Investigation of unsteady and asymmetric flow phenomena in continuous casting moulds by physical modelling

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Physical modelling CC-mould

Objectives

Increasing customers demands are requiring a steady improvement of product quality and therefore of the production process

The continuous casting mould, where the phase transformation from the liquid melt to the solidified product occurs, is a process stage of high interest

Therefore detailed knowledge of flow conditions in the mould are essential, e.g. for improvement of:

- Flow symmetry
- Process stability
- Solidification

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Ways and Means

- Direct plant measurements are nearly impossible due to the rough environmental conditions.
- For provision of information on the relevant flow conditions simulation approaches are proved to be useful.
- Here physical and mathematical modelling simulation are two main approaches successfully used. Their further development offers a high potential for an efficient optimisation of the continuous casting process.

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Similarity: steel melt/water, scale

Water is transparent, non-toxic, cheap, can be used at room temperature.

Reynolds Number

$$Re = \frac{\rho v d}{\eta} = \frac{v d}{\nu}$$

Water has the **same kinematic viscosity** as steel melt at 1600 °C.

Re is observed in **full-scale water models** for the same casting rate.

Original SEN can be used in **full-scale** water CC-models.

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Similarity criteria for flow and mould level conditions

Reynolds Number

(Characterises turbulence)

$$Re = \frac{\rho v d}{\eta} = \frac{v d}{\nu}$$

Characteristic length in **numerator**

Froude Number

(Characterises surface waves)

$$Fr = \frac{v}{\sqrt{gL}}$$

Characteristic length in **denominator**

Velocity v has to be **increased** to keep *Re* const. for reduced scale.

Velocity v has to be **decreased** to keep *Fr* const. for reduced scale.

Re and Fr can be observed **simultaneously** only for **full-scale** models.

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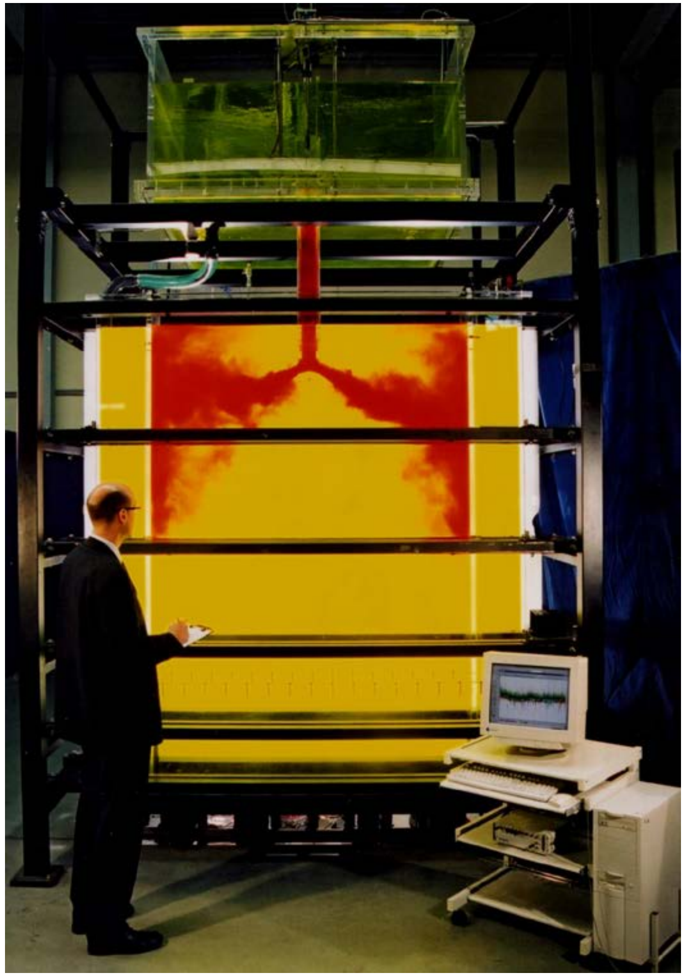
Physical Modelling



- Conventional and thin slab casting mould models with variable casting width and thickness
- Tundish with stopper rod system for flow and level control also with gas injection
- Colour injection for flow visualisation and flow symmetry quantification
- Particle Image Velocimetry (PIV) for time-dependent flow field, flow fluctuation and flow frequency analysis
- Ultrasonic sensors for local time-dependent mould level behaviour, mould level fluctuation and mould level frequency analysis

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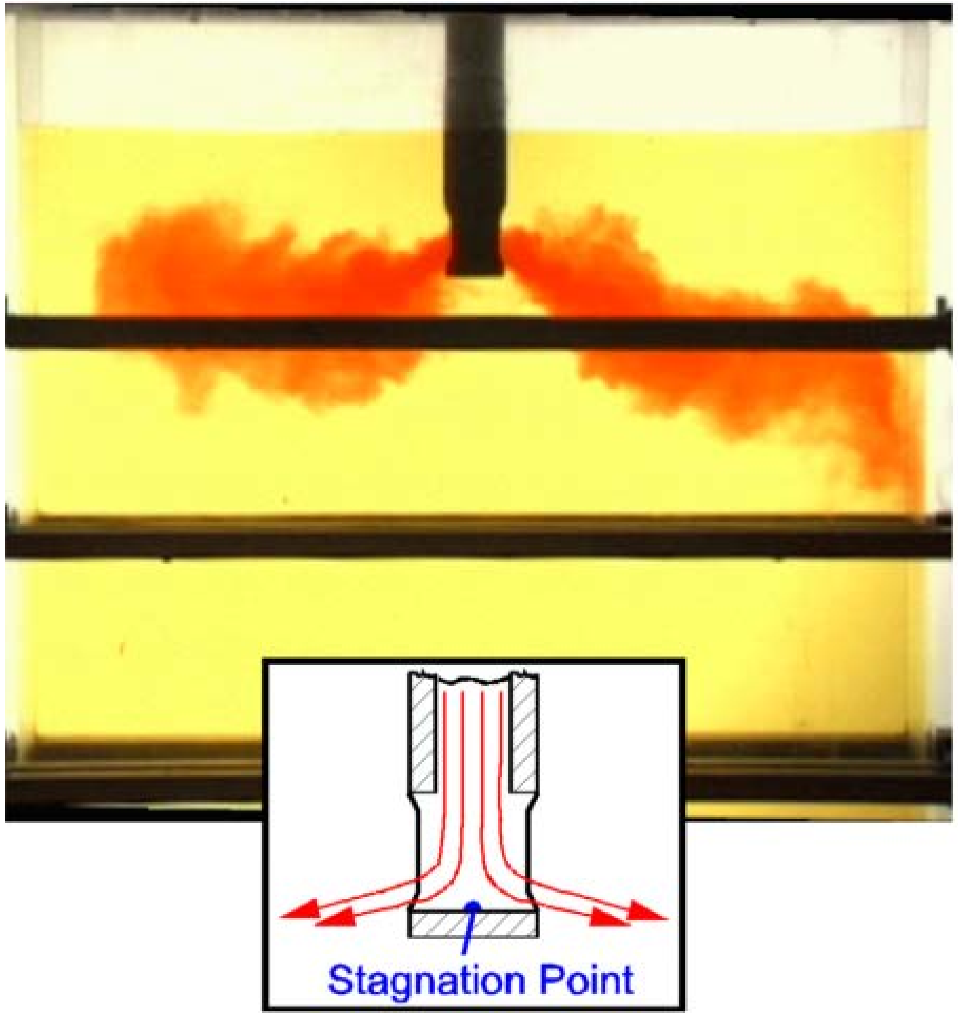
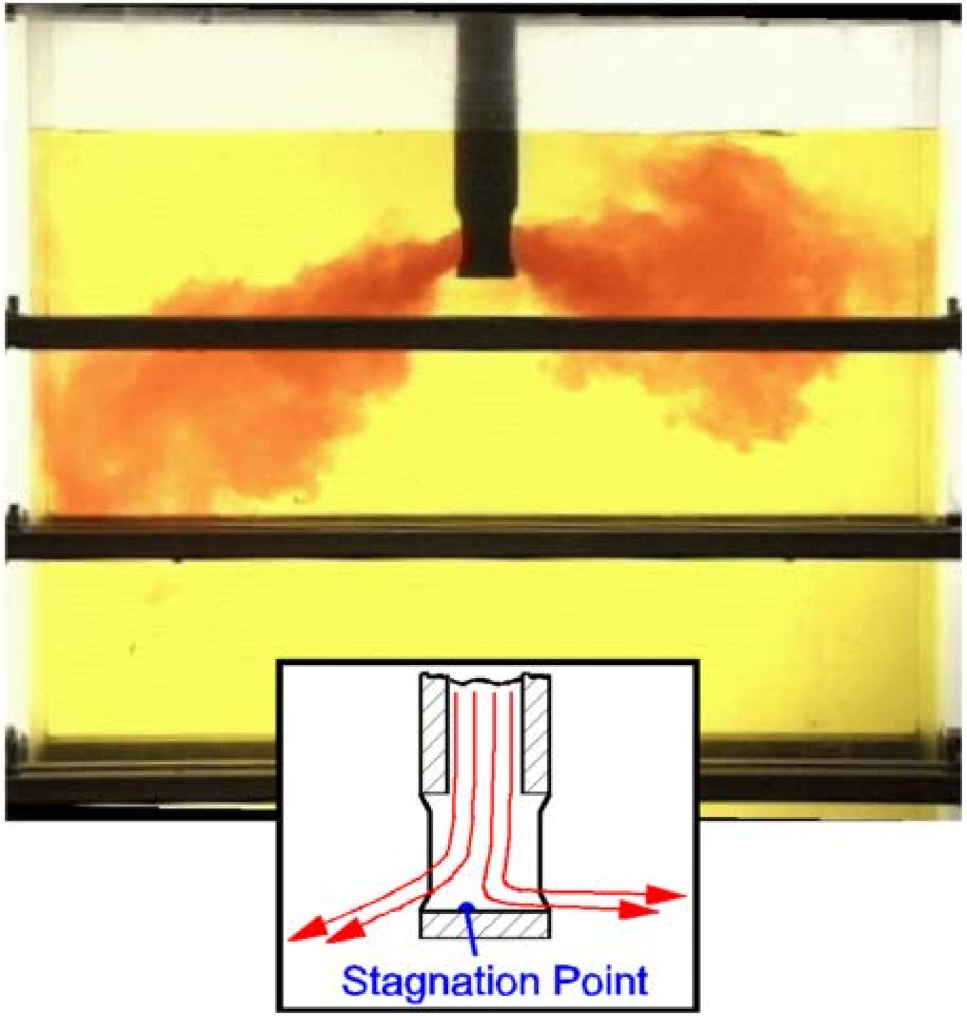
Flow Symmetry - SEN design





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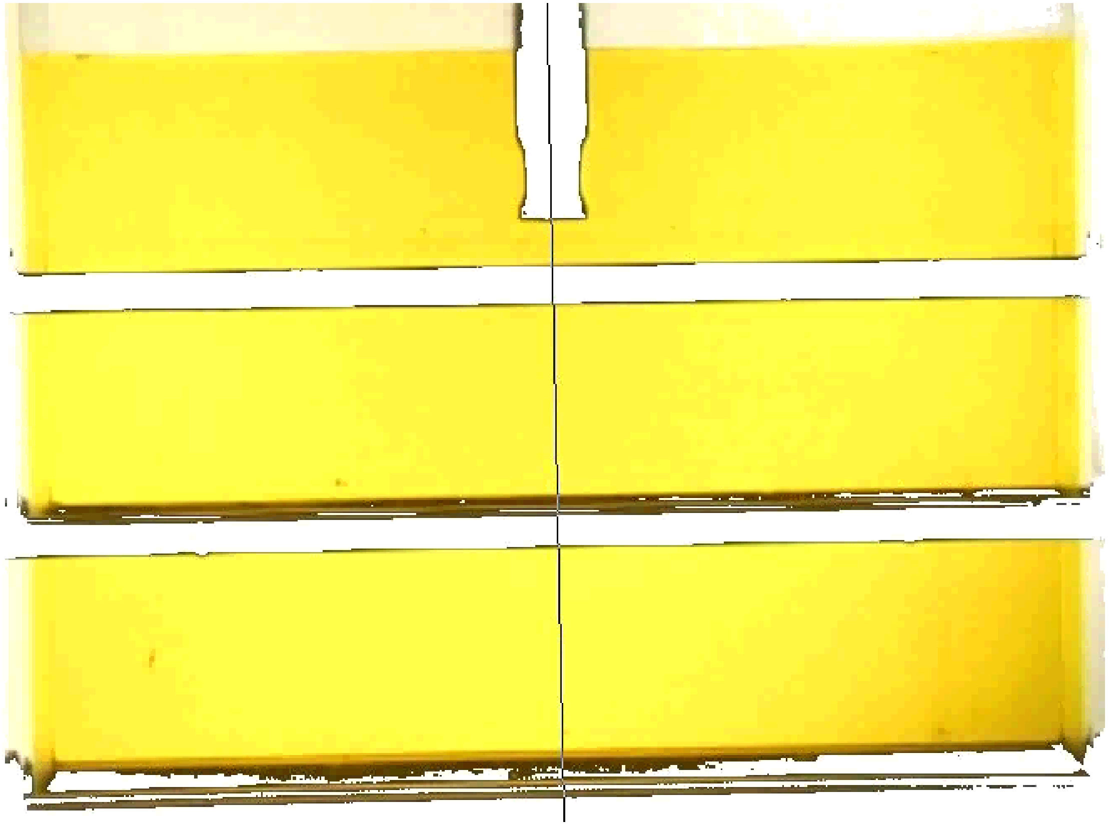
Flow Symmetry without Gas Injection

Flow Visualisation

Flow Symmetry Detection



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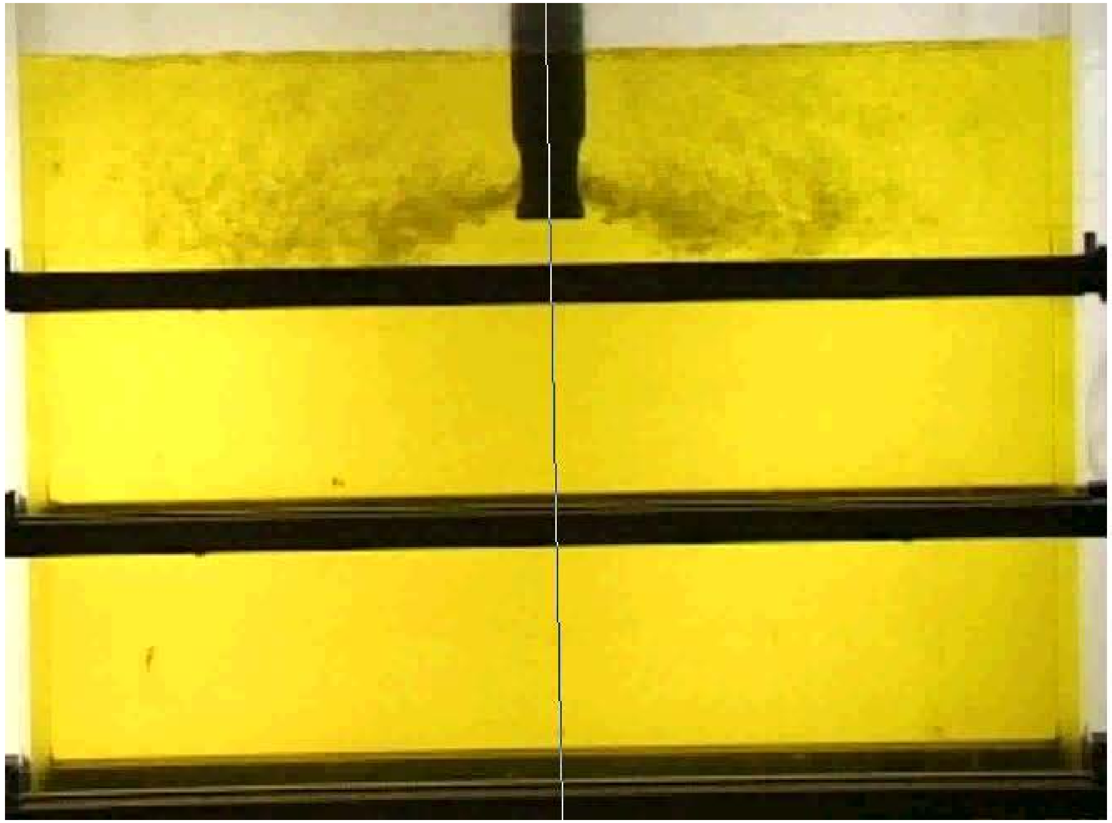
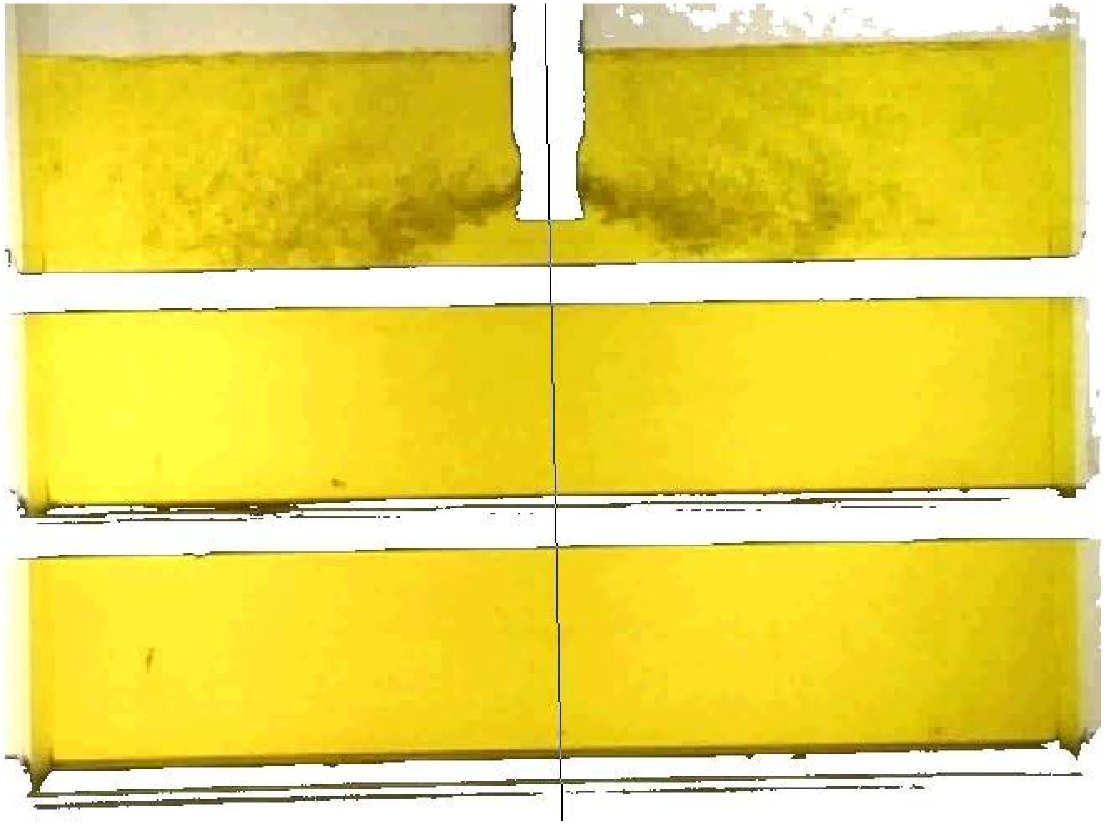
Flow Symmetry with 5 Nl/min Gas Injection

Flow Visualisation



Flow Symmetry Detection



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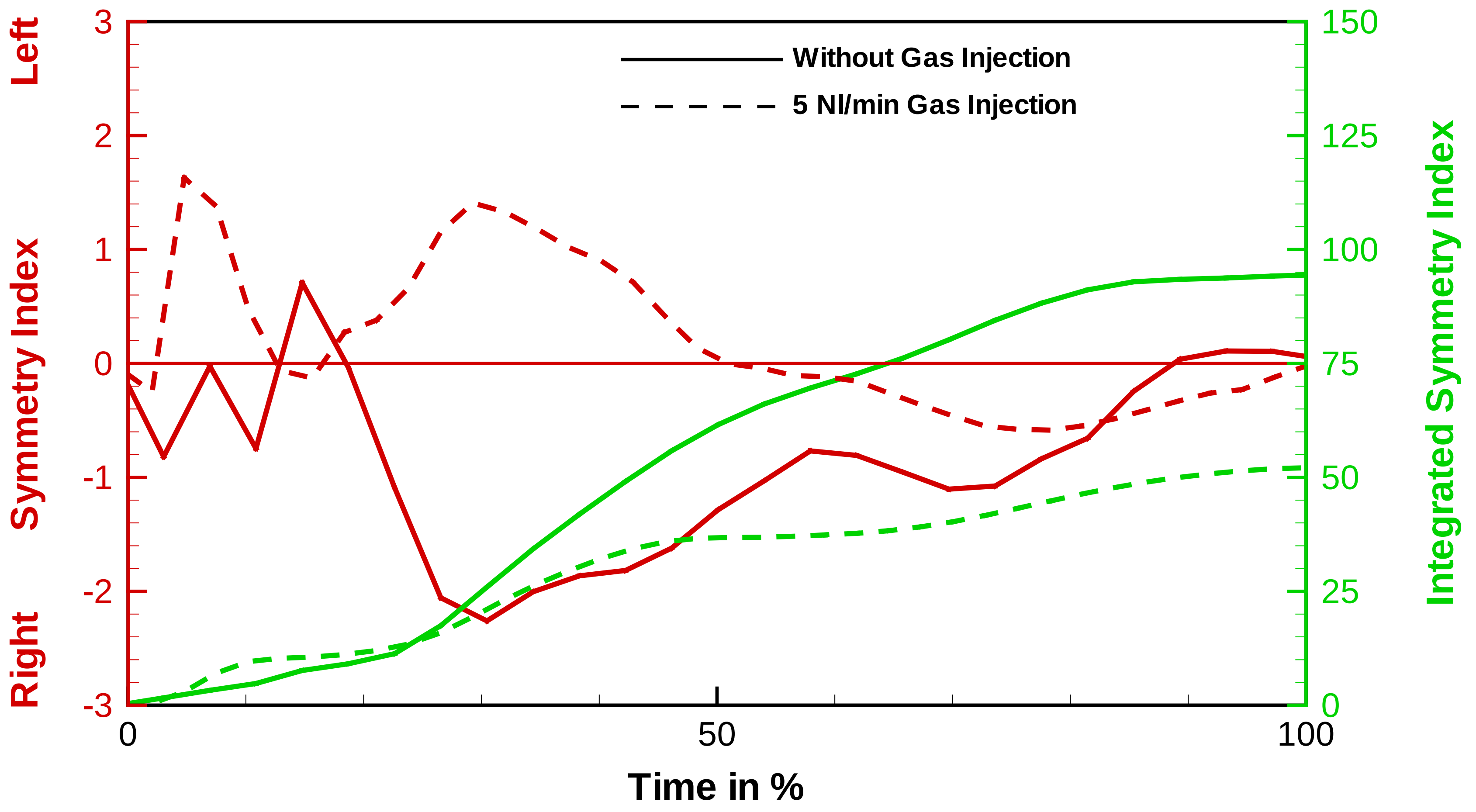
Flow Symmetry Quantification



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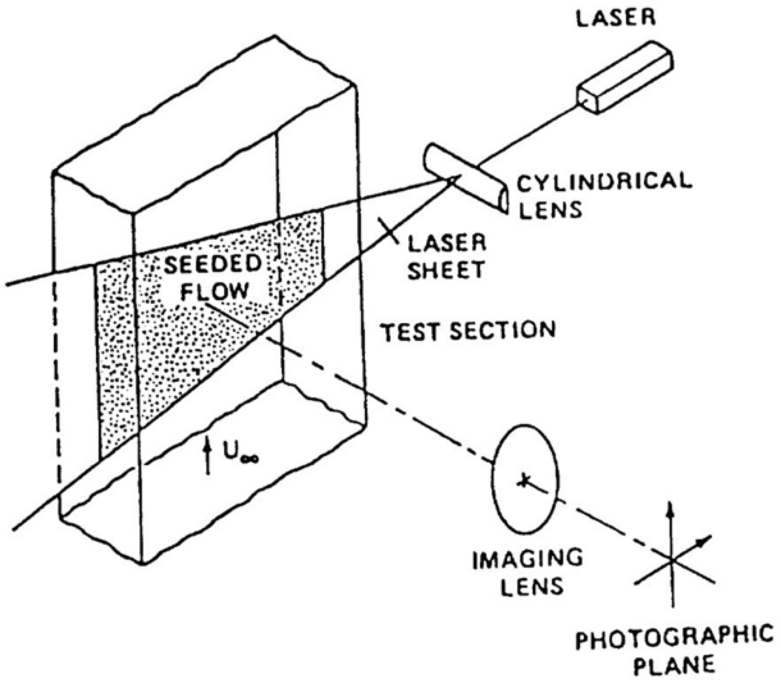
Particle Image Velocimetry (PIV)



NASA Contractor Report 17758

Particle image velocimetry (**PIV**) is an optical (non-intrusive) method. It is used to obtain instantaneous velocity measurements and related properties in fluids. The fluid is seeded with sufficiently small tracer particles which are assumed to faithfully follow the flow. The fluid with entrained particles is illuminated so that particles are visible. The motion of the seeding particles is used to calculate speed and direction (the velocity field) of the flow being studied.

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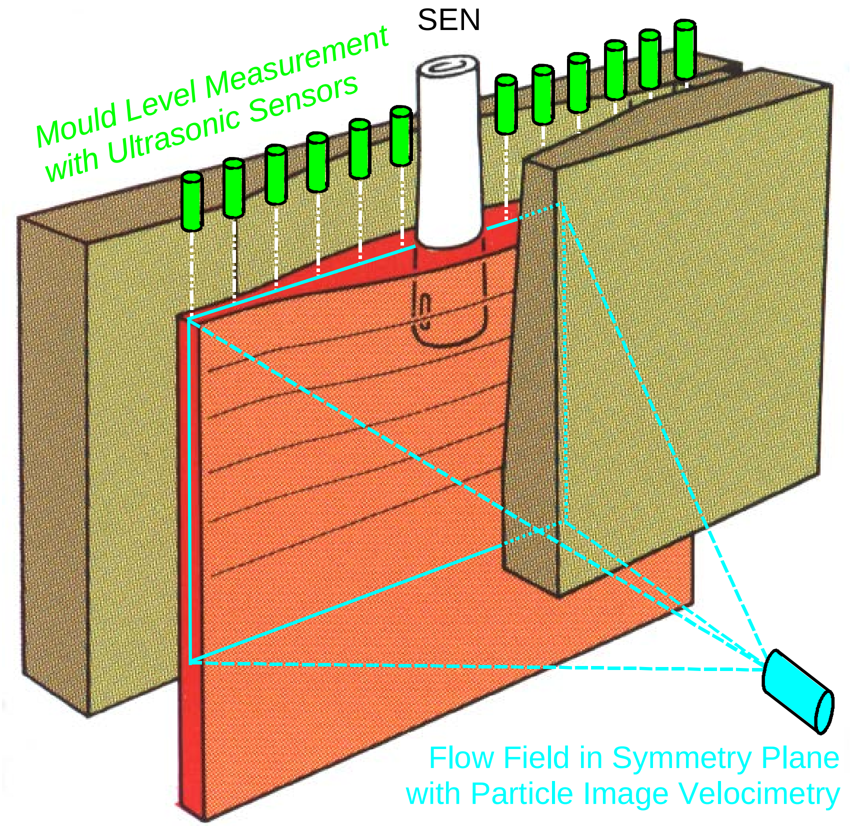
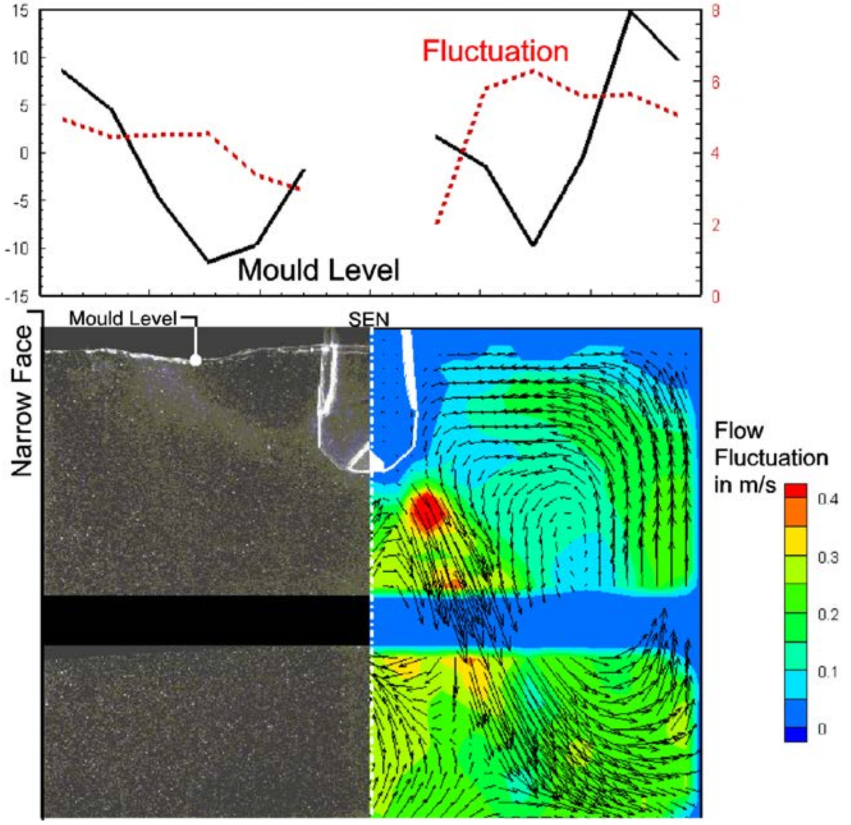
Process Stability - Measurement Techniques



Schematic of thin slab casting mould model with measurement arrangement



Simultaneous measurement of flow field and mould level behaviour

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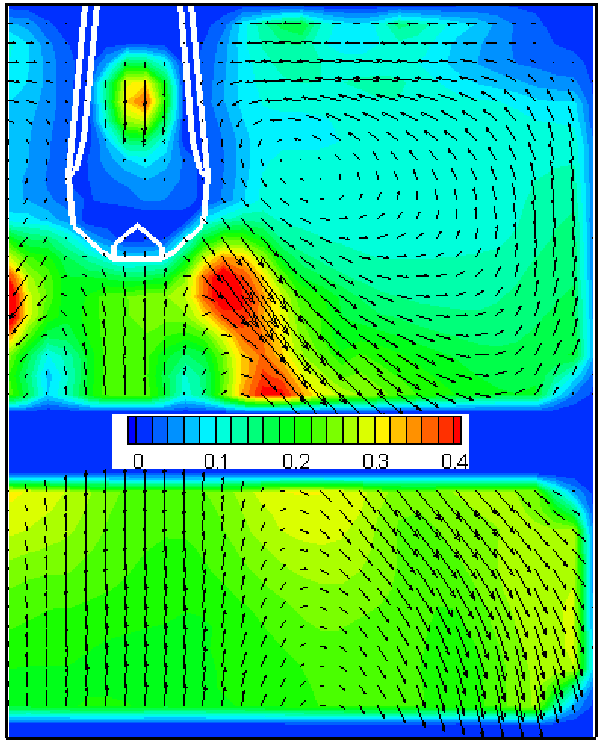
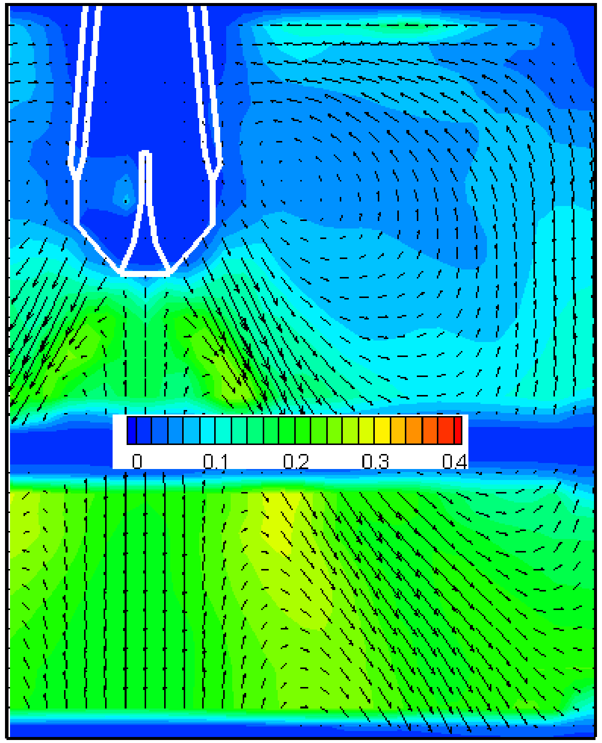
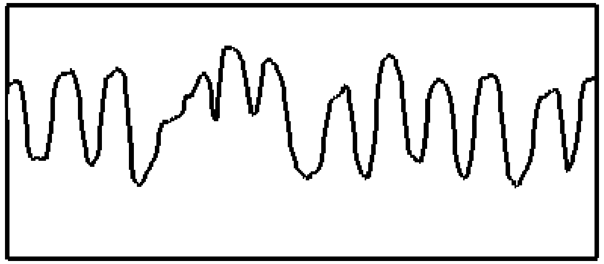
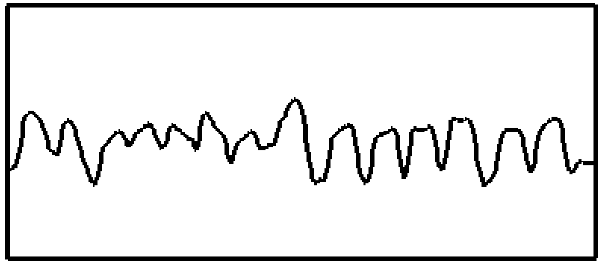
Process Stability - Flow Field

	Standard SEN	Optimised SEN
Time-Dependent 2-dimensional Flow Field (Vectors) and Flow Instability (Coloured Contours)		
Average Flow Instability (high / low)		

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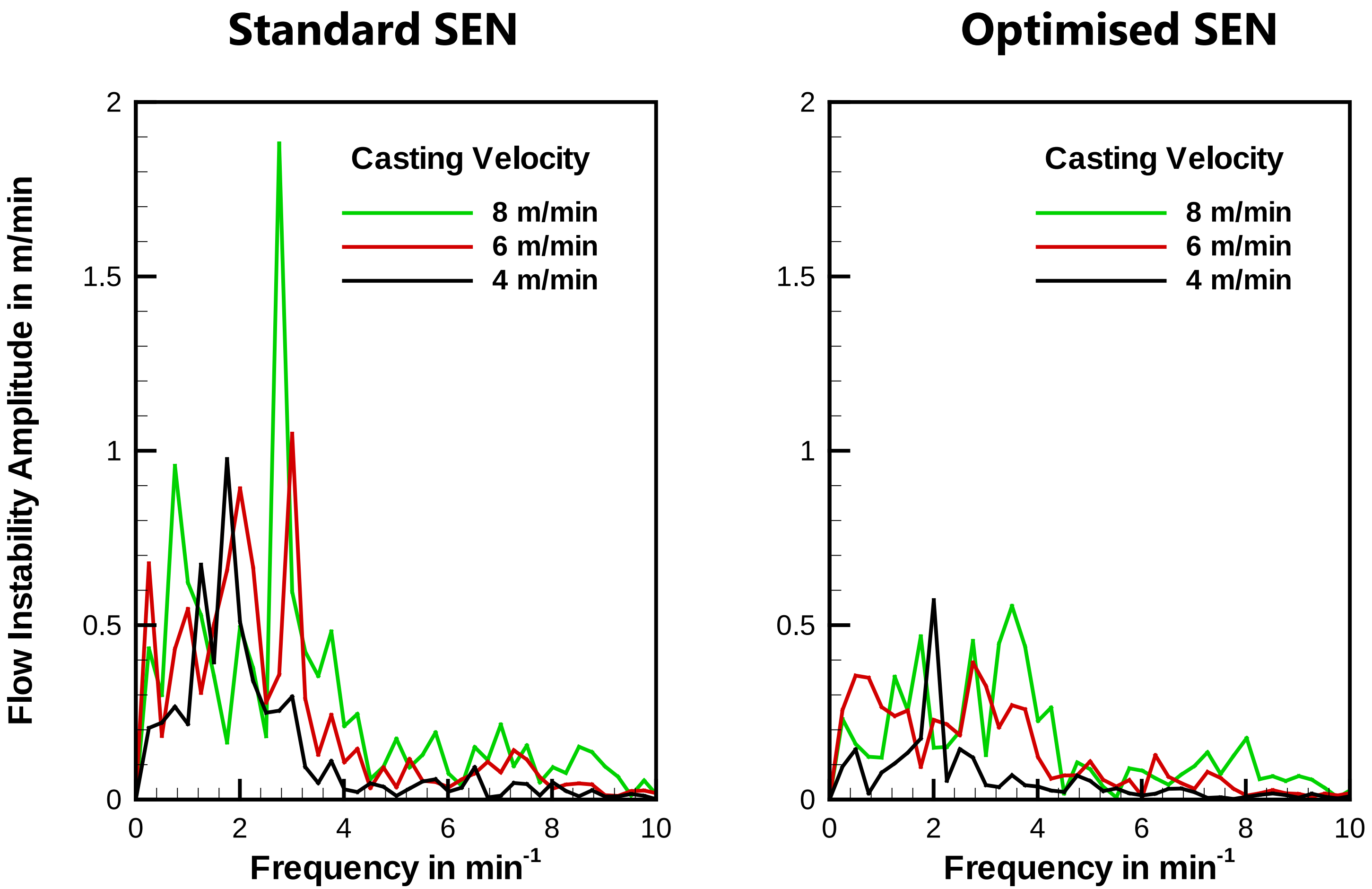
Process Stability - Frequency Analysis



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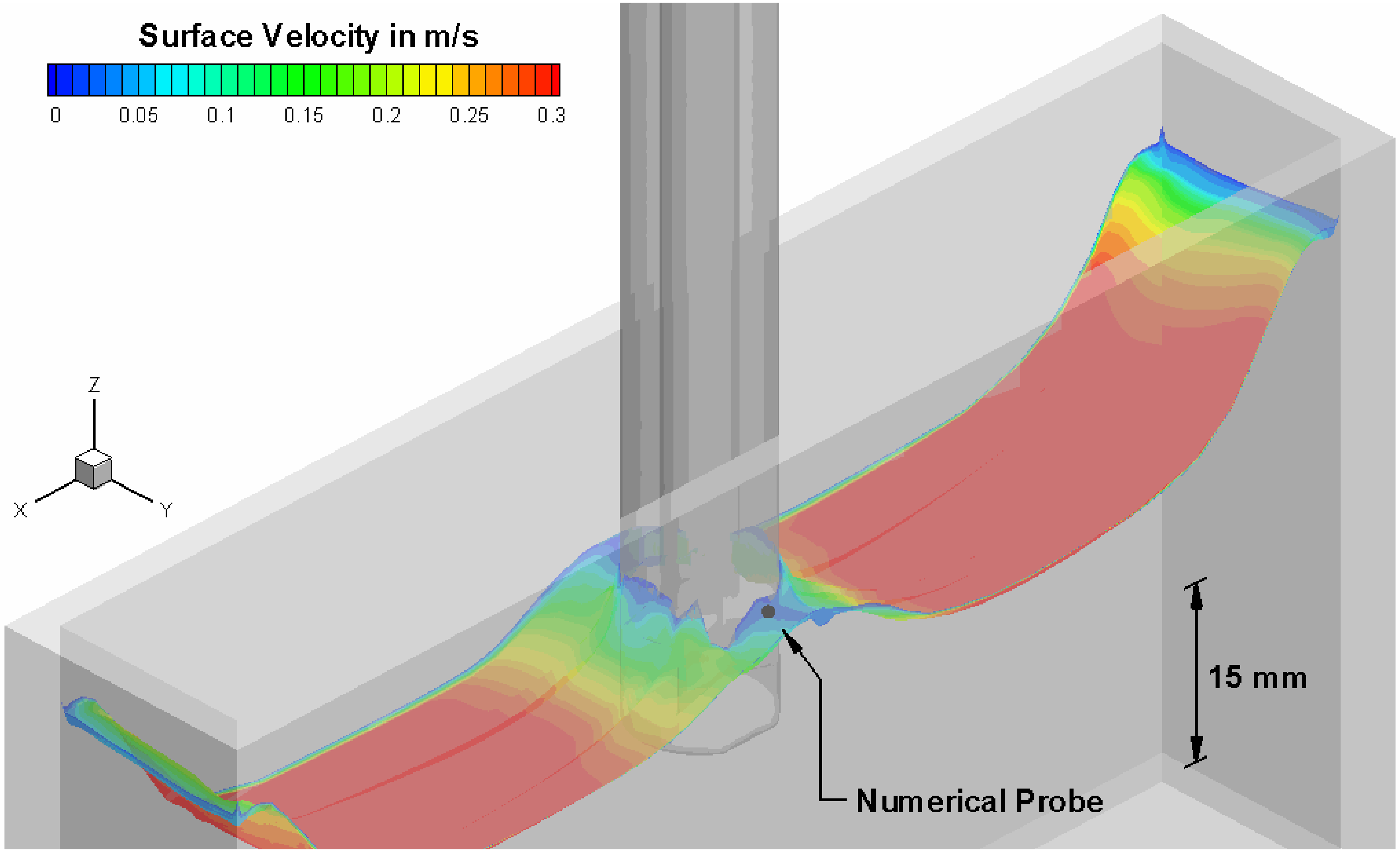
Process Stability – Mould Level Behaviour



Frequency in Hz

Num.	Exp.
0,07	0,05
0,13	0,16
1,11	1,09

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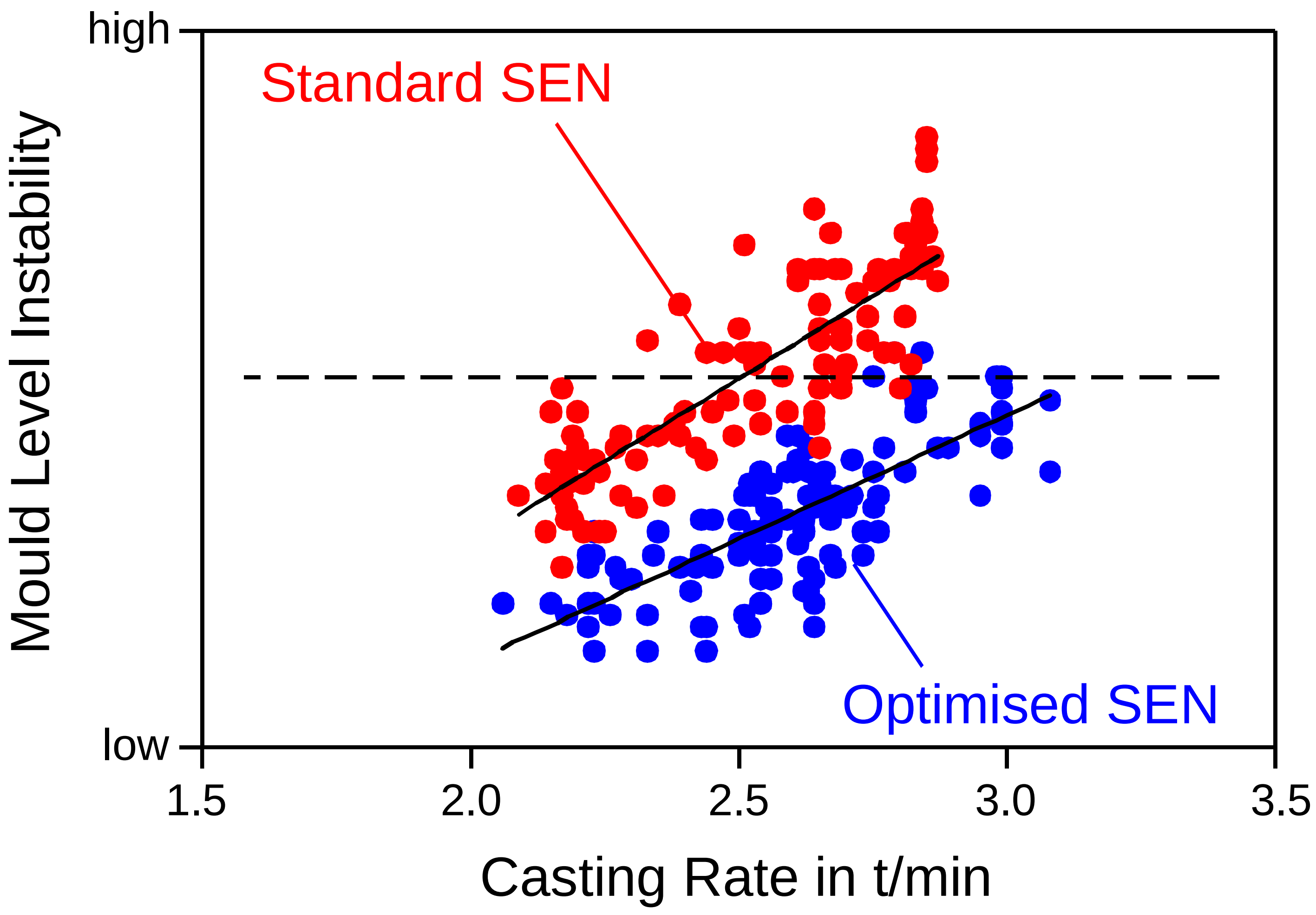
Process Stability - Plant Data



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Results

- The investigated SEN can affect flow symmetries, due to the flat inner SEN bottom. Gas injection, primary to avoid clogging, can help to stabilise the flow symmetry.
- The simultaneously measurement of flow field and mould level behaviour allows the design of an optimised SEN for higher process stability and higher productivity.

Thank you for your attention!

Questions?

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