Combining process simulation and sensing for optimised composites manufacturing

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ECOMISE Project

Enabling Next Generation COmposite Manufacturing by In-Situ Structural Evaluation and Process Adjustment

www.ecomise.eu

Objective

A breakthrough composite manufacturing system is being developed comprising probabilistic process prediction, online process monitoring, in-situ structural evaluation and in-situ process adjustment. By means of industrial applications the focus is laid upon preforming processes such as pick & place and dry fibre placement, as well as subsequent infusion and curing processes such as Resin Transfer Infusion (RTI) and Resin Transfer Moulding (RTM).

Industrial Demonstrators

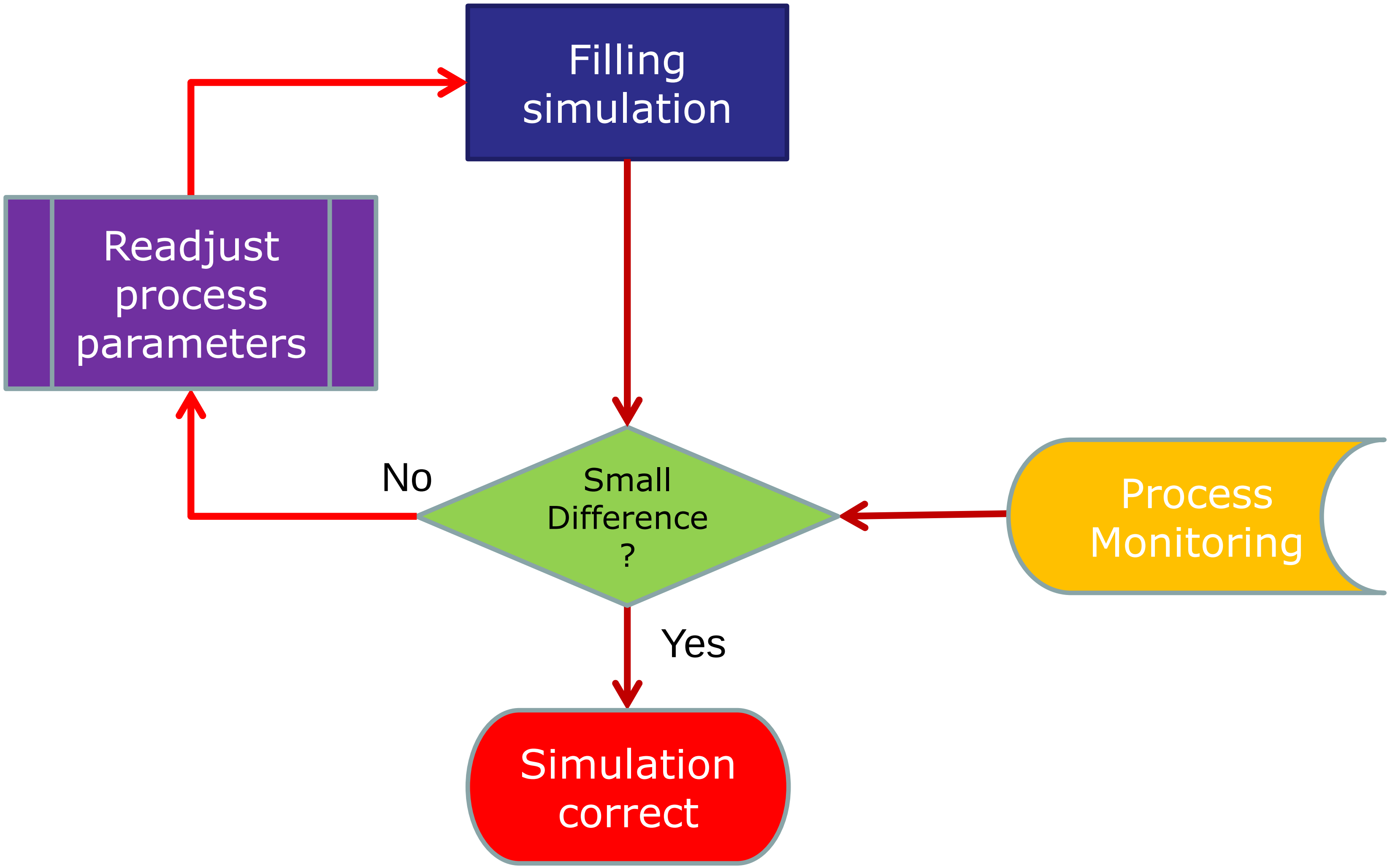
- Aerospace (Bombardier)
- Automotive (Hutchinson)
- Marine (Airborne)

Partners

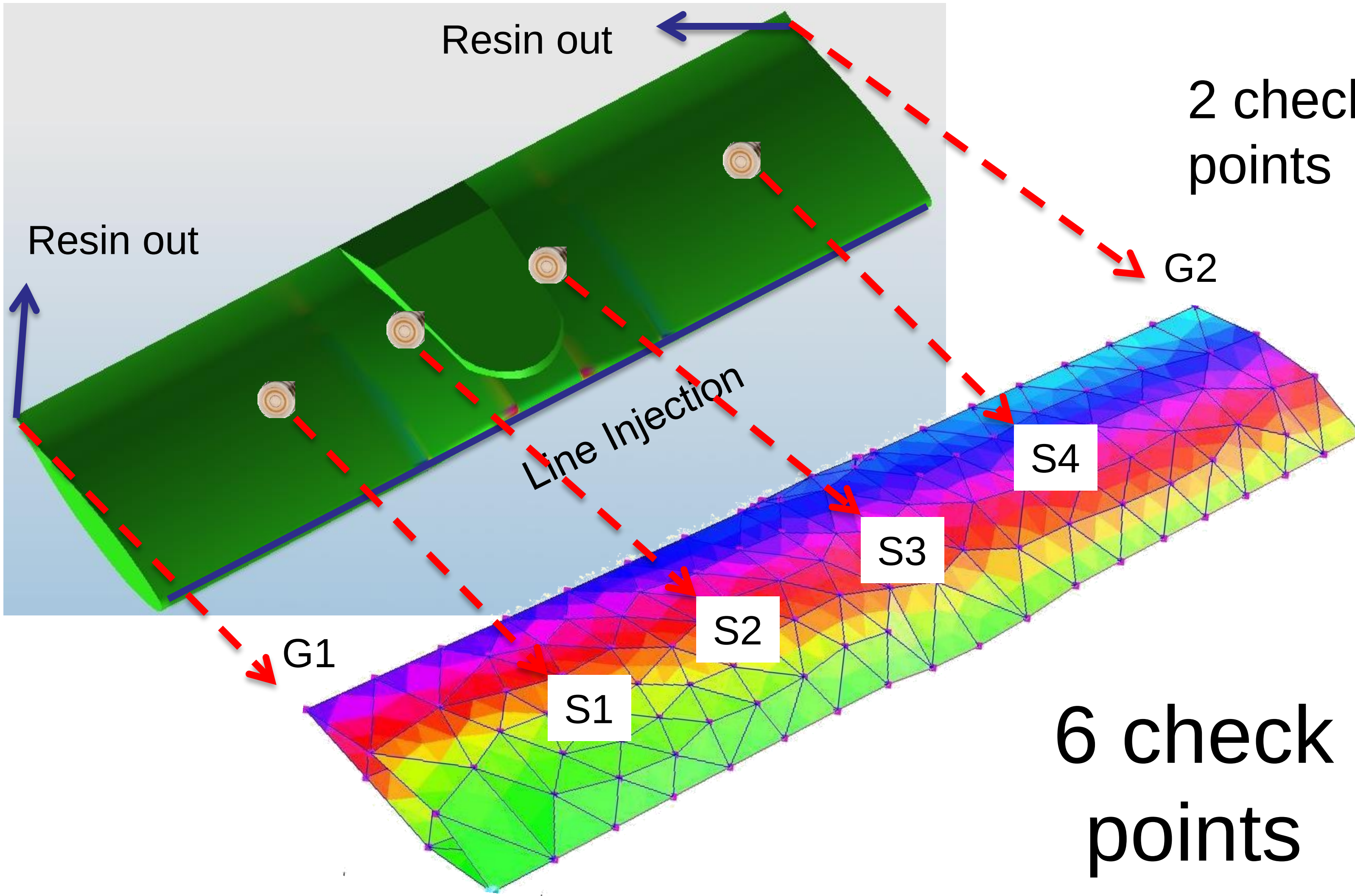
Eliminating the deviation between simulations and reality at industrial level

- Introduce an outer identification loop in the simulation task to adjust automatically specific process parameters in order to minimise the deviation between simulations and measurements
- Include numerous flow sensors to improve accordingly simulation accuracy
- Introduce new flow sensors for minimum flow disturbance
- Advance the concept for industrial applications

Outer Identification Loop



Real Case example



2 check points

6 check points

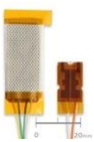
Process Monitoring in composites manufacturing

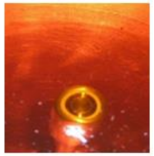
- Check resin quality and adjust process accordingly
- Detect accurately resin arrival at critical locations
    - Open/close valves based on sensors' feedback
- Monitor viscosity changes and decide when start heating
- Identify minimum viscosity and decide about pressure
- Detect unexpected events and follow alternative routes
- Improve simulation accuracy and design intelligent strategies
- Real-time decision of the cure cycle based on Tg and degree of cure (depends on the resin) rather than time

Process monitoring and simulations

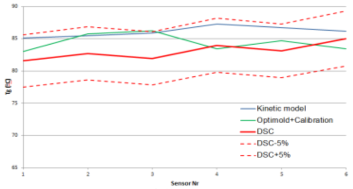
OptiMold system for monitoring resin cure, resin viscosity, mixing ratio quality and resin quality

OptiFlow system for optimising mould filling, process automation and simple process control

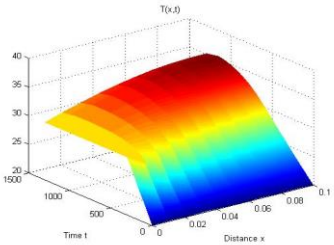




OptiSensors (durable/ disposable, flexible, outlet, custom)



Real-time calculation of Tg/ degree of cure/ viscosity/ resin quality



Simulations, Automation, Design and Prototyping solutions

Optimold: Cure, viscosity and resin quality check

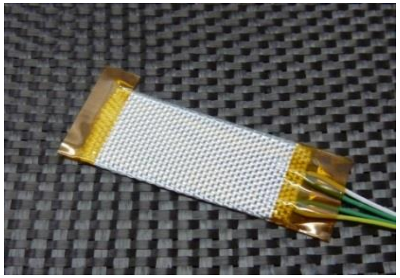
Real-time measuring of

- Resin's electrical resistance (from 0.1 MOhm up to 50 TOhm) and
- temperature (0.1^{o}C accuracy)

Characteristics

- Non-intrusive
- Range of sensors
- Good Repeatability
- Fast Acquisition
- Compact design
- Wireless
- Quality and Process control

process monitoring sensor = electrical resistance + RTD sensors

Durable sensor	Flexible sensor	Inline sensor	Pot sensor
			

High Temp RTM
- Resin arrival
- Viscosity rise
- Gelation
- End-of-cure

VI and RT cure
- Resin arrival
- Viscosity rise
- Gelation
- End-of-cure

- Avoid pipe cleaning
- Adjust cycle
- Mixing ratio check

- Mixing ratio
- Resin Quality
- Resin aging
- Adjust cycle

OptiFlow: Resin arrival and temperature

- 4 temperature and resin arrival sensors
- Electrical resistance-based measurements and RTD temperature sensing
- Continuous connection checking
- One relay output for process automation

Resin arrival and temperature sensors

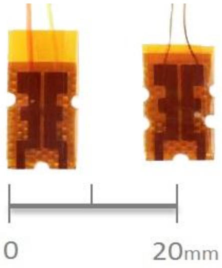
In-mould Durable

- flat areas
- possible mark

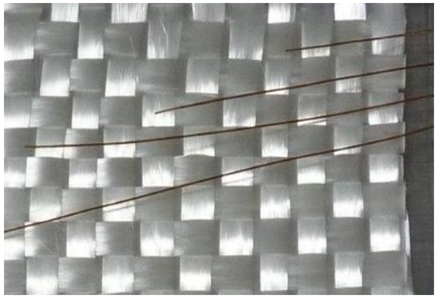
Gate sensor

- ideal for vacuum infusion in oven/ autoclave (gates, pipelines, pots etc.)

Flexible disposable

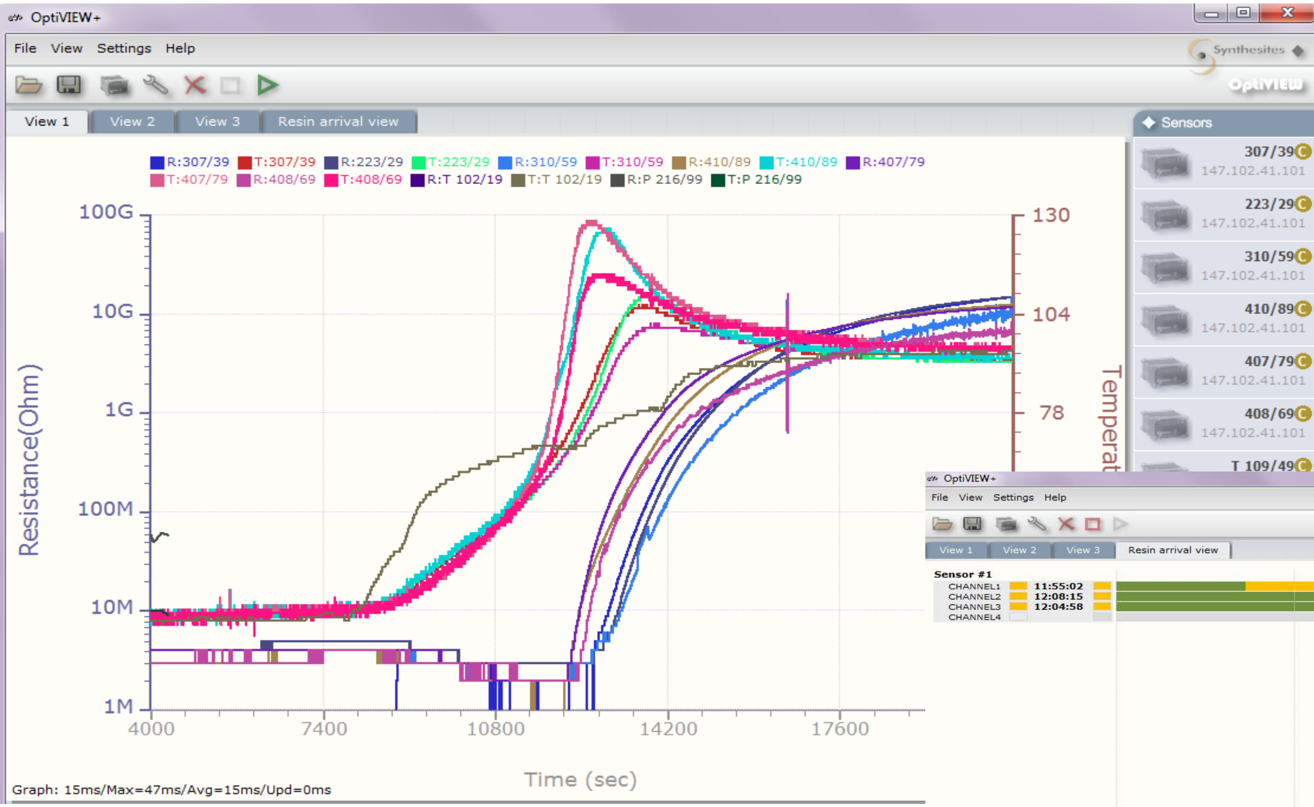


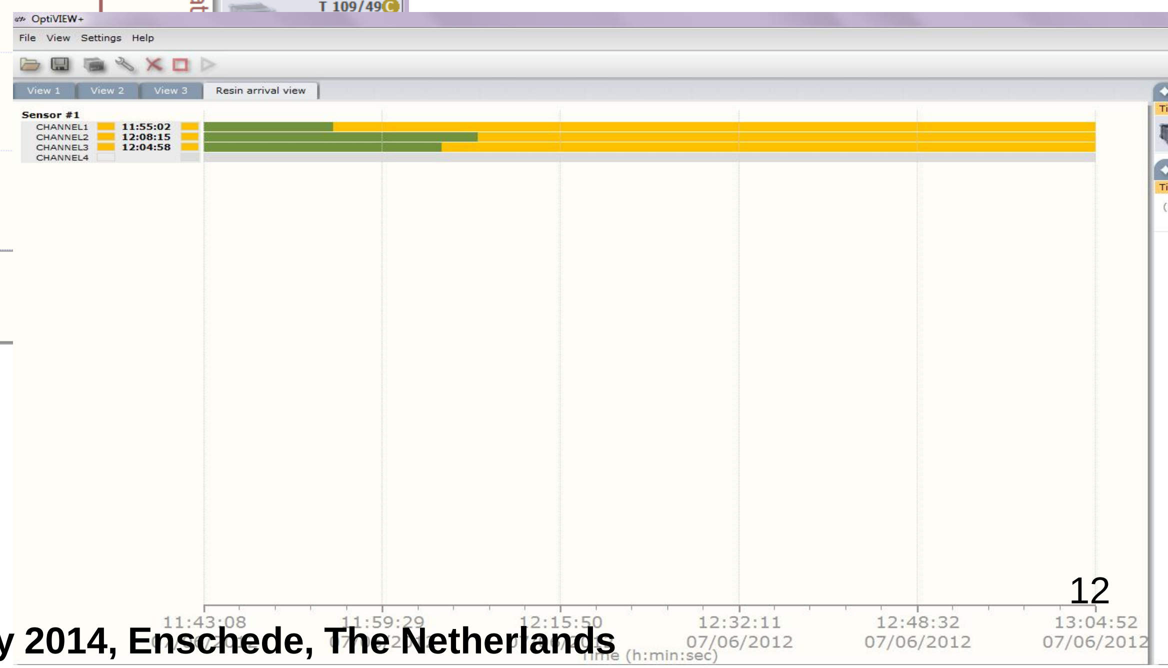
Wire sensors



- Curved surfaces
- In the laminate for development
- Over the peel-ply
- Suitable for very long parts
- no extra protection for Carbon Fibre Preforms

Optiview: DAQ software





OptiView software for both
Optimold and OptiFlow systems

Sources of process variations

Source of variation	Permeability value	Permeability Tensor angle	V_f	Viscosity	Thickness
1 fibres' direction and density		* Global	* Global		
2 fabrics' formability	*** Local	**** Local	** Local		
3 cutting equipment	***** Local		*** Local		
4 Workers' craftsmanship		** Local			** Local
5 fabric placement	***** Local	* Local	**** Local		*** Local
6 temperature across the mould				**** Local	
7 Injected resin temperature				*** Global	
8 Vacuum integrity	*** Loc-Glob		*** Loc-Glob		***** Loc-Glob

Process Parameters to identify

Dry-spots

- fabrics misplacement
- fabrics miscut
- fabrics draping
- Non-uniform mould temperature
- Thickness deviation

→ Permeability variations

Filling time

- wrong resin temperature
- wrong mould temperature
- variable clamping pressure

→ viscosity variations

In Practice

- Measure permeability at 'lab-scale' conditions and tool.
- At industrial level adjust parameters e.g. permeability tensor to match the 'expected' flow path and the outlet gates timing.

Drawbacks

Due to limited feedback in the real cases i.e. very few outlet gates, the unknown parameters should be kept to a minimum e.g. considering homogeneity of permeabilities in the whole cavity.

Solution

Introduce more feedback locations and an identification loop to deal with the simulation errors.

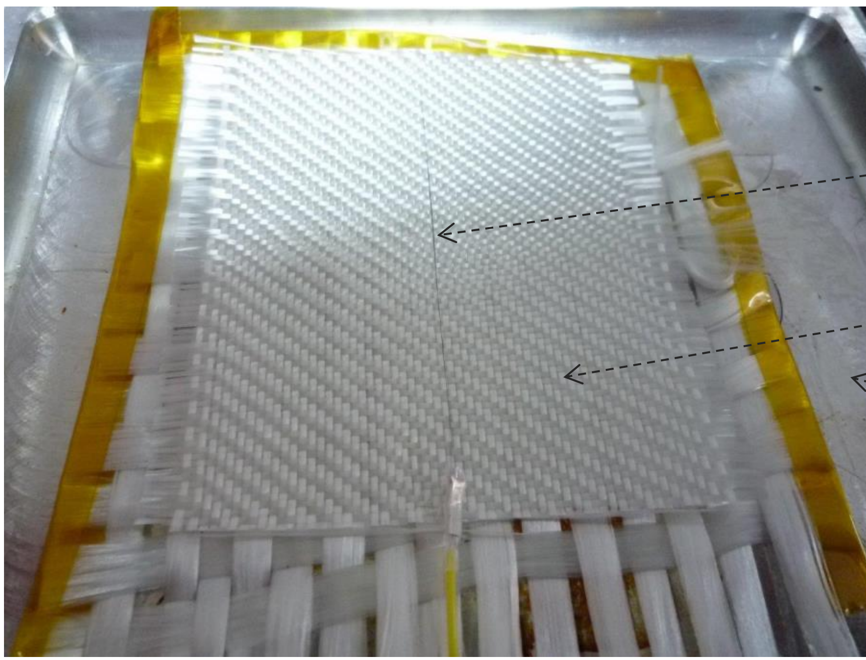
New sensors have been developed and tested

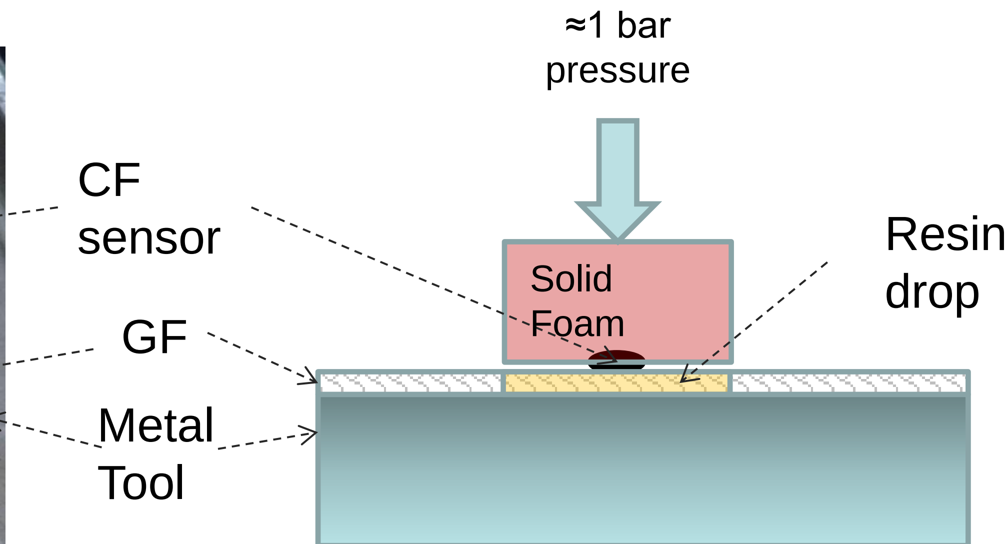
- Carbon fibre sensor (for glassfibre preforms)
  - CF or wire sensors can be used as lineal flow sensors and cure sensors when used with **Optimold** cure monitoring system
- Very thin wires (>0.2 mm) (for carbon fibre preforms)
  - In combination with Optiflow system

New Resin Arrival sensors

New disposable and, practically, non-intrusive sensors

- Carbon Fibre Strands + metal tool



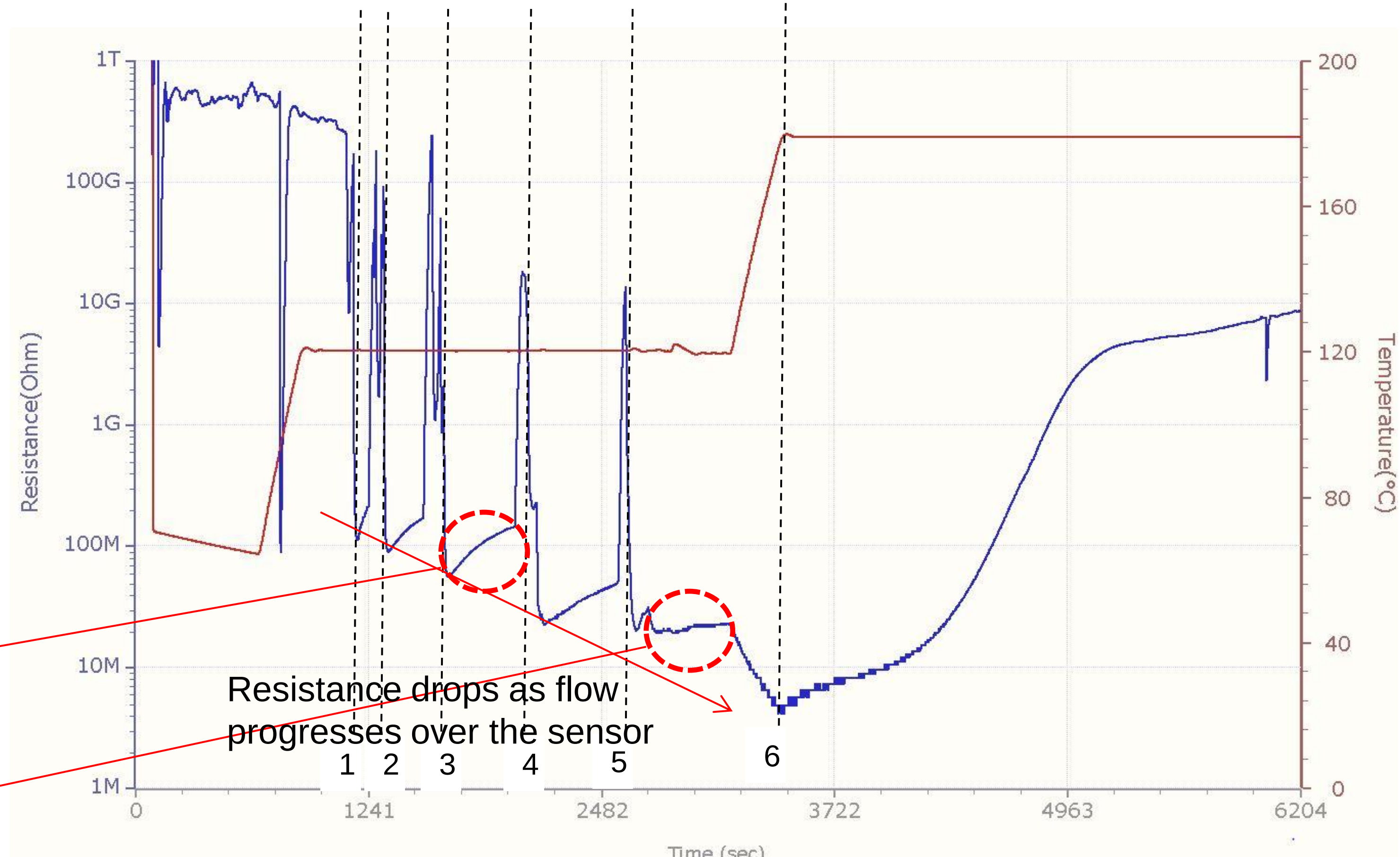


Experimental set-up

Resin Flow sensing

CF or wire sensors can be used as lineal flow sensors and cure sensors when used with **Optimold** cure monitoring system

Nr	Comment
1	25% resin covered
2	50% resin covered
3	75% resin covered
4	100% resin covered
5	Resin overflow
6	Curing



Resistance increases due to resin spreading.

No electrode polarization

Numerical Methods employed

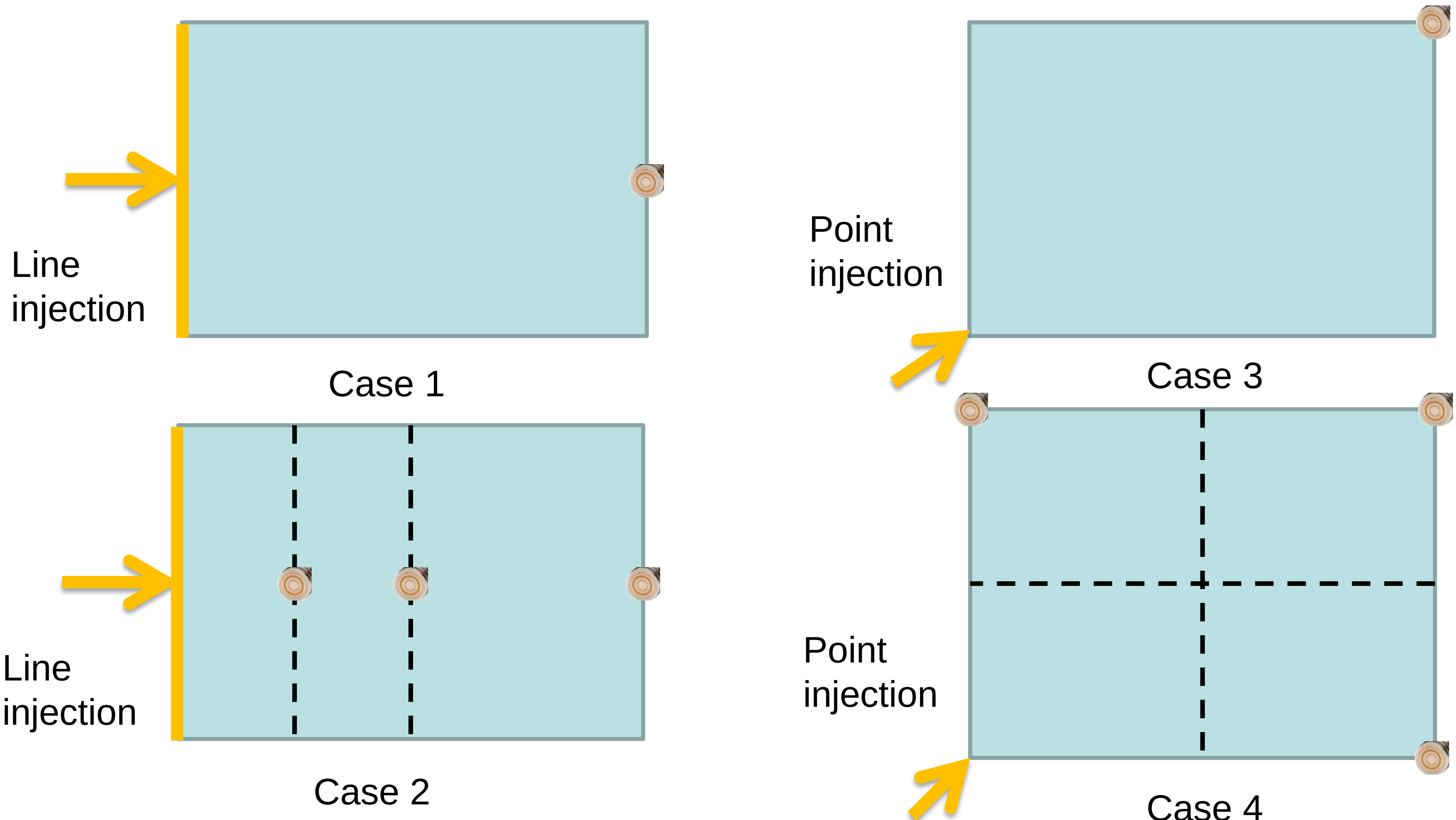
Filling Simulation Tool

- Darcy Law
- Control Volumes with 2D triangular elements
- Point or line injection
- Constant pressure or volume injection
- Variable permeability, viscosity in zones
- Non-isothermal simulation

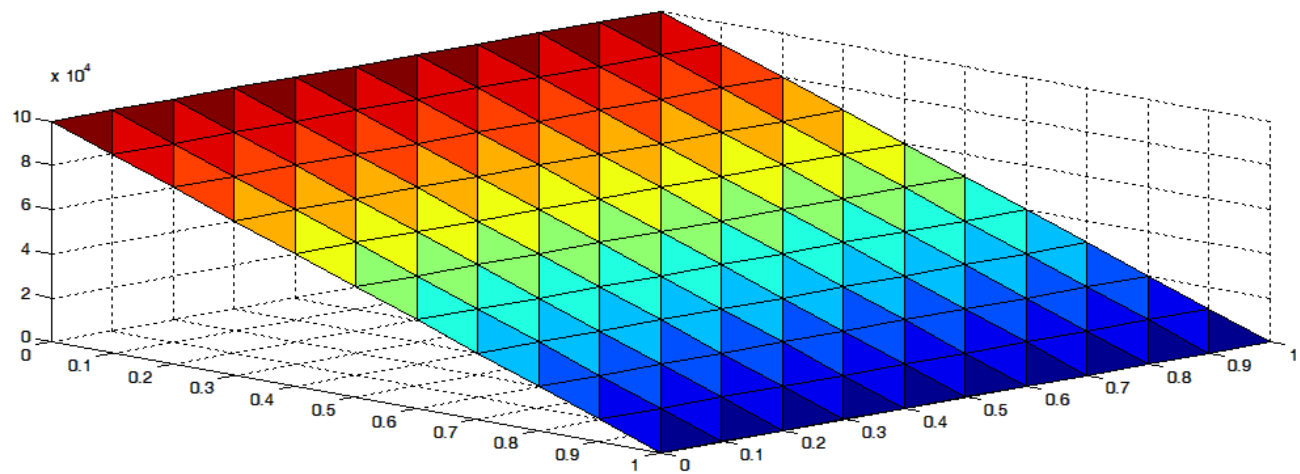
Optimisation Tool

- Evolution strategies (Genetic-type algorithm)
- Objective function: minimise time differences at sensor points between simulation (t_s) and measurements (t_m) $\sqrt{\sum_1^N (t_s - t_m)^2}$
- Penalty functions for limits e.g. negative times

Test cases

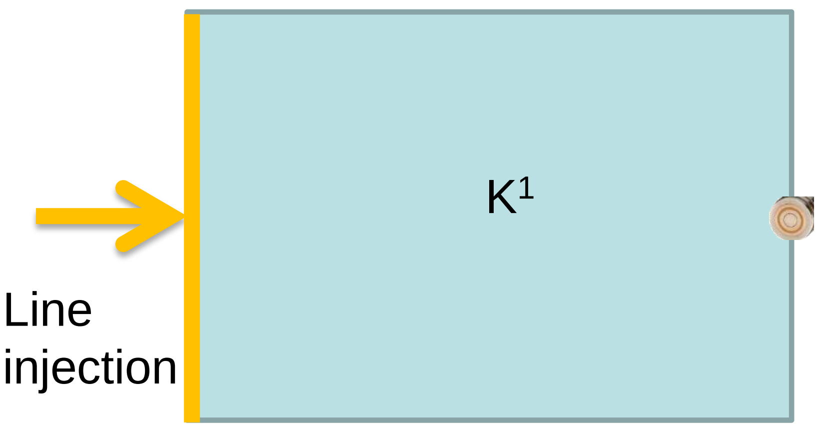


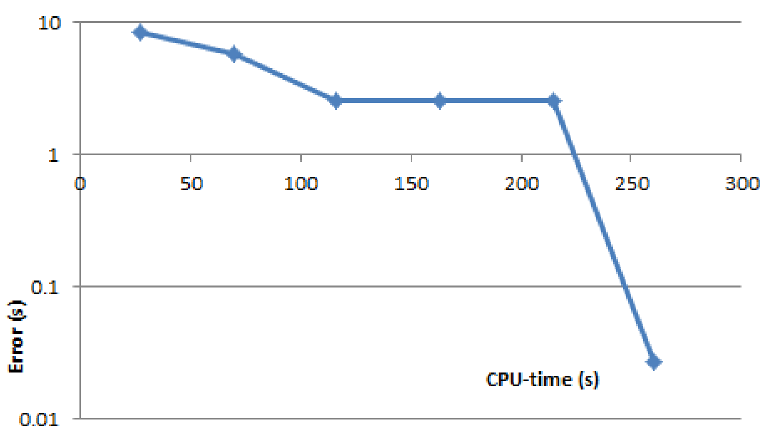
Line injection
Case 1
Point injection
Case 3
Line injection
Case 2
Point injection
Case 4

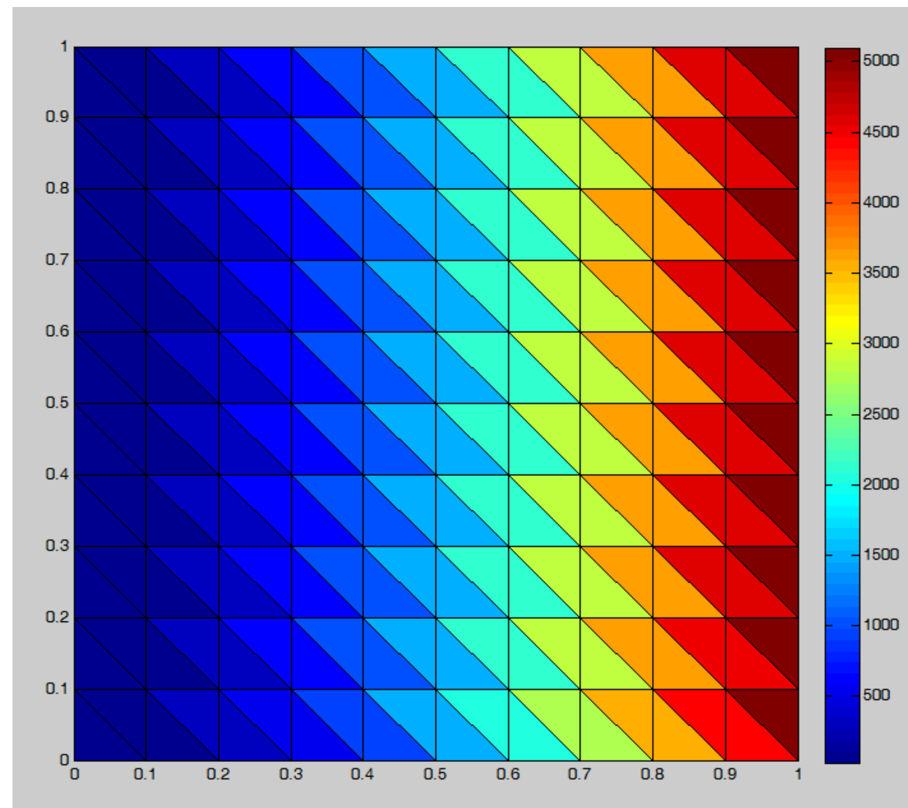


Pressure distribution for case 1

Case 1

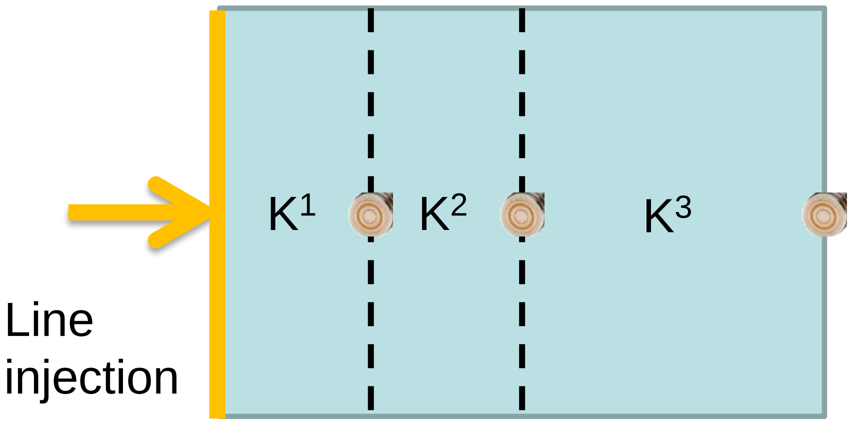

K1
Line injection

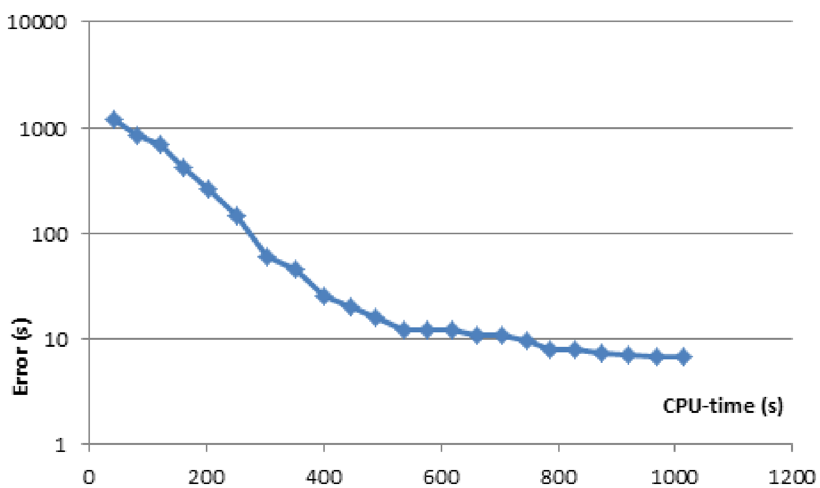

10
1
0.1
0.01
0
50
100
150
200
250
300
Error (s)
CPU-time (s)

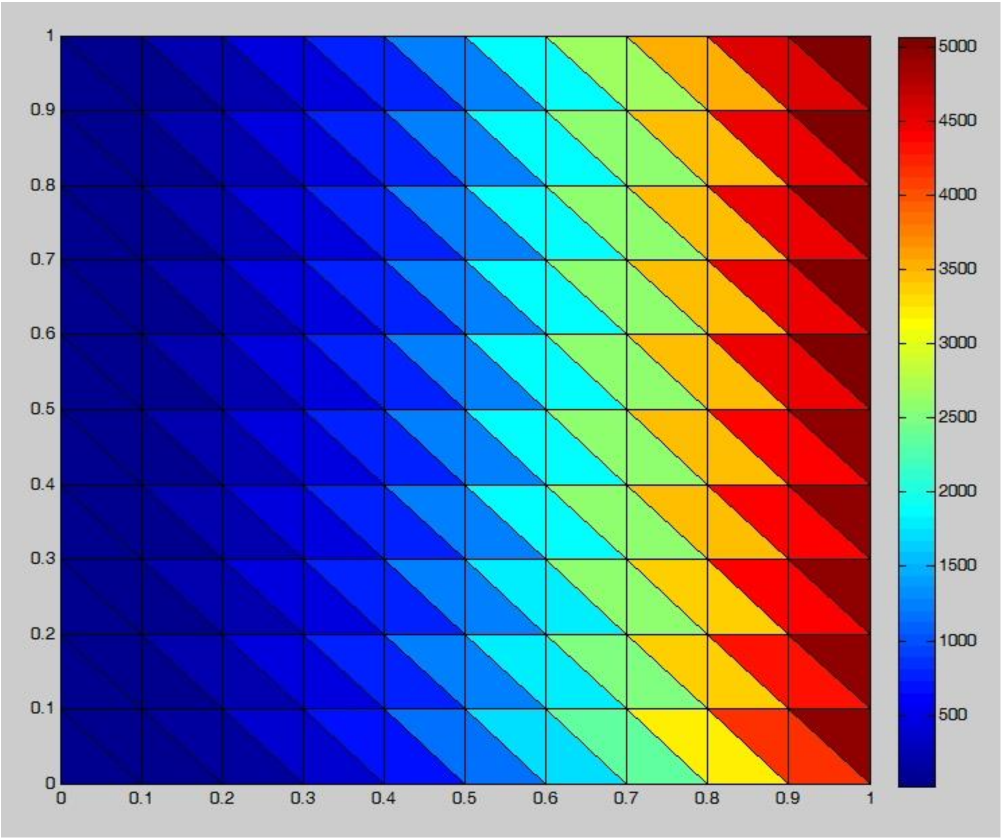

0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
500
1000
1500
2000
2500
3000
3500
4000
4500
5000

Results

Case 2

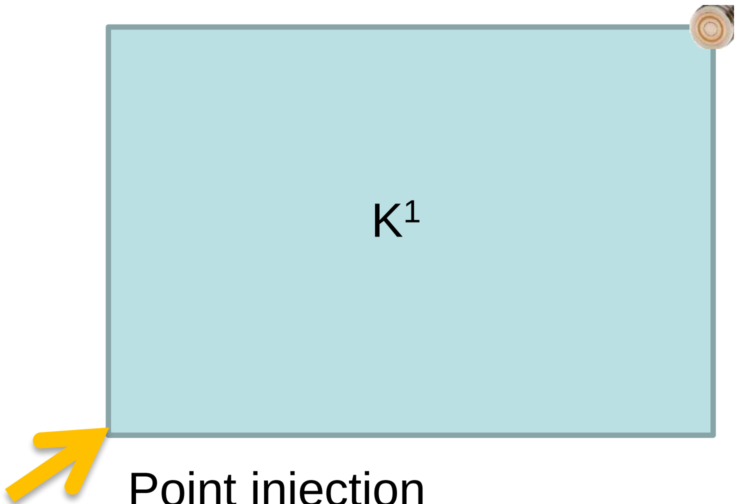




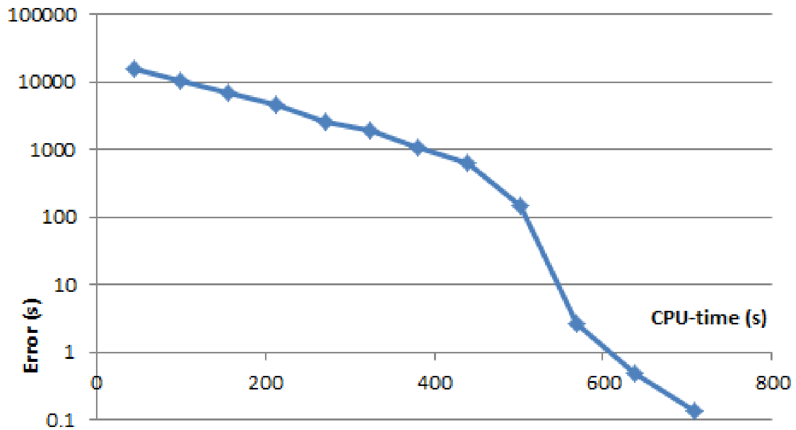


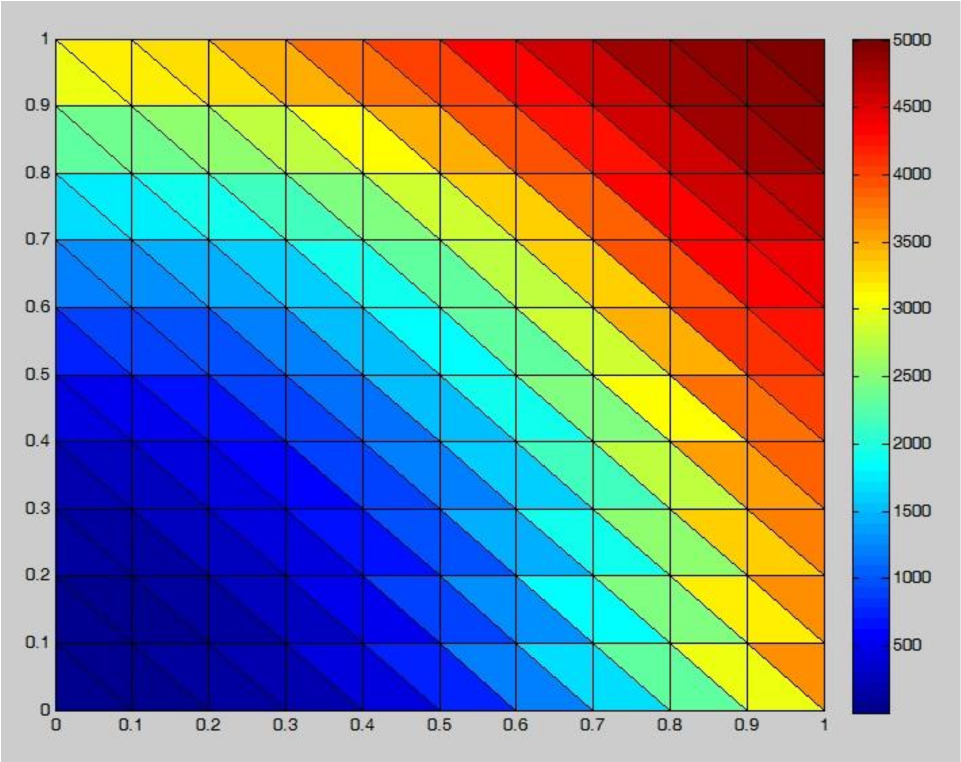
Flow path (s)

Case 3



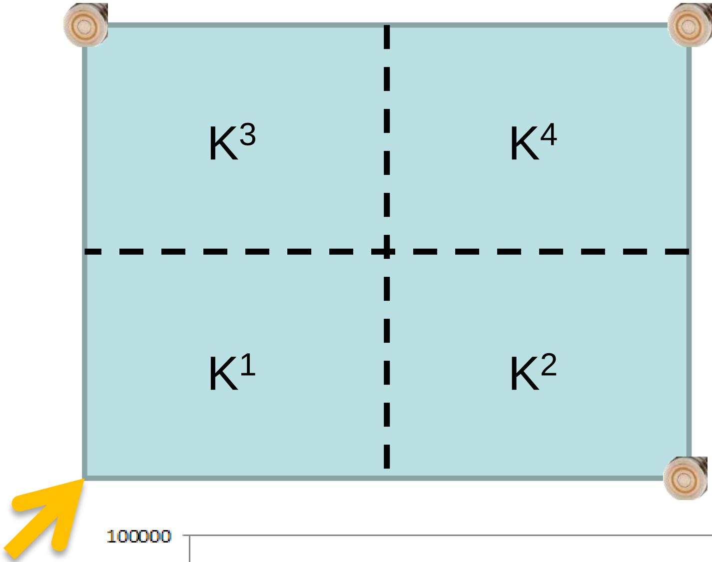
Point injection

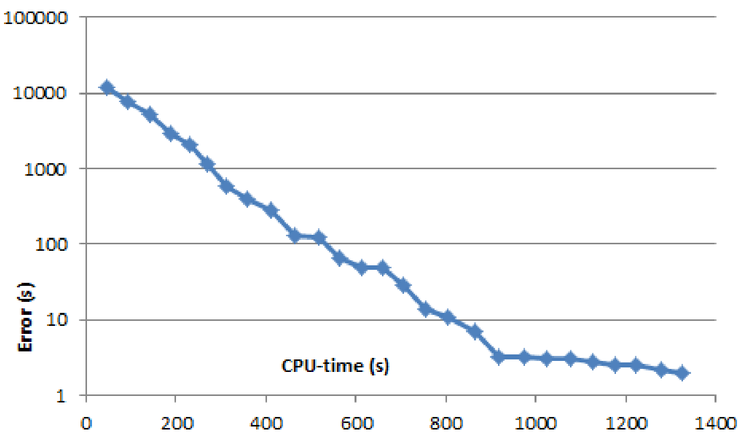


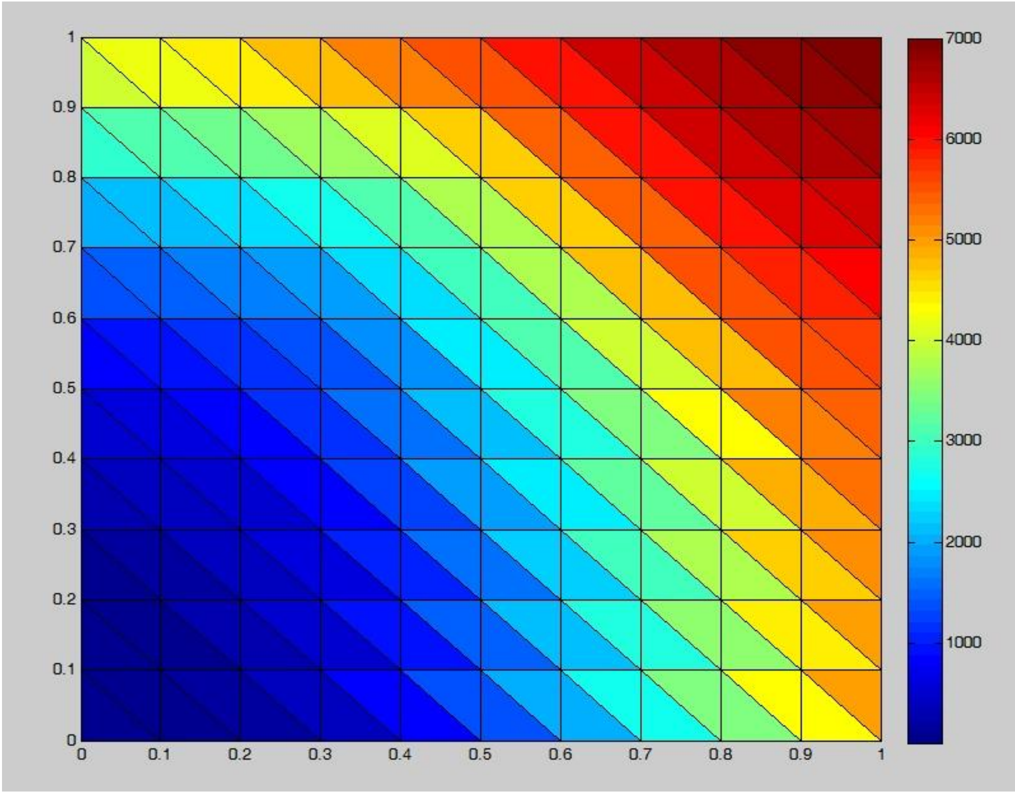


Flow path (s)

Case 4





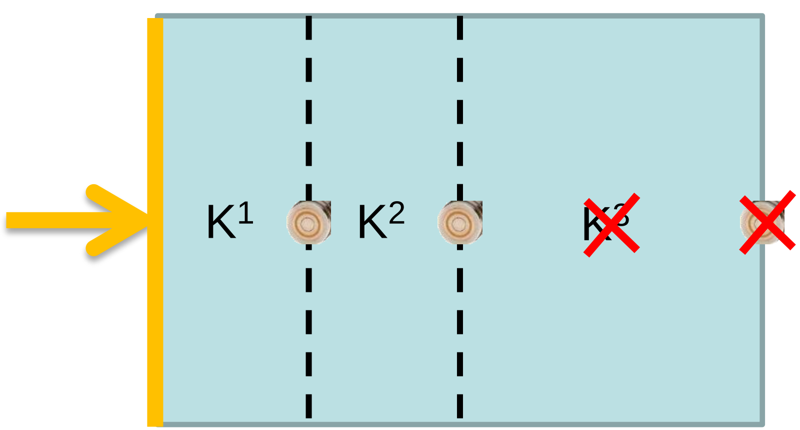


Flow path (s)

Guidelines

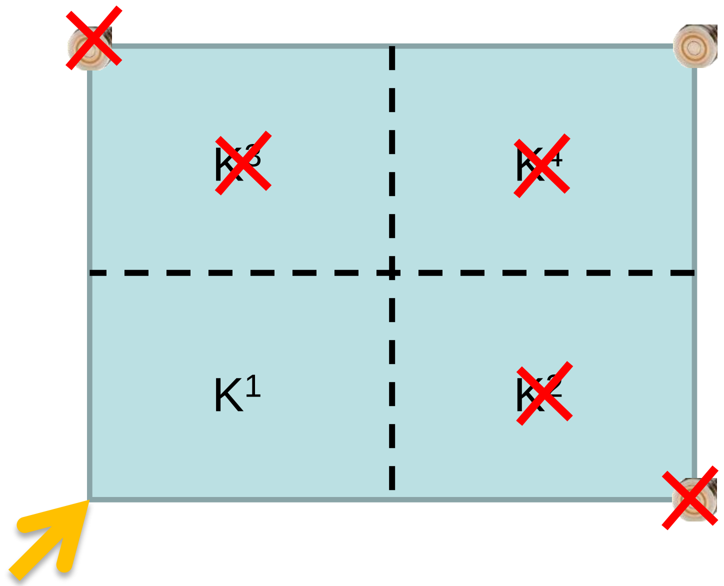
Don't expect from the algorithms to provide solutions that contradict to physics e.g. K^3 can not be calculated in Case 2 if the 3rd sensor doesn't exist.

Case 2



Match number of sensors with number of unknown parameters e.g. don't expect accurate solution when searching for 8 unknowns with a single sensor

Case 4



Conclusions

- An Intelligent Process Modelling platform combining simulations and measurements has been developed for the accurate calculation of the permeability tensor in real moulds.
- New non-intrusive wire and gate sensors have been developed to provide the necessary experimental feedback.
- The adaptation and the tuning of the platform to the process-specific needs can be done on-site so no costly lab-scale trials are necessary.
- The use of this platform with any suitable filling or curing simulation tool is straightforward. Although simulation speed is paramount for a successful implementation.

Acknowledgements

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SEVENTH FRAMEWORK PROGRAMME

ecomise