVES probes) and ultrasound.







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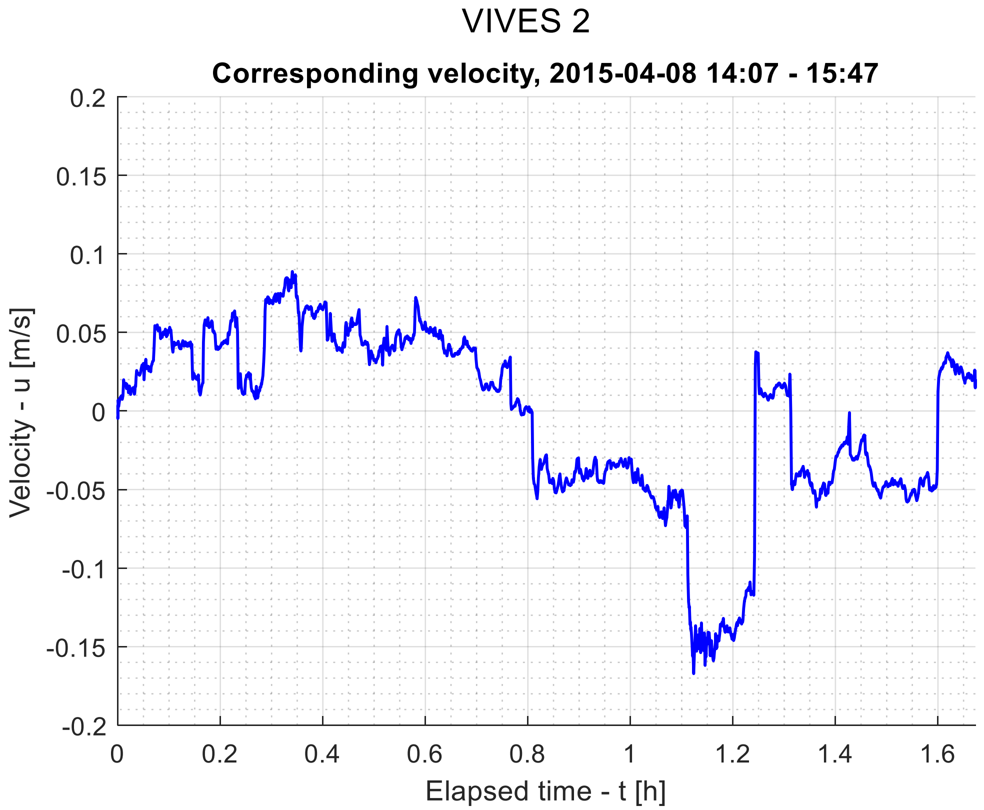
Velocity measurements

Electromagnetic (VIVES probe)

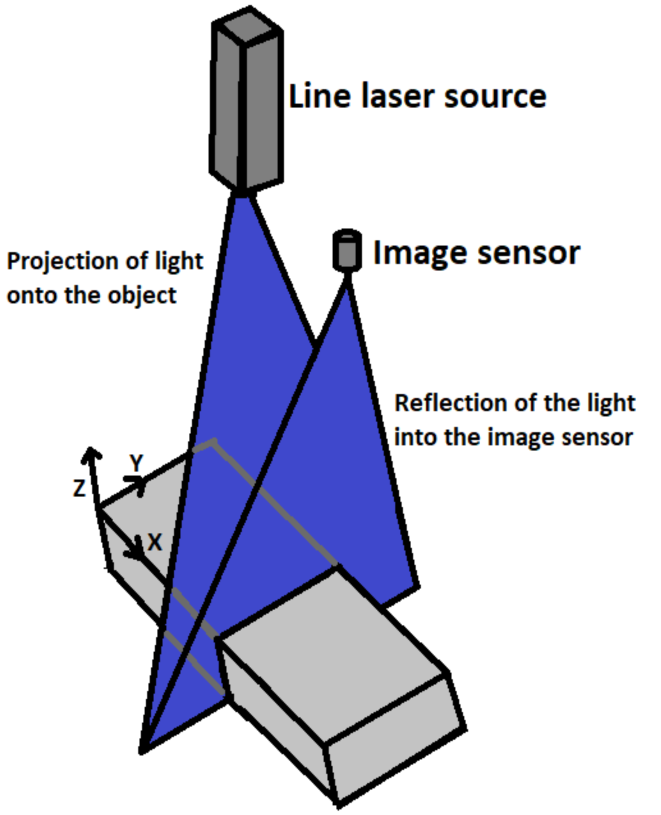
- Postprocessing
  - Averaged over 5 s
  - Derivatives above $5 \cdot 10^{-8} \frac{dV}{dsample}$ and absolute values above $17.5 \cdot 10^{-5}$ V treated as noise
  - Each peak was matched with velocities
  - Linear equation fit to the data
- Results
  - Voltages directly translated to velocities
  - Data not useable
    - No verification
    - Considerable disturbance of surface during trial

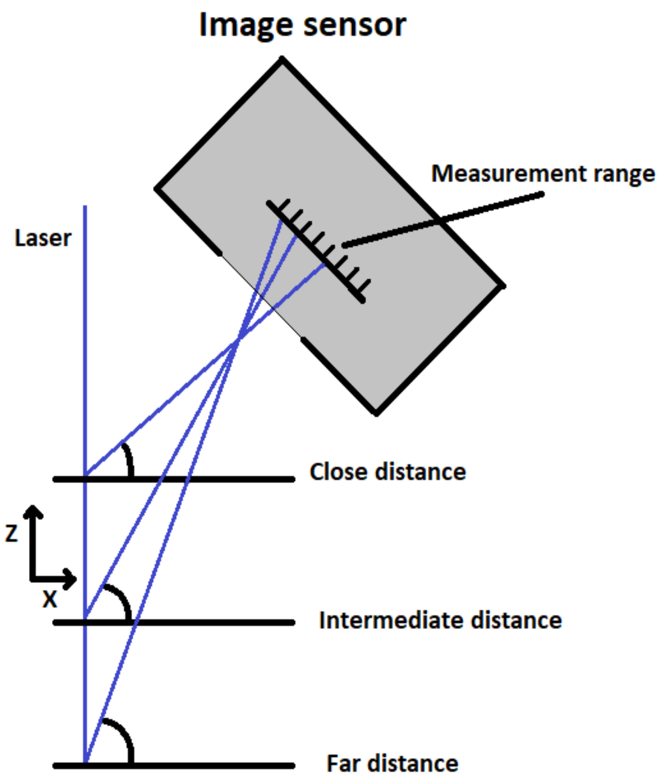


Mould level measurements

Optical probes

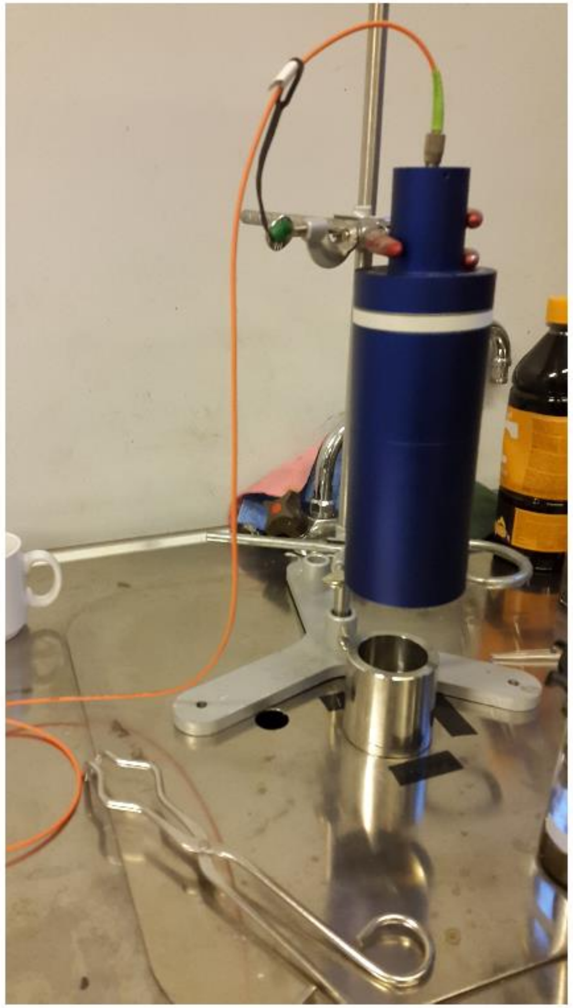
- Light beam
  - Chromatic confocal type
  - Working distance 76.5 mm
  - Working range 25 mm
- Blue laser line scanner
  - Laser triangulation type
  - Working distance 240 mm
  - Working width 100 mm



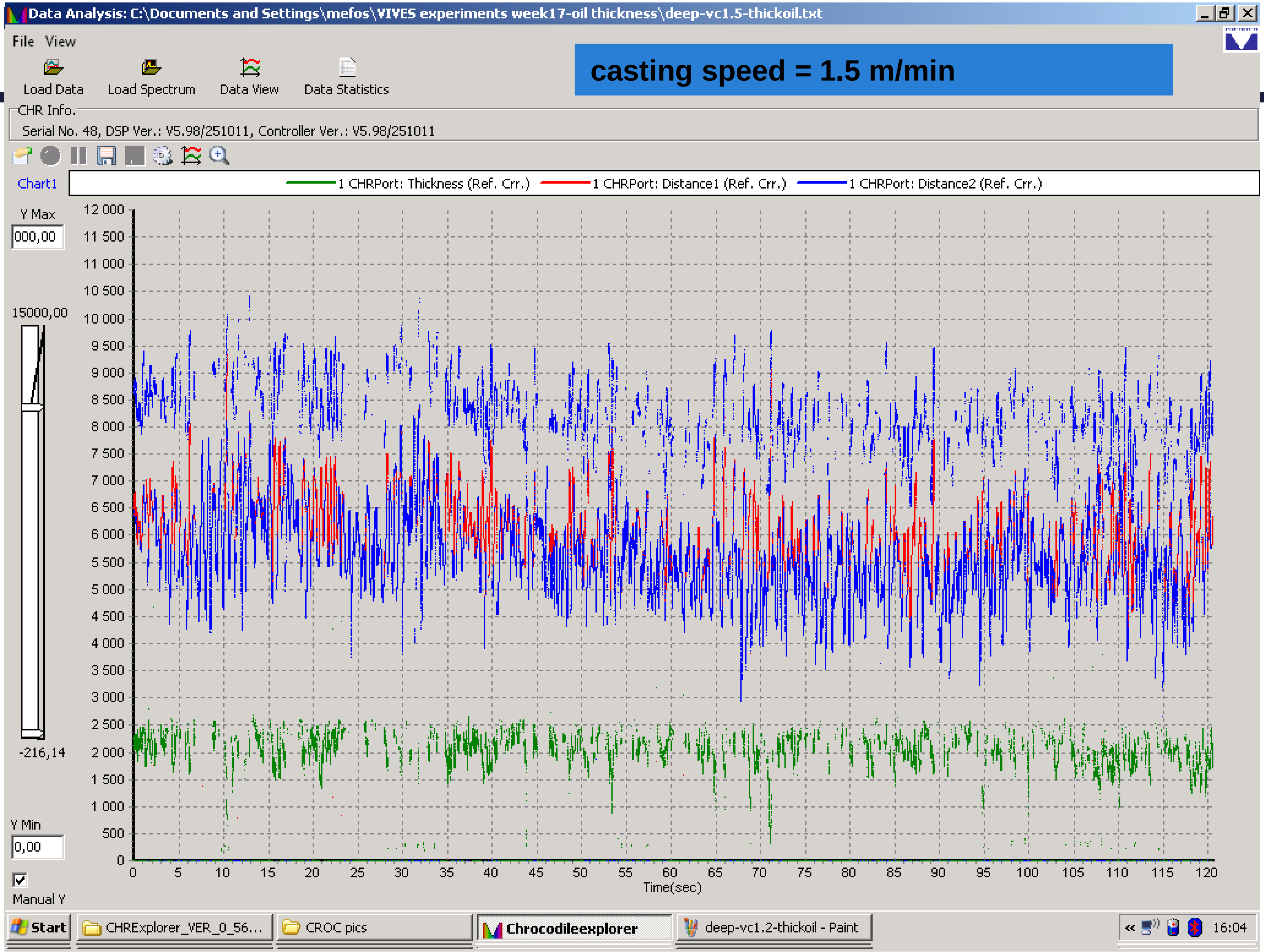


Mould level measurements

Light beam installation

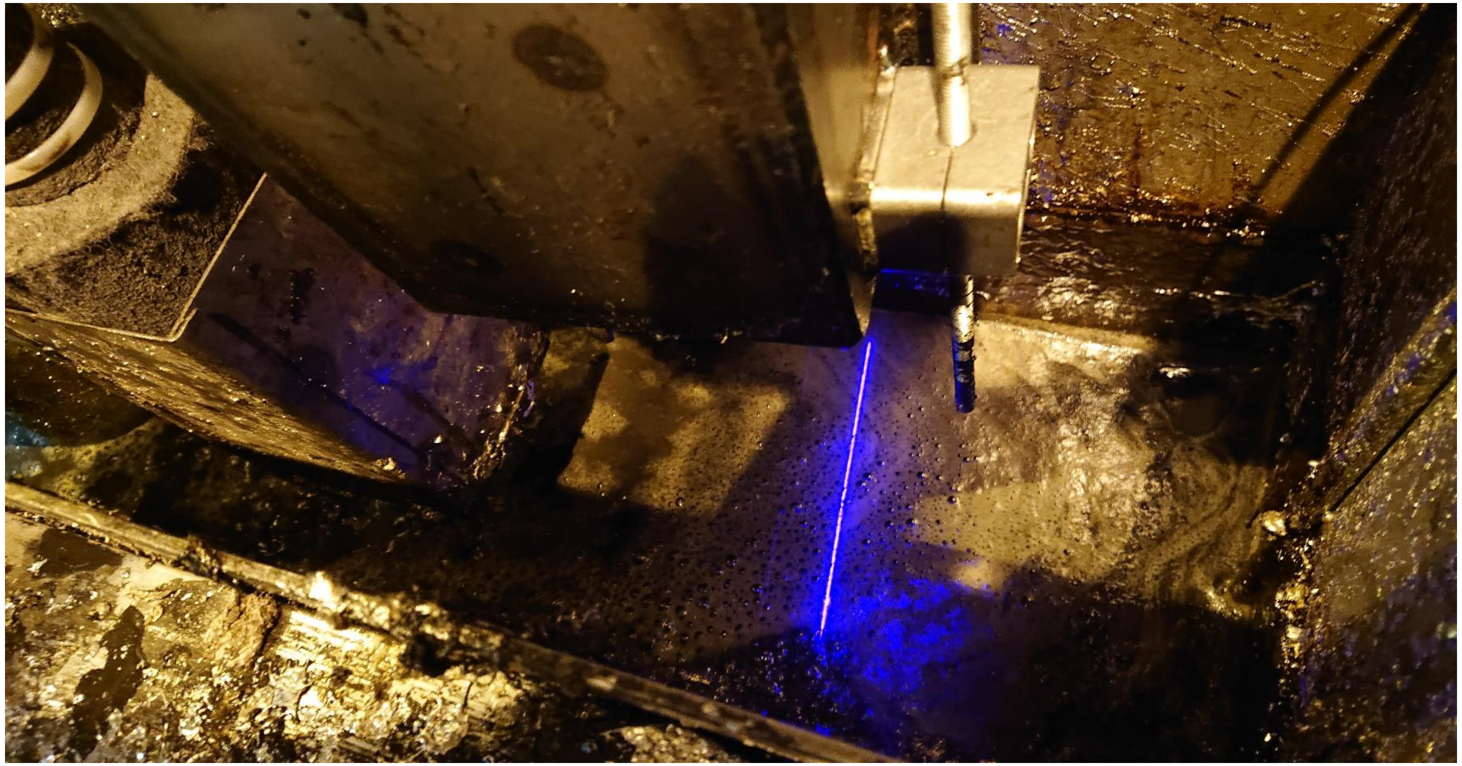


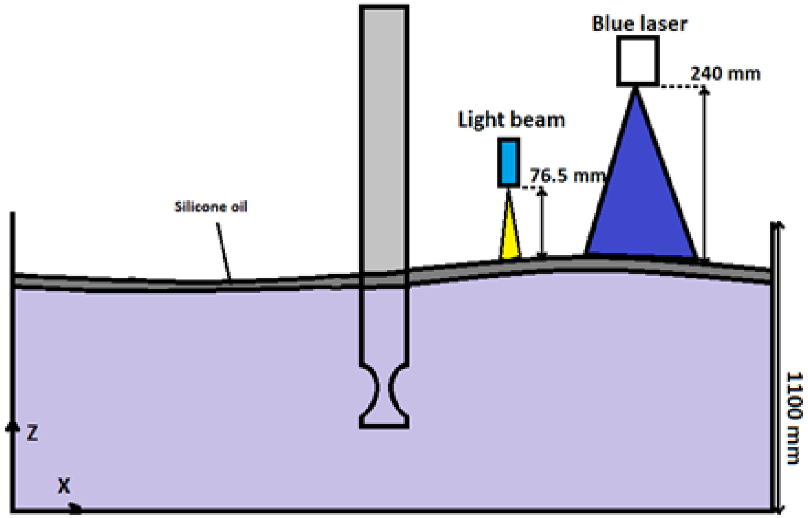
Mould level measurements



Mould level measurements

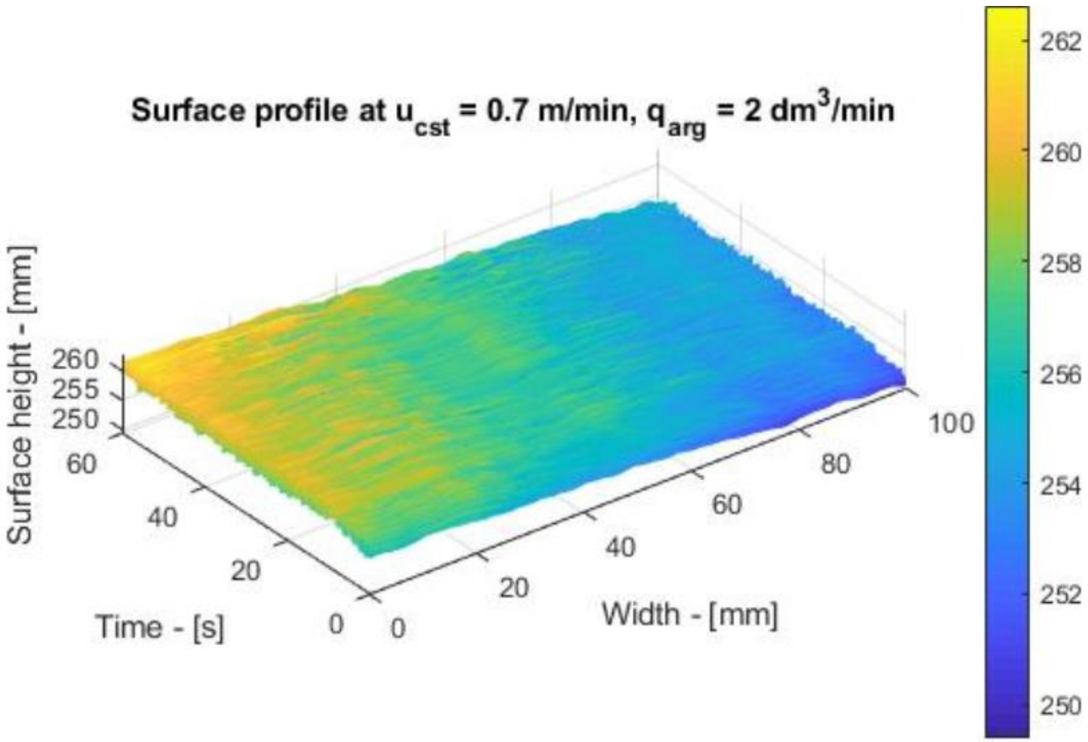
Blue laser installation

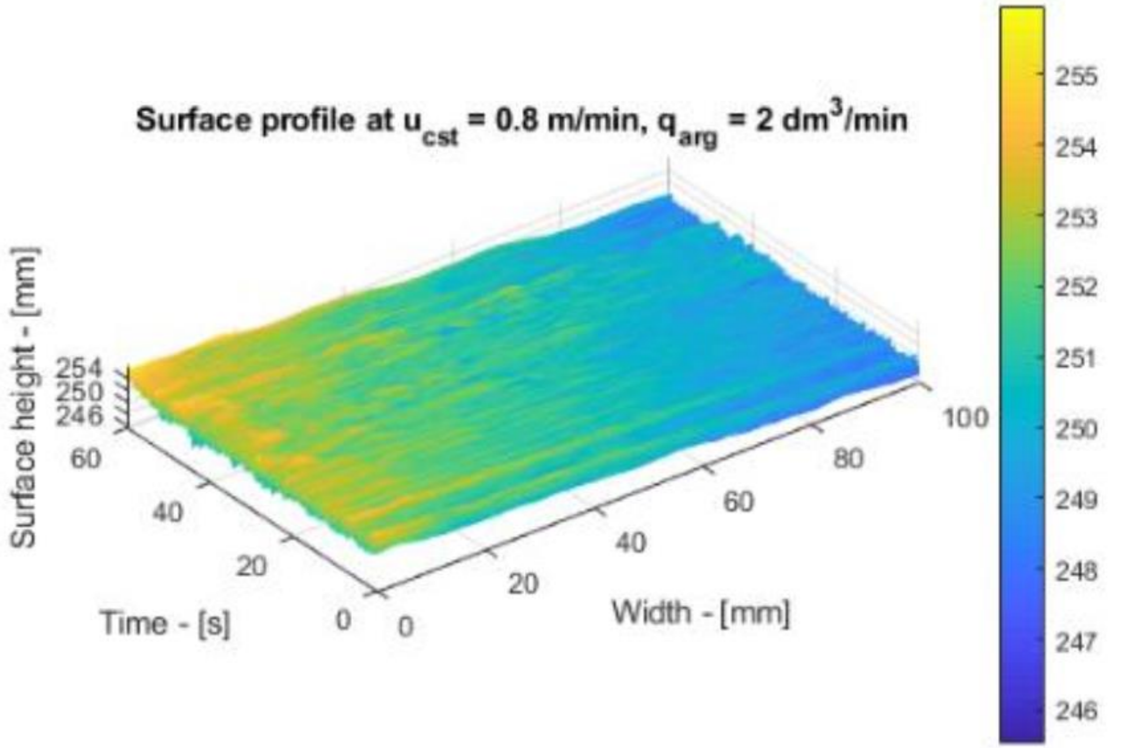




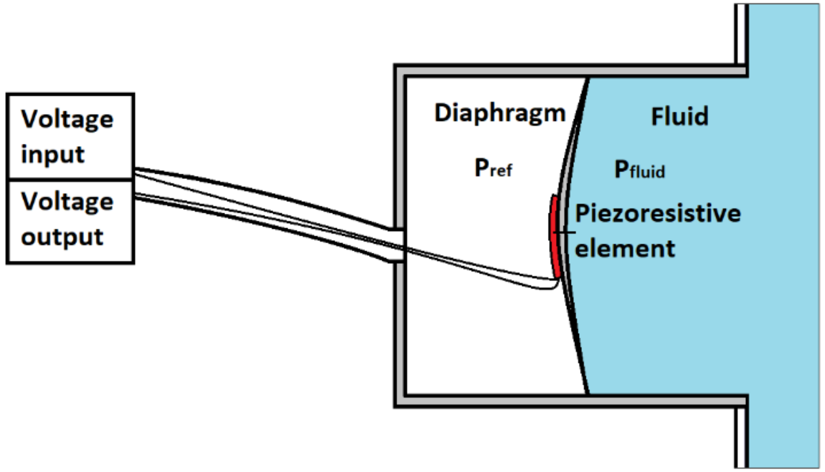
Mould level measurements

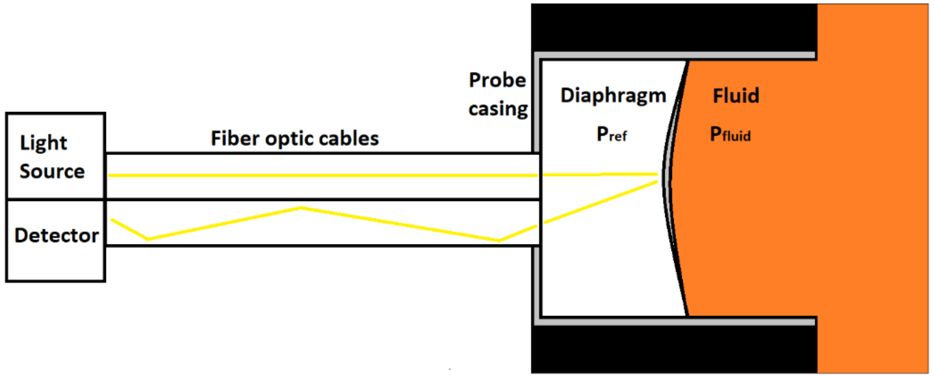
Blue laser

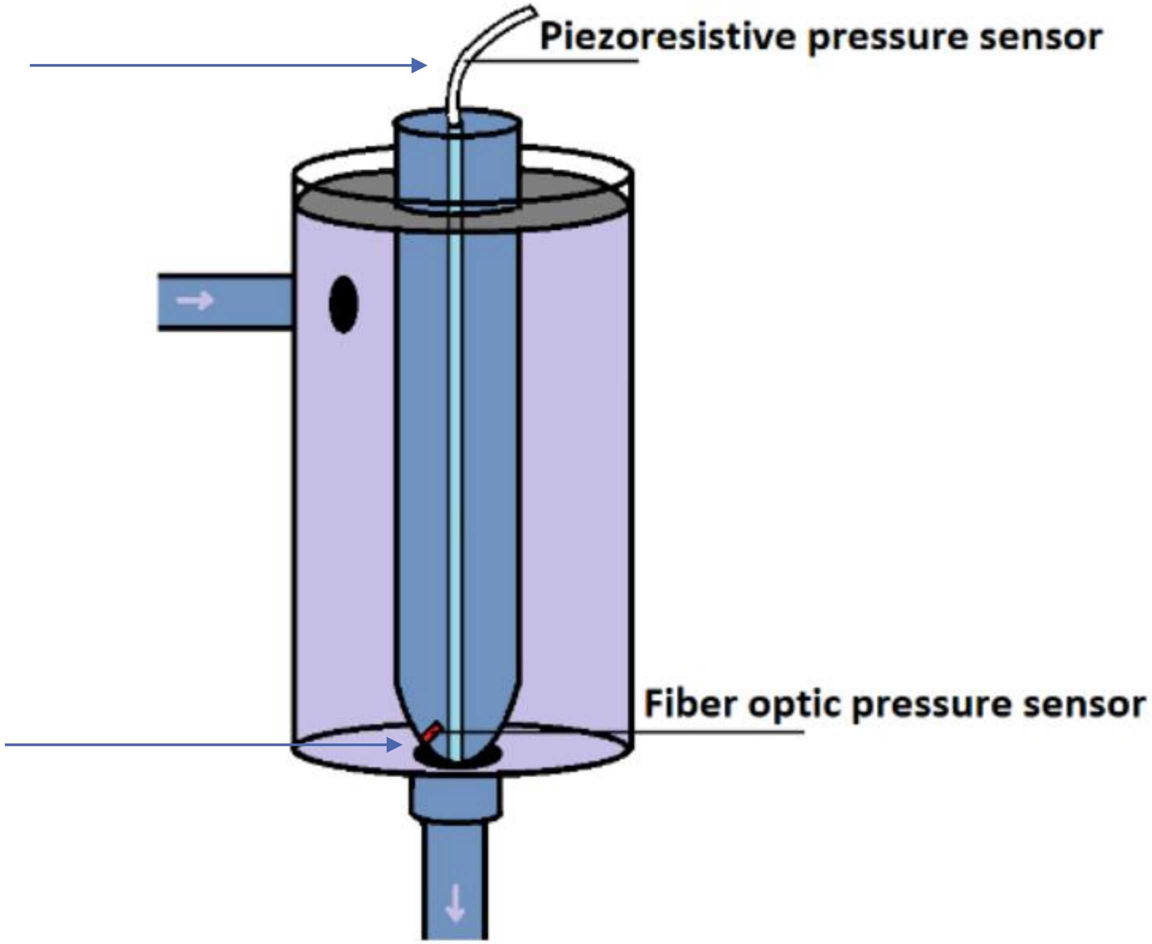




Pressure in flow regulation zone

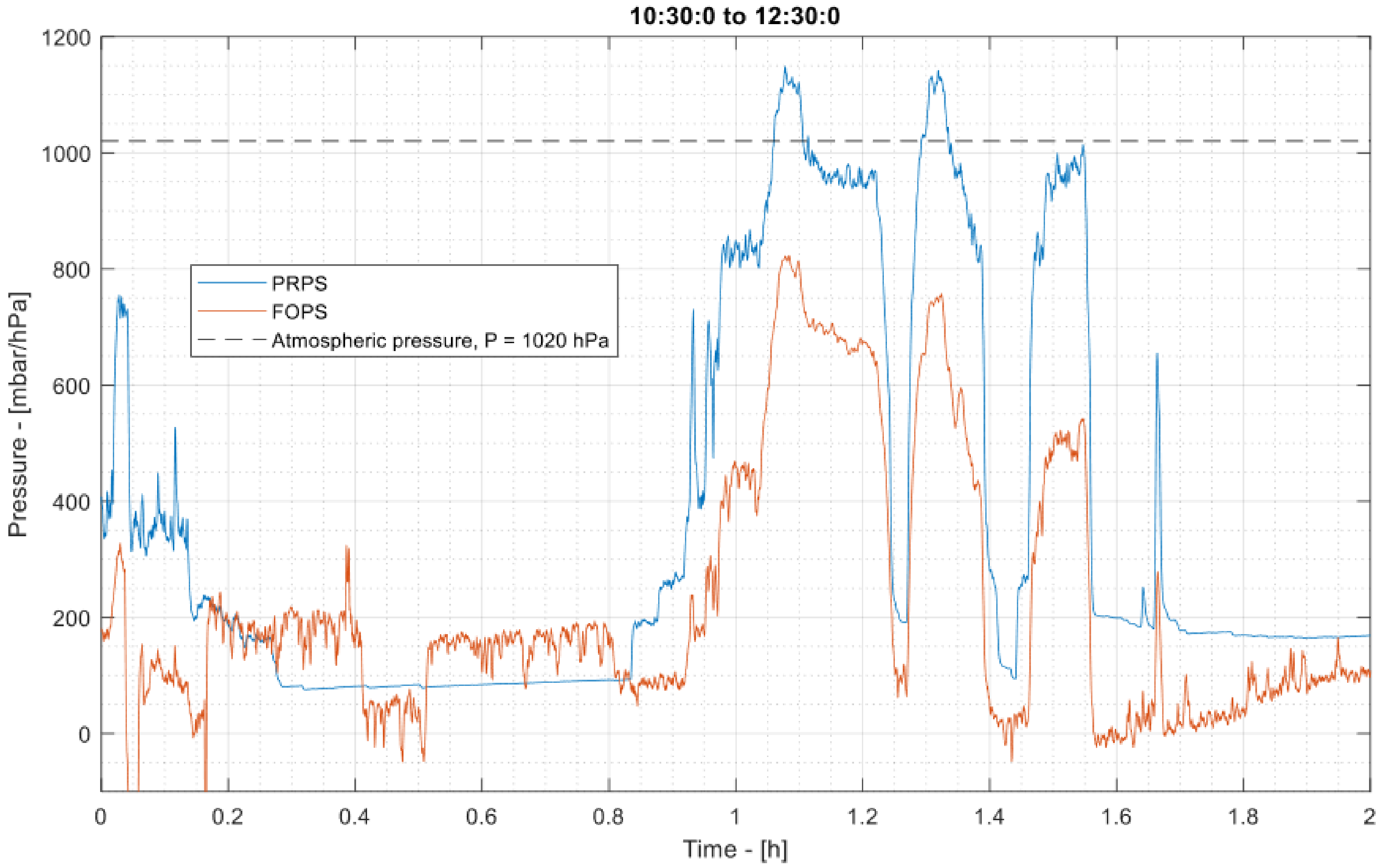






Pressure in flow regulation zone

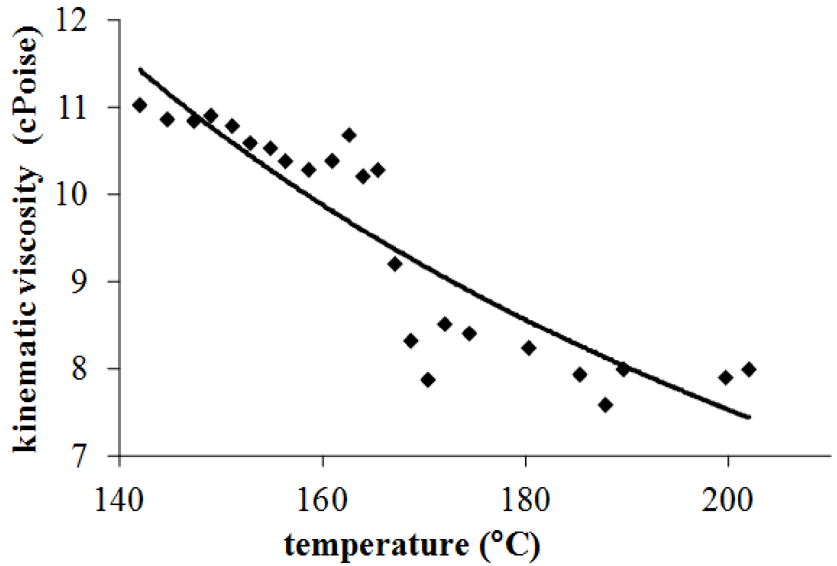
Measurements in argon line vs stopper

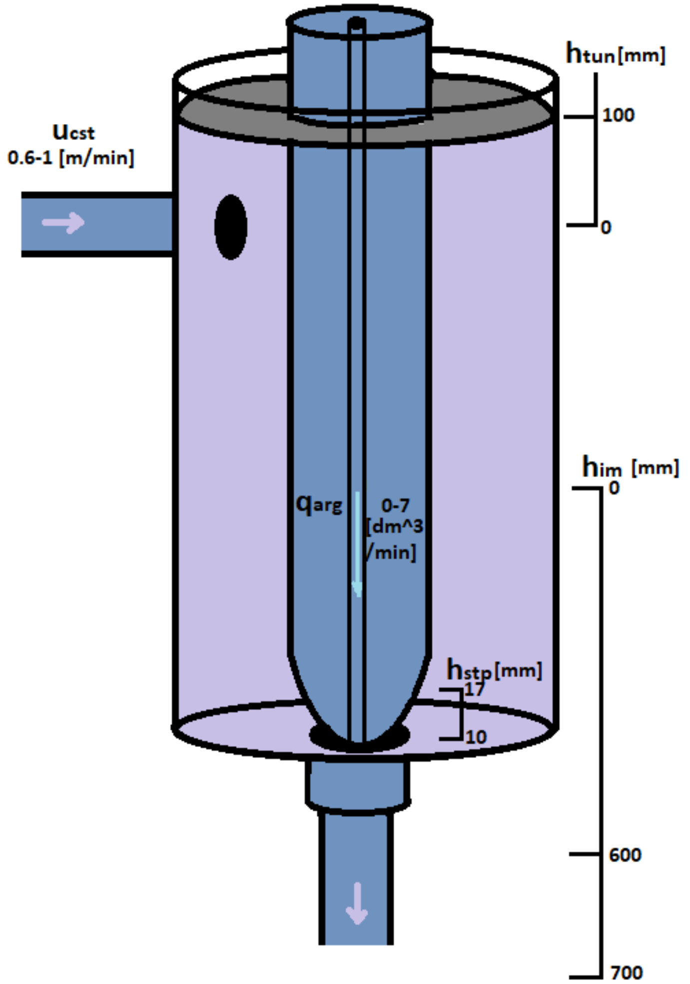


Research projects

Test variables

- Casting speed, 0.6 to 1.2 m/min
- Argon flow rate, 0 to 8 liters/min
- Stopper position, closed to 17 mm
- Immersion depth: variable





Increased process knowledge

Change in vc from 1.0 to 1.4 m/min

Metal level fluctuations

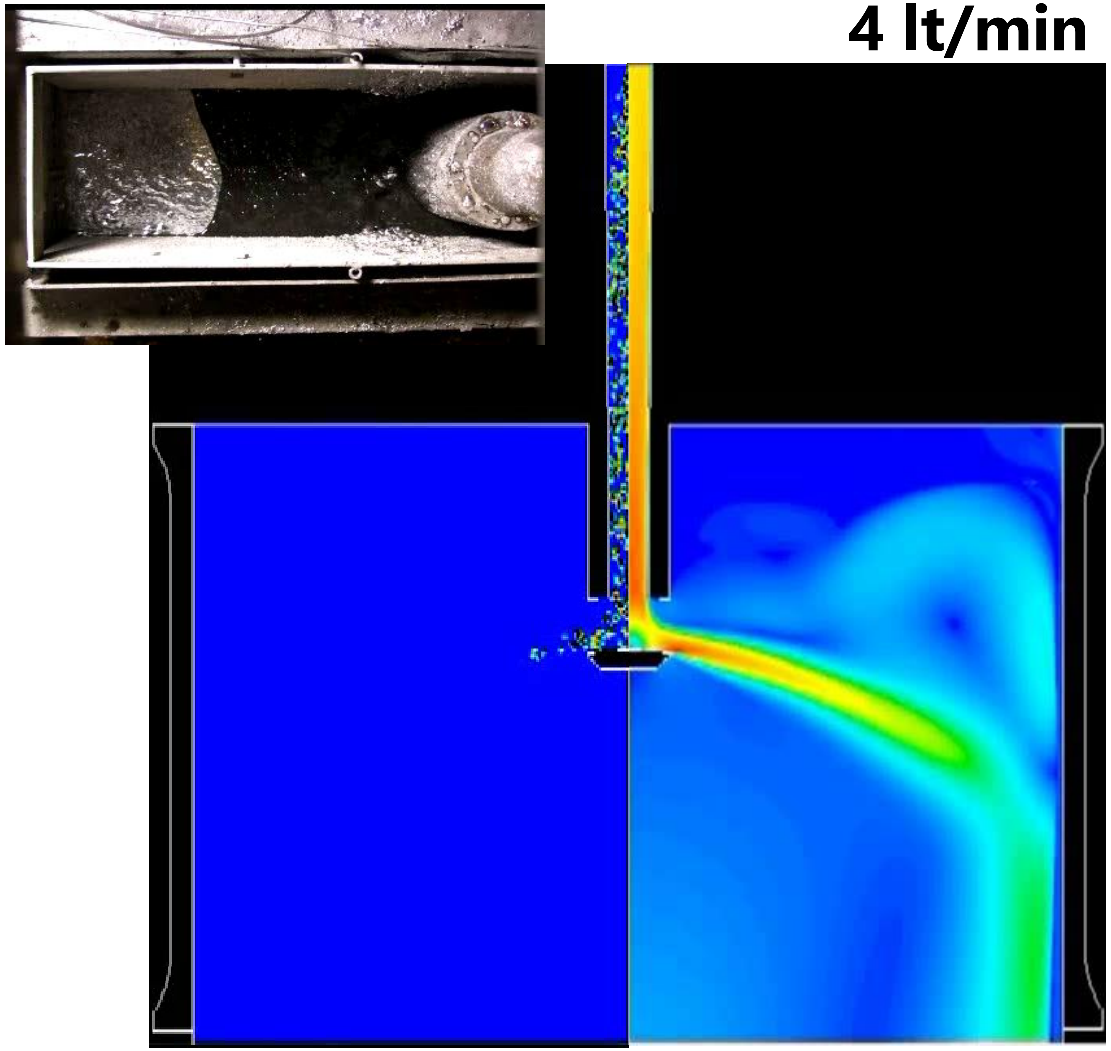
Finding the right amount of Argon for a caster

casting speed 1.2 m/min
and argon=4 lt/min

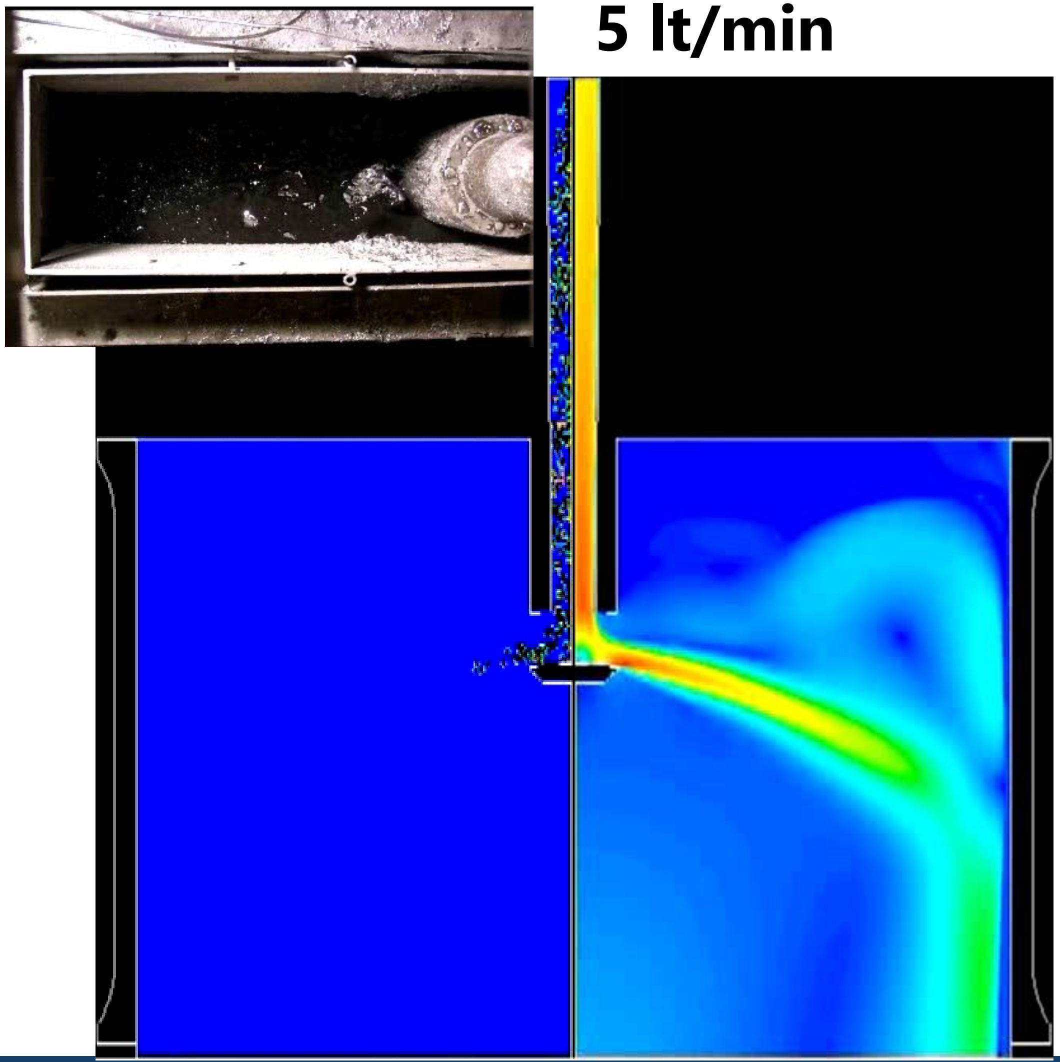
casting speed 1.2 m/min
and argon=5 lt/min

Finding the right amount of Argon for a caster

4 lt/min



5 lt/min



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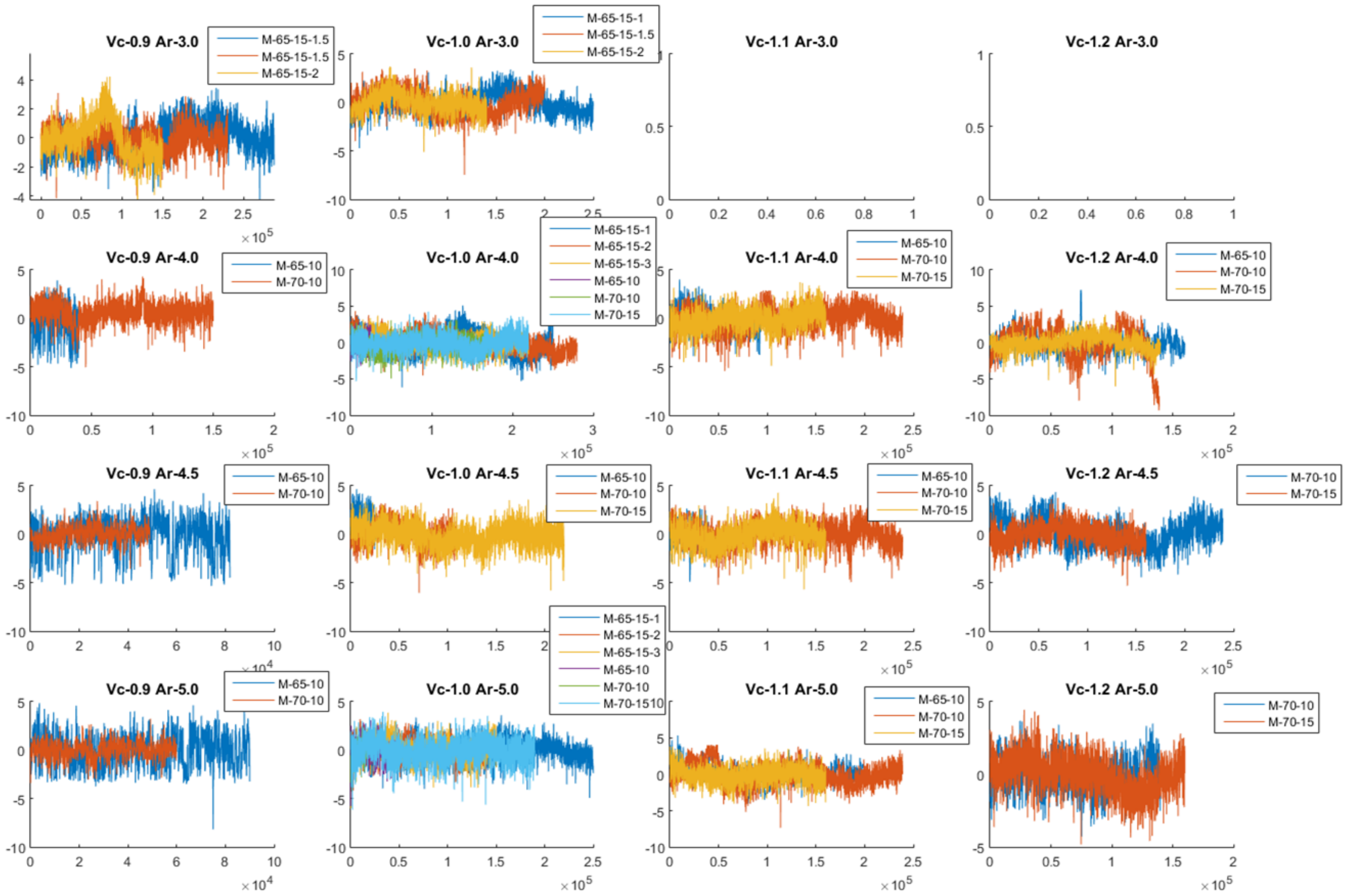
Mould level stability

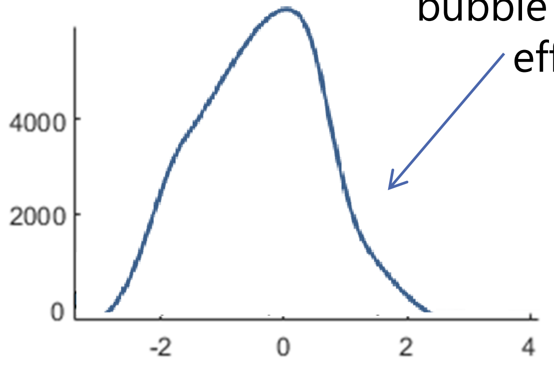
(Light Beam Sensor)



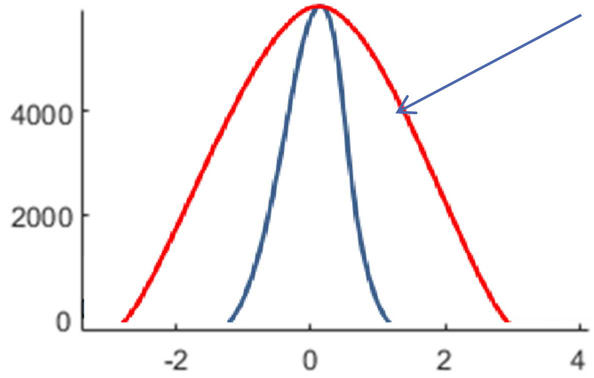
Mould level stability

(Light Beam Sensor)

Asymmetry due to bubble bursting effect

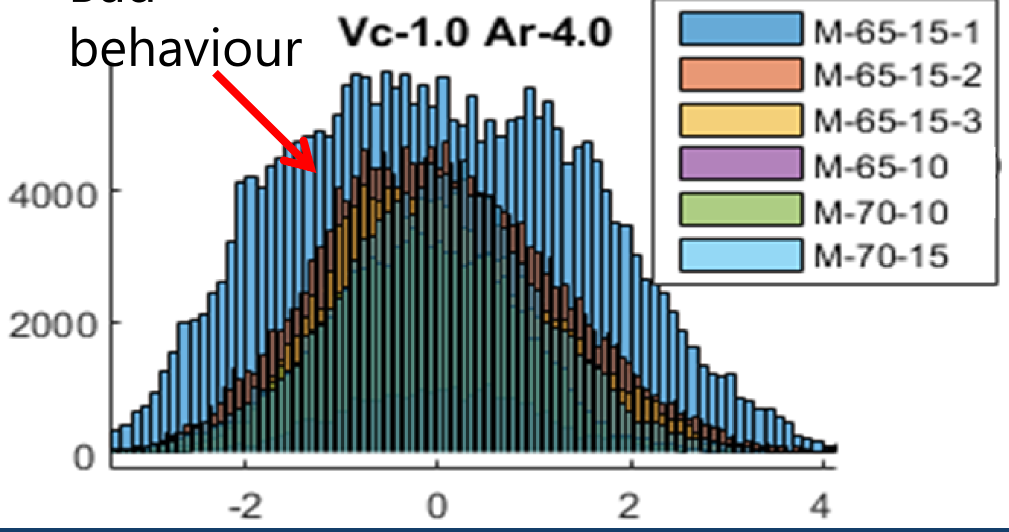


Stable behaviour

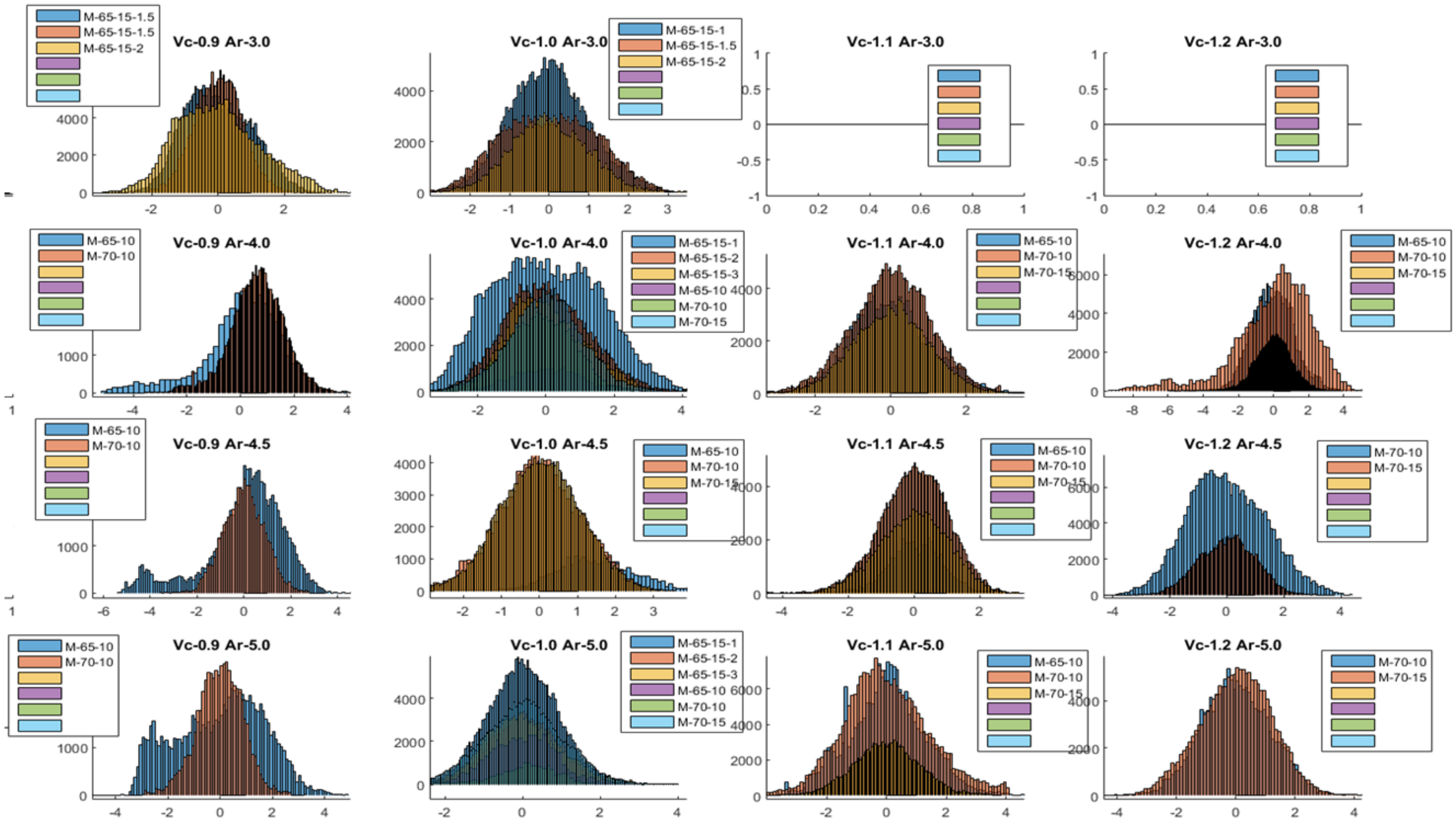


Bad behaviour

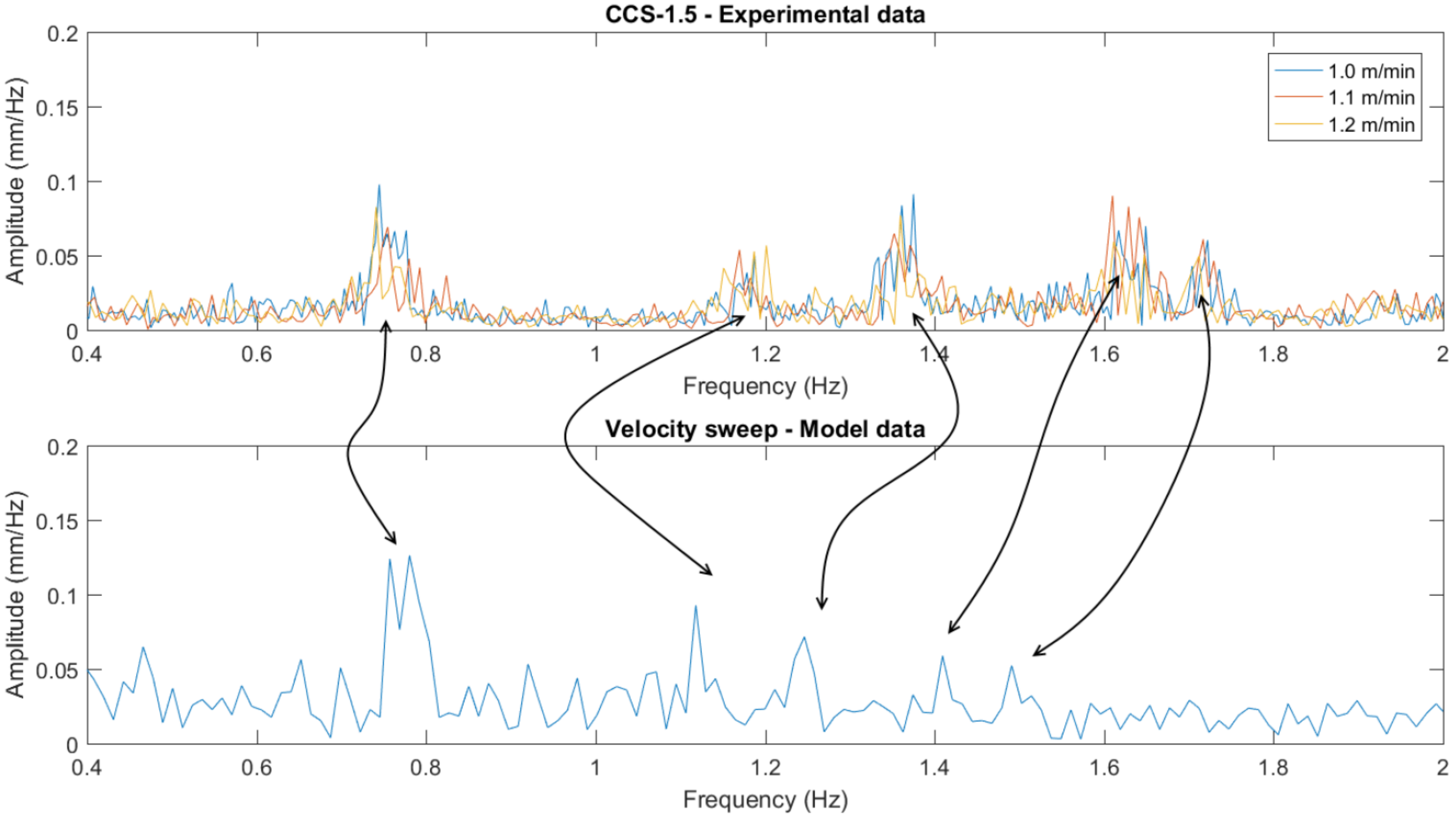
Bad behaviour



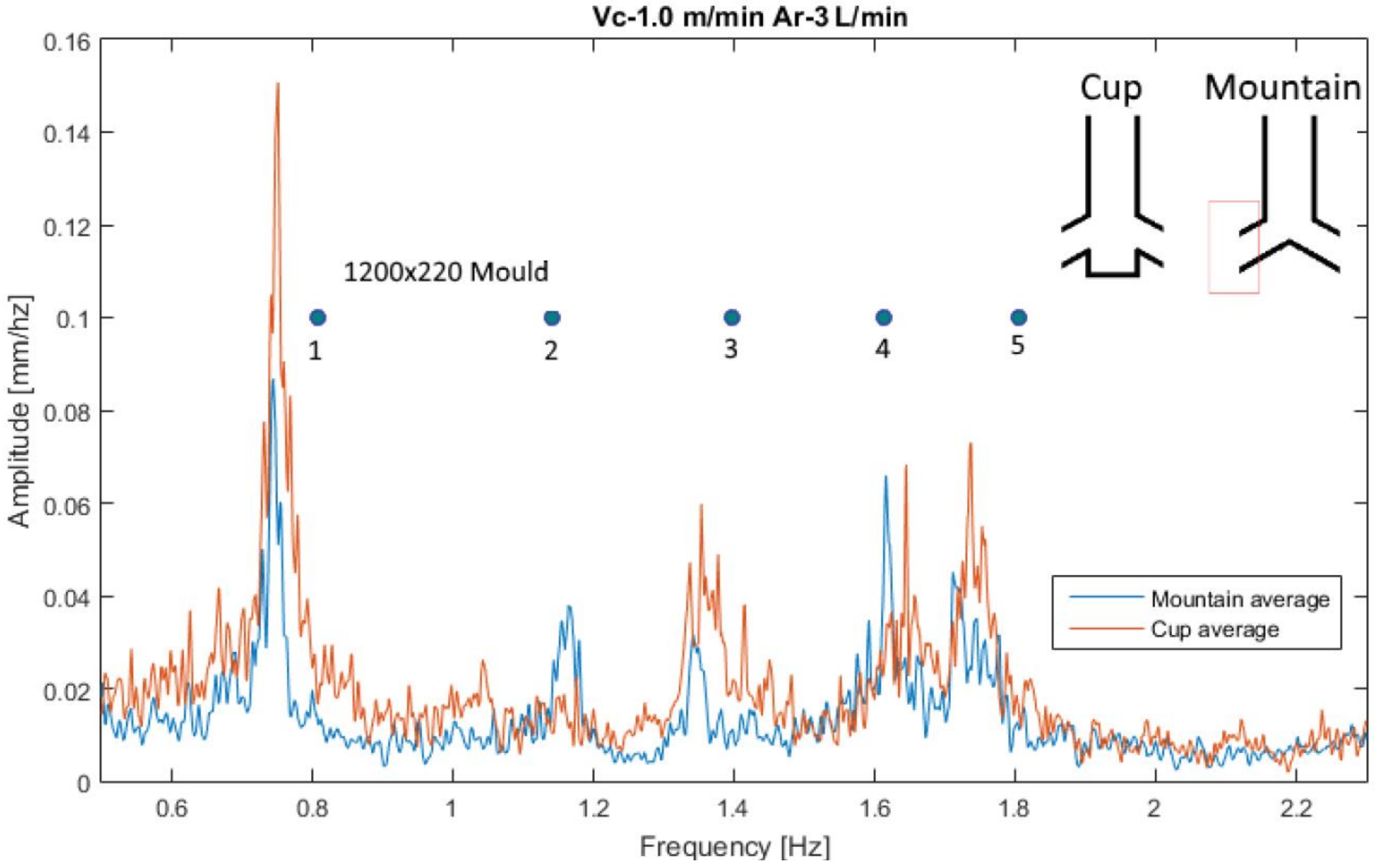
Mould level stability

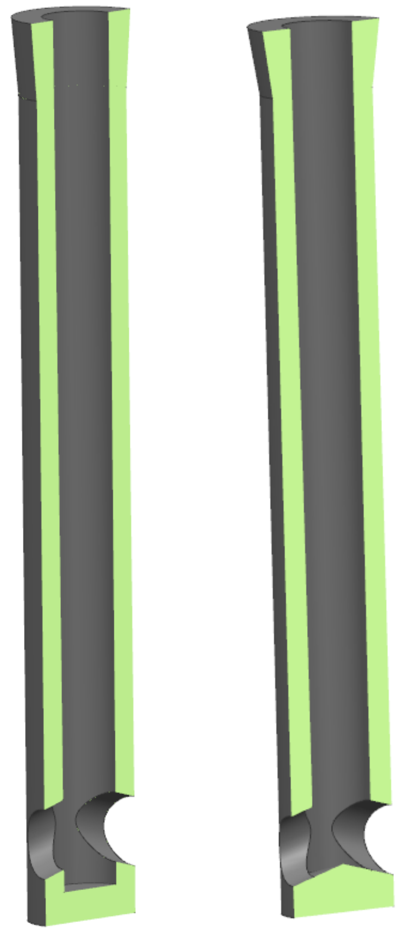


Nozzle frequency signatures



Nozzle frequency signatures





cup **mountain**

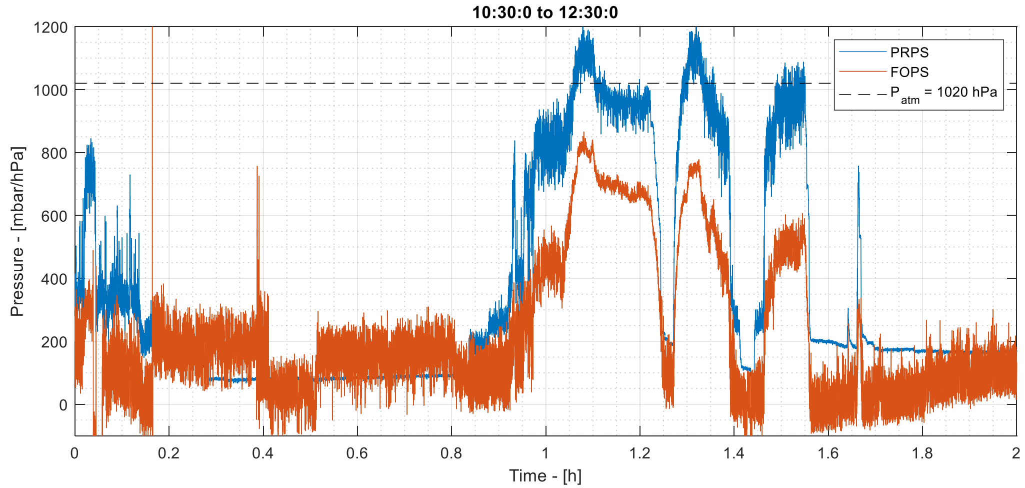
H. Barestrand and T. Forslund. http://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-59847

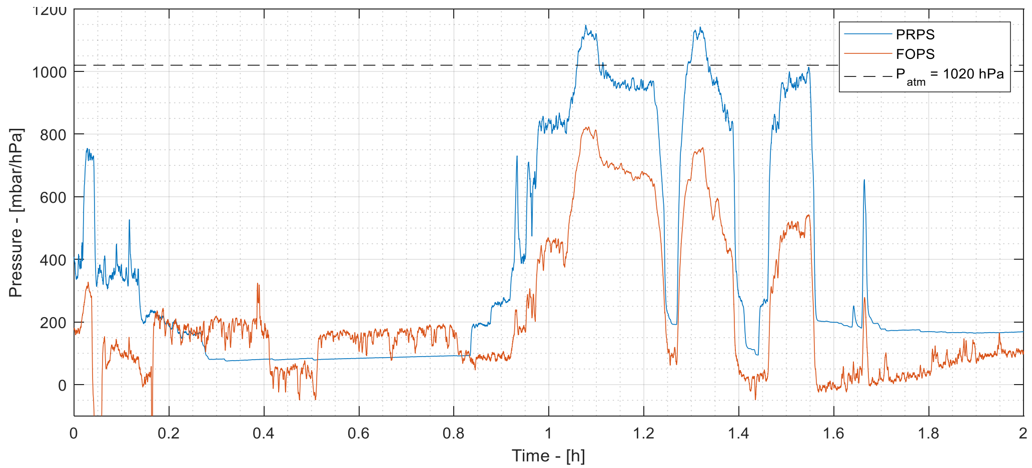
Flow characterization in stopper-SEN

Pressure measurements

- Postprocessing
  - Filtered by using moving average over 12.5 s, points with high rate of change set to adjacent points value
  - Graph split into different setup numbers
  - Pressure averaged over each setup number and matched with test variables
  - Single variable regression for each flow condition
  - Highest contributing variables used in a multiple variable regression

- Results
  - High R^2 pressure model

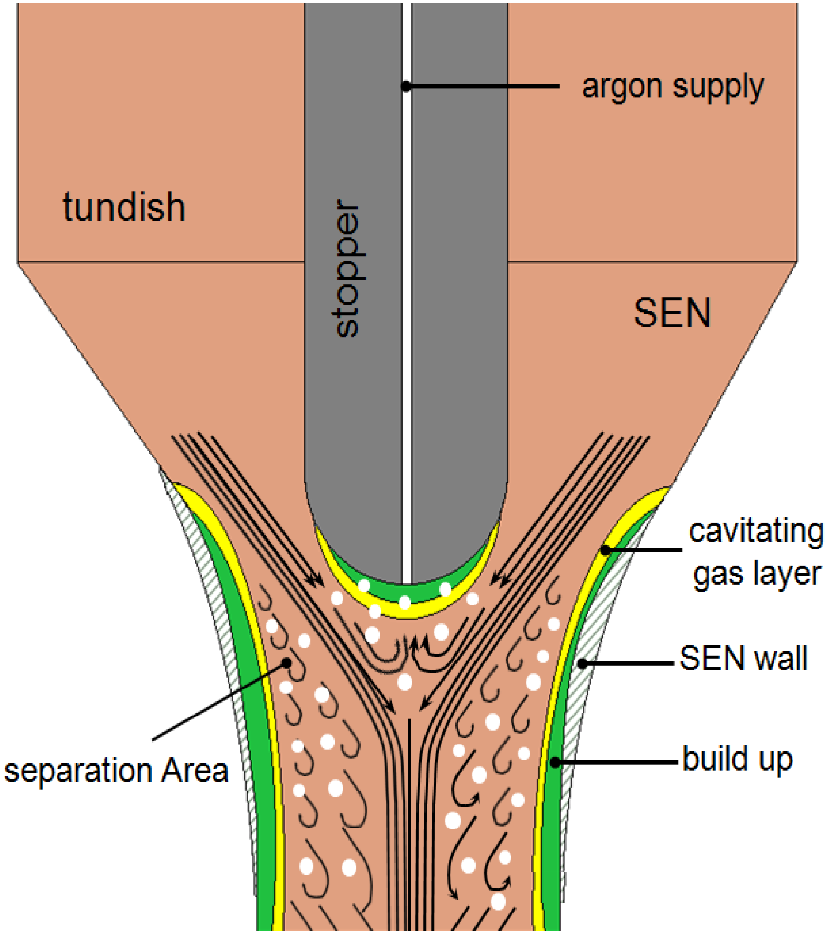




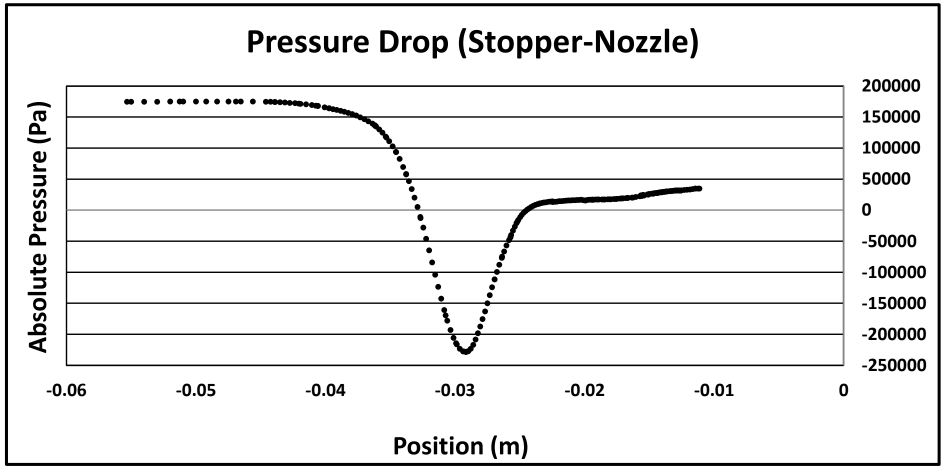
J. Eck. Development of systematic measurement on liquid metal. http://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-75347

Possible cavitation?

Pressures of a few mBar



Cavitation damage in metallic stopper?



Other pilot facilities at SWERIM

Pilot Trials – Full Scale

Pilot trials of secondary cooling

EU-RFCS Research Highlights

EU research highlights

European Commission

Science
Research
Development

technical steel research

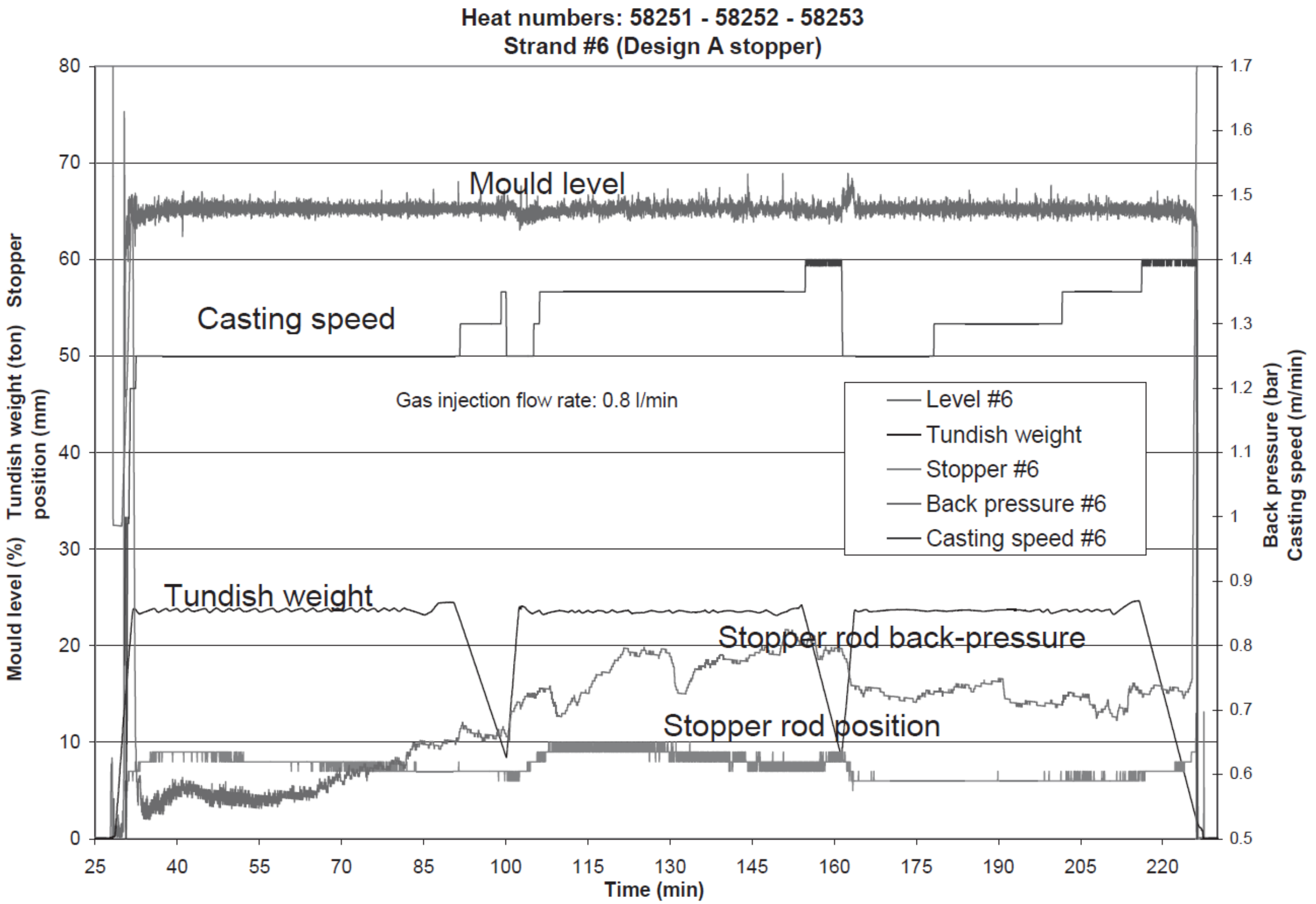
Hot rolling and continuous casting

Improvement in cast product quality by the visualisation and control of the steel flow pattern in the tundish pouring nozzle (SEN/SES)

Report

EUR 21247 EN

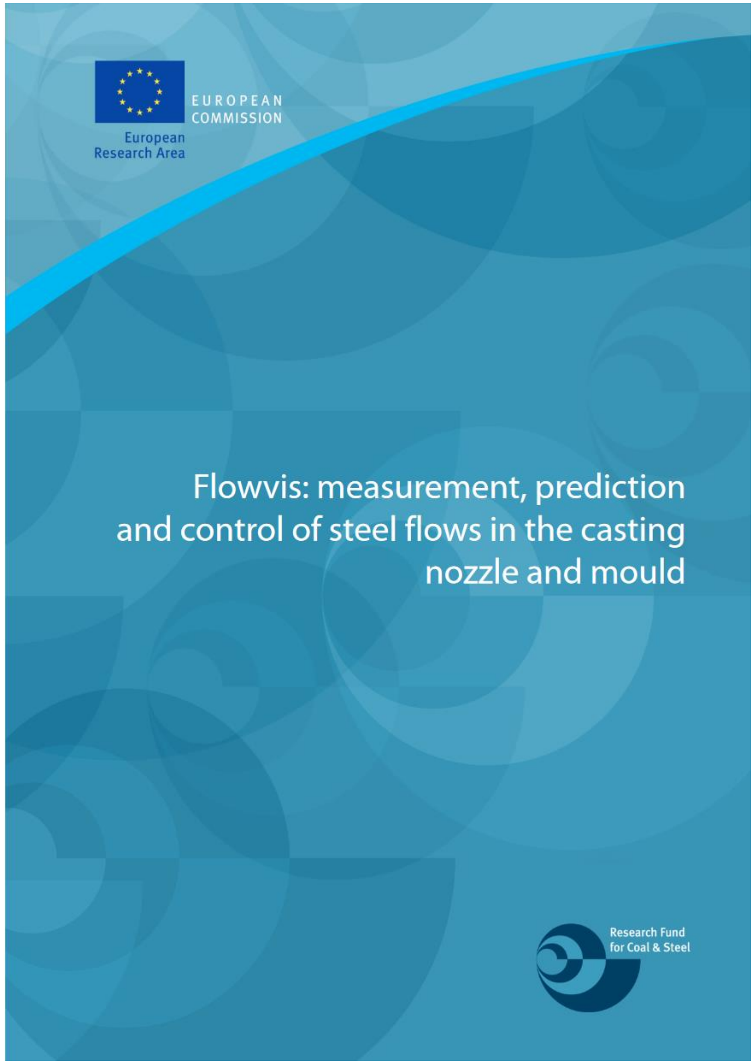
STEEL RESEARCH



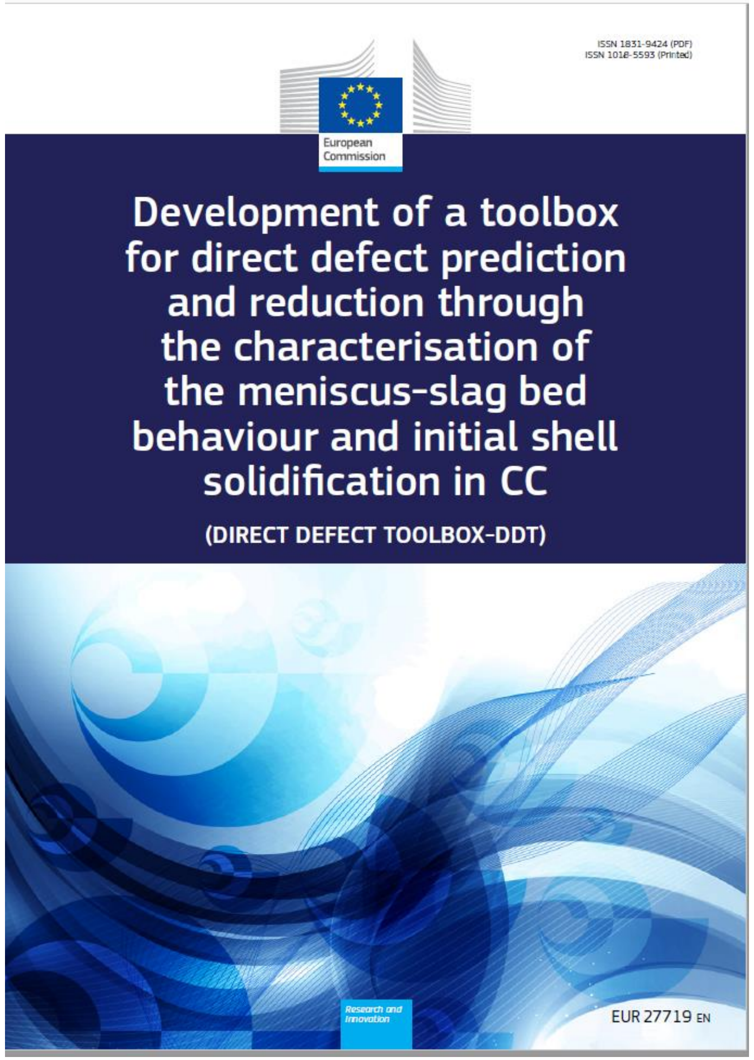
HEAT 58251 – 58252 – 58253 (TRIAL 7)

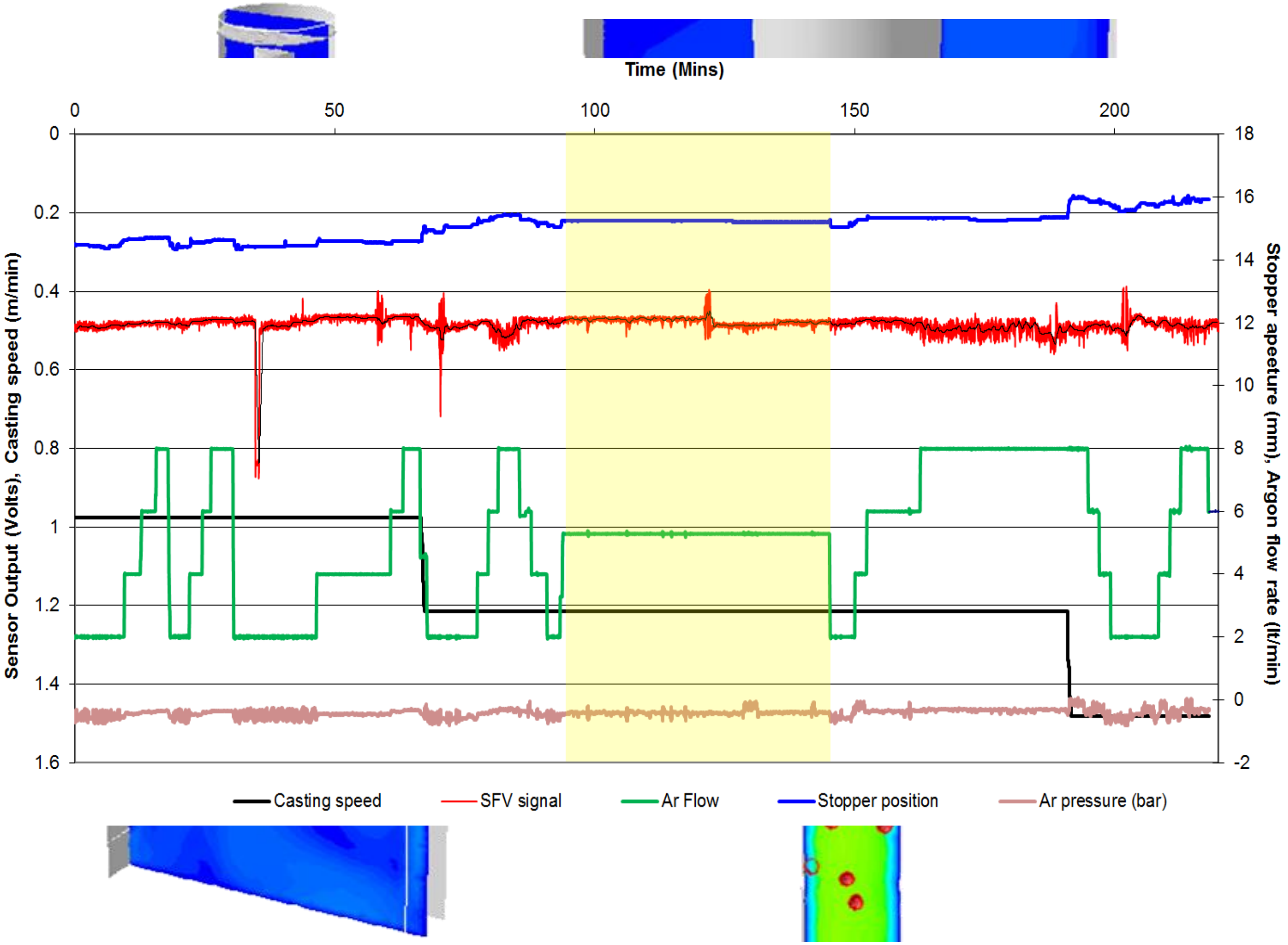
FIG. 106

EU research highlights



EU research highlights





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EU research highlights

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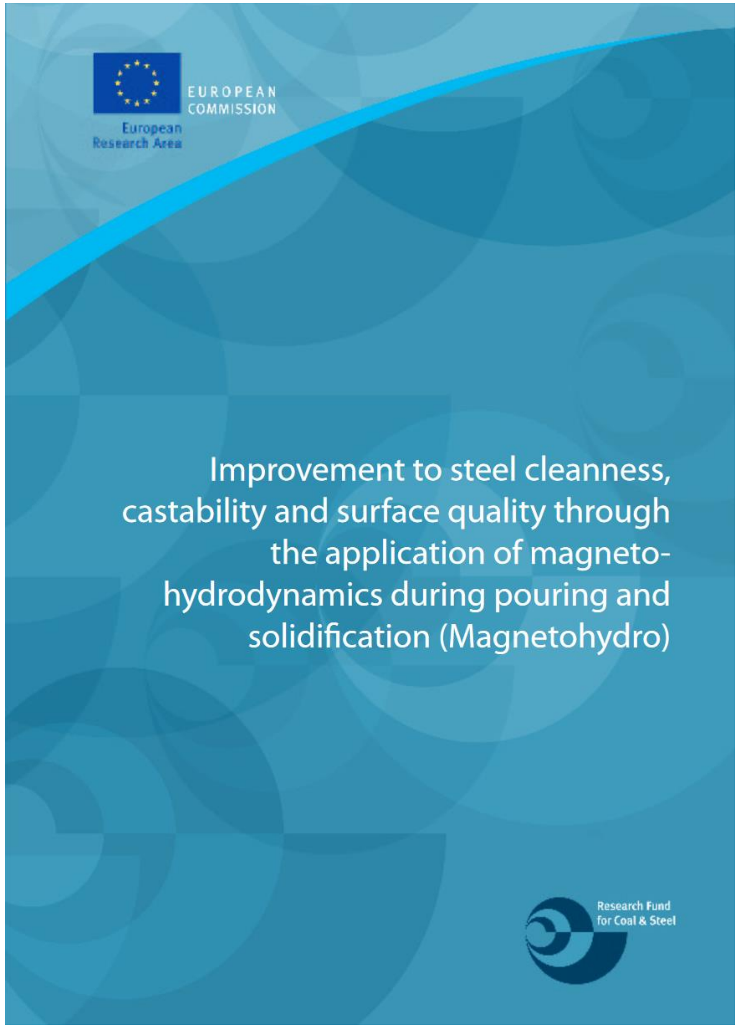

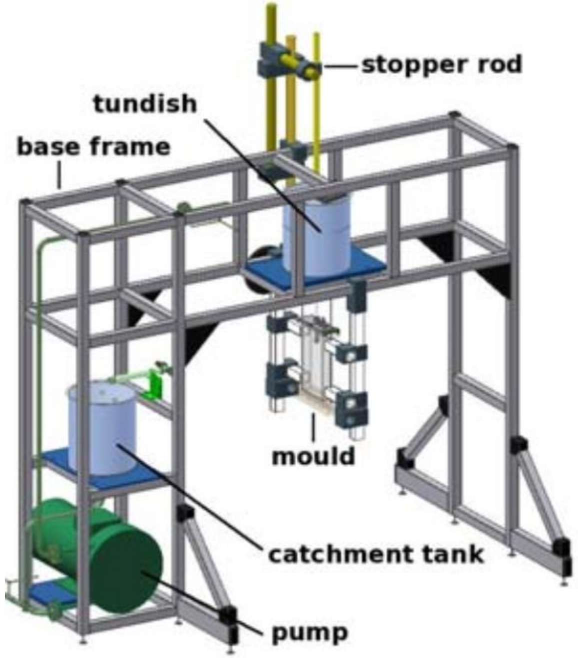

HZDR
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

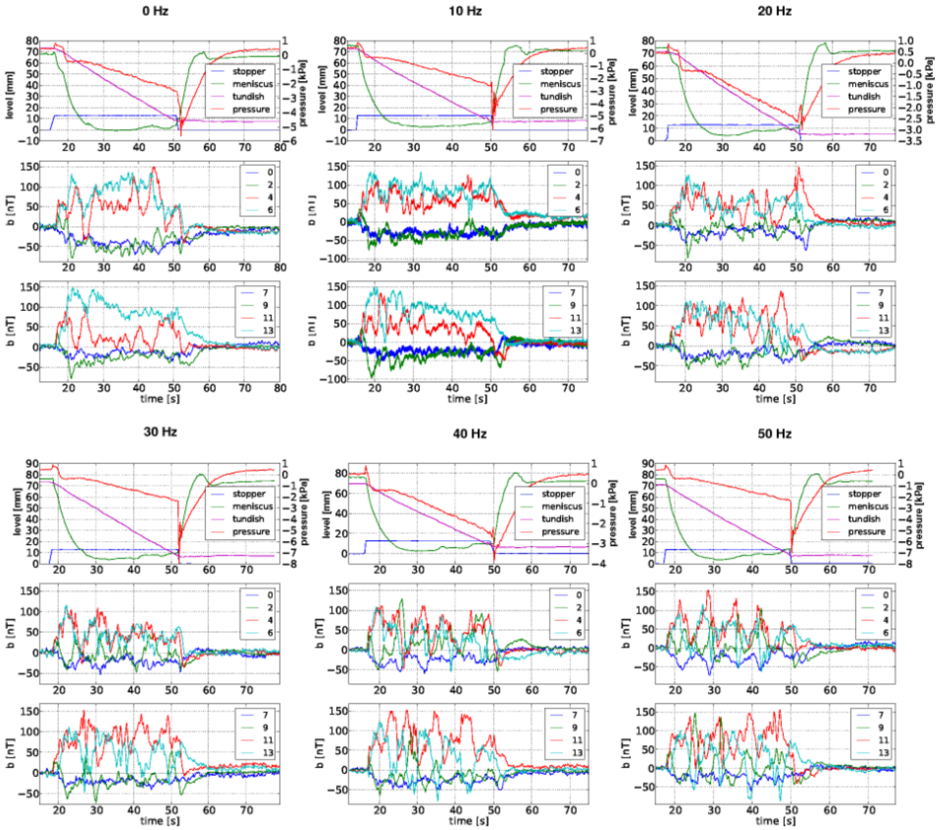

Figure 2.2.79 (Tata Steel). Time-dependence of the stopper rod position, of the fluid level in the tundish, of the distance of the meniscus from the upper edge of the mould, of the pressure in the Argon supply tube, as well as of 2x4 measured induced magnetic fields for six representative runs with different stirrer rotation rates between 0 and 50 Hz. The numbers of the magnetic field signals correspond to the flux-gate sensors indicated in Fig. 2.2.77.

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Thanks for the attention!

Stay informed

http://valcra.eu/

https://www.linkedin.com/company/european-continuous-casting-network

VALCRA linkedin group (linkedin.com/groups/13794289/)