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CFD MODELLING OF WATER OF WATER SPRAY IMPINGEMENT COOLING

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IWMA
International Water Mist Association

INTRODUCTION

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WATER SURFACE COOLING

Water surface cooling can be efficient in:

- **preventing the pyrolysis** of combustible materials (to limit flame spread and fire growth), and
- **avoiding excessive heating of structural elements** (which can potentially lead to structural damage).

COMPUTATIONAL FLUID DYNAMICS (CFD)

Advanced tool which can:

- further improve our understanding of the physics,
- support or be a good alternative to costly experimental campaigns, and
- be used for design.

Challenge: Reliability of CFD

→ need for validation studies

EXPERIMENTAL TESTS (LEMTA, FRANCE)

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GENERAL CONFIGURATION

- Horizontal 1 m × 1 m steel plate, 3.1-mm thick
- Radiant panel: heating from below
- Water mist nozzle above the plate

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HEATING

- Radiant panel positioned at 20 cm below the steel plate
- Gas flow rate varying between 0.50 and 1.40 g/s
- Temperatures in the center of the plate between 300 and 800°C

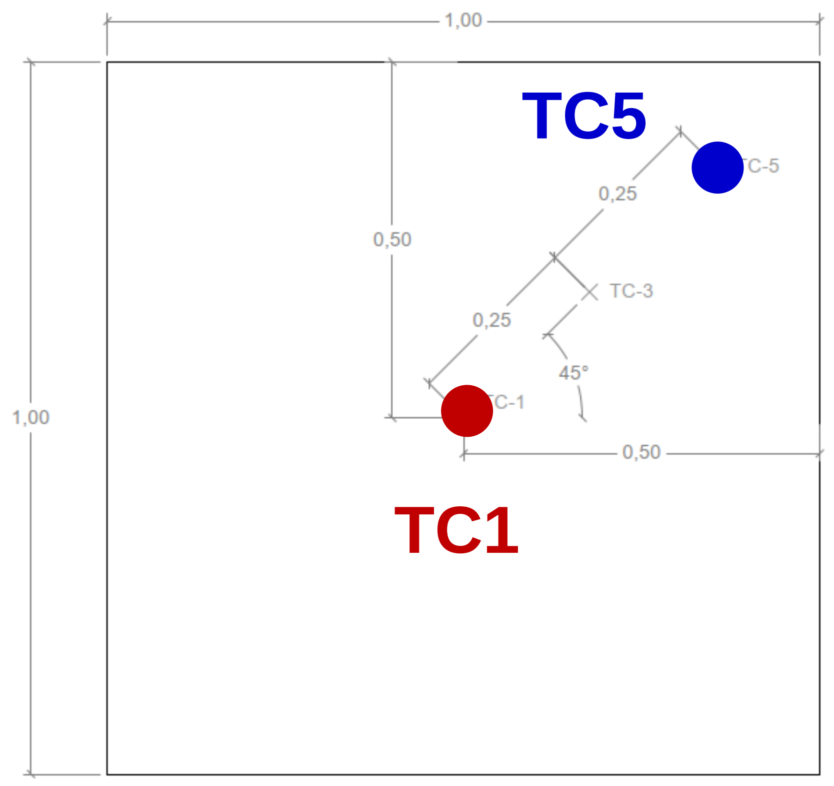
WATER SPRAY SYSTEM

- Water mist nozzle (Tyco Protectospray)
- Positioned at 50 cm above the center of the plate
- Water pressure: 6 bar
- Water flow rates: 5 and 10 L/min
- 60° conical jet
- Volume-median droplet diameters between 220 and 245 µm

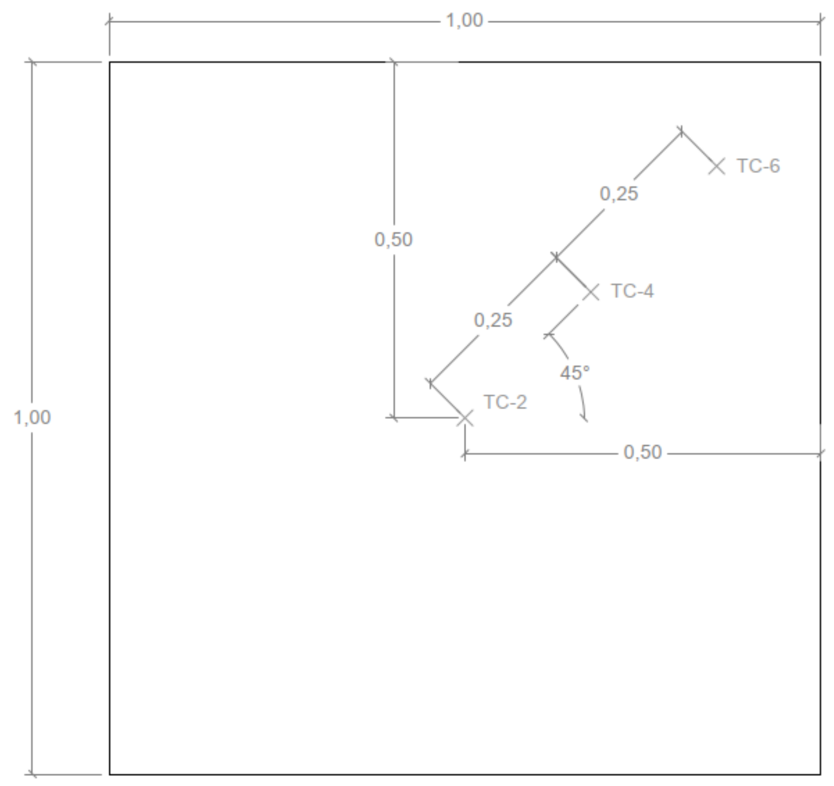
STEEL TEMPERATURE MEASUREMENT

- Thermocouples directly welded onto the surface (connection made by the steel)
- Positioning of the thermocouples

Side exposing to cooling



Side exposing to heating



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CFD MODELLING (UGENT): FIRE DYNAMICS SIMULATOR FDS 6.8.0

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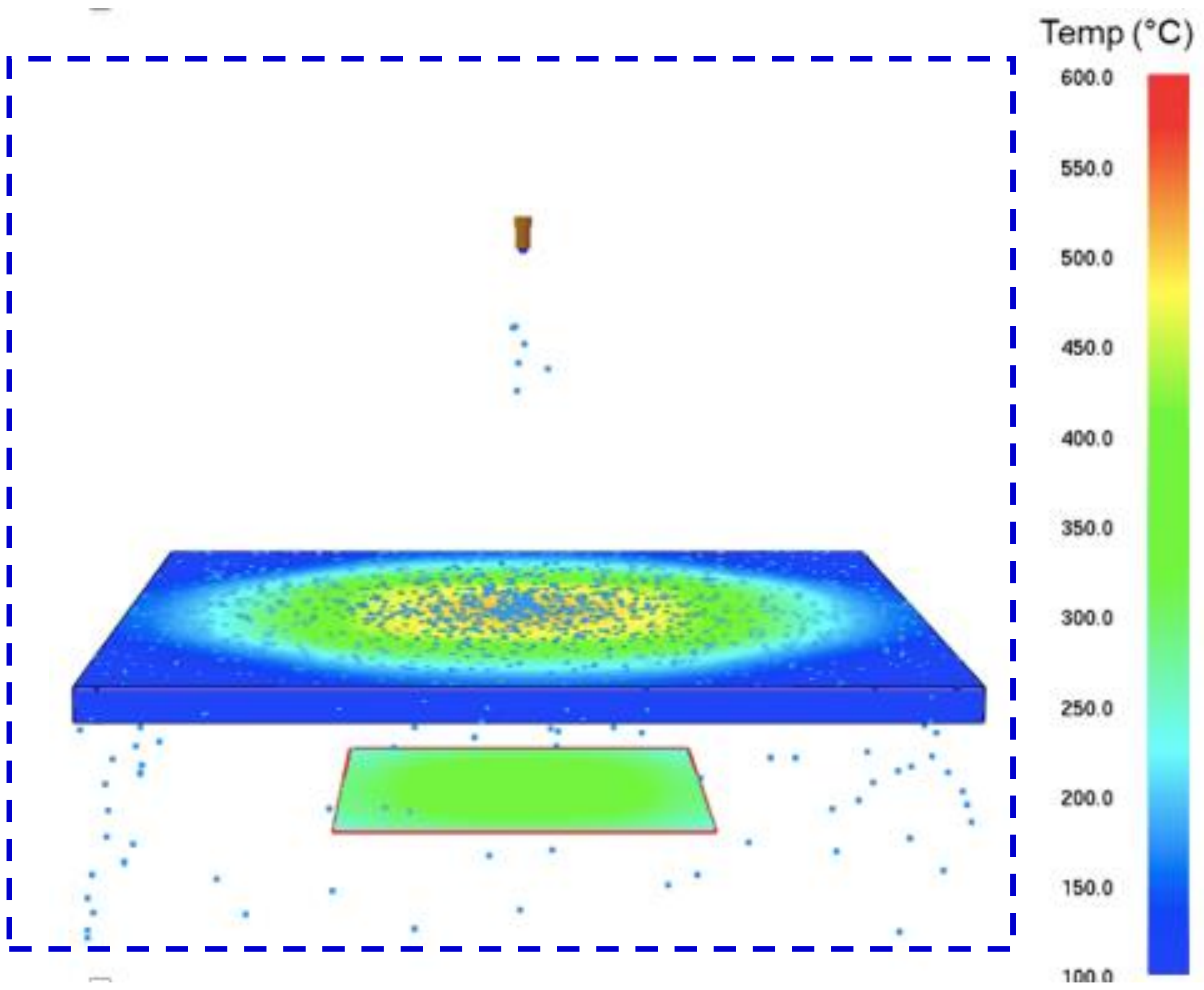
GENERAL CONFIGURATION

- Computational domain: 1.2 m × 1.2 m × 1.2 m
- ‘OPEN’ boundary condition at the sides (----)



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HEATING

- Solve 1D Fourier's equation
- Specify the thermal properties of steel (e.g. see table)
- Specify `NET_HEAT_FLUX` at the surface of the radiant panel to obtain the experimental steel temperature prior to cooling

Temperature (°C)	200	300	400	500	600	700
$k\ (W \cdot m^{-1} \cdot K^{-1})$	51.1	44.5	39.1	34.8	31.7	32.2
$c_p (J \cdot kg^{-1} \cdot K^{-1})$	500.3	526.4	554.6	608.9	707.4	851.6

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WATER SURFACE COOLING

- Heat flux due to cooling $\dot{q}_w'' = h_w \left(T_p - T_g \right)$
  - h_w: convective heat transfer coefficient
  - T_p: plate surface temperature
  - T_g: gas temperature

- **Convective heat transfer coefficient (see FDS guides)**

1) Constant, h_w = 300 W/(m^2·K) (former default in FDS), or

2) Correlation

$$h_w = \frac{\mathrm{Nu} \times k_g}{L}$$ where $$\mathrm{Nu} = 0.0296\,\mathrm{Re}^{4/5}\mathrm{Pr}^{1/3}$$

NUMERICAL PARAMETERS

- Sensitivity analysis on the gas phase cell size (10 cm, 5 cm or 2.5 cm): good convergence with **5 cm**.
- Number of radiation angles = **100** (default), no significant difference with 200.
- The default number of computational droplets Np = **5,000** droplets per second suitable.

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RESULTS

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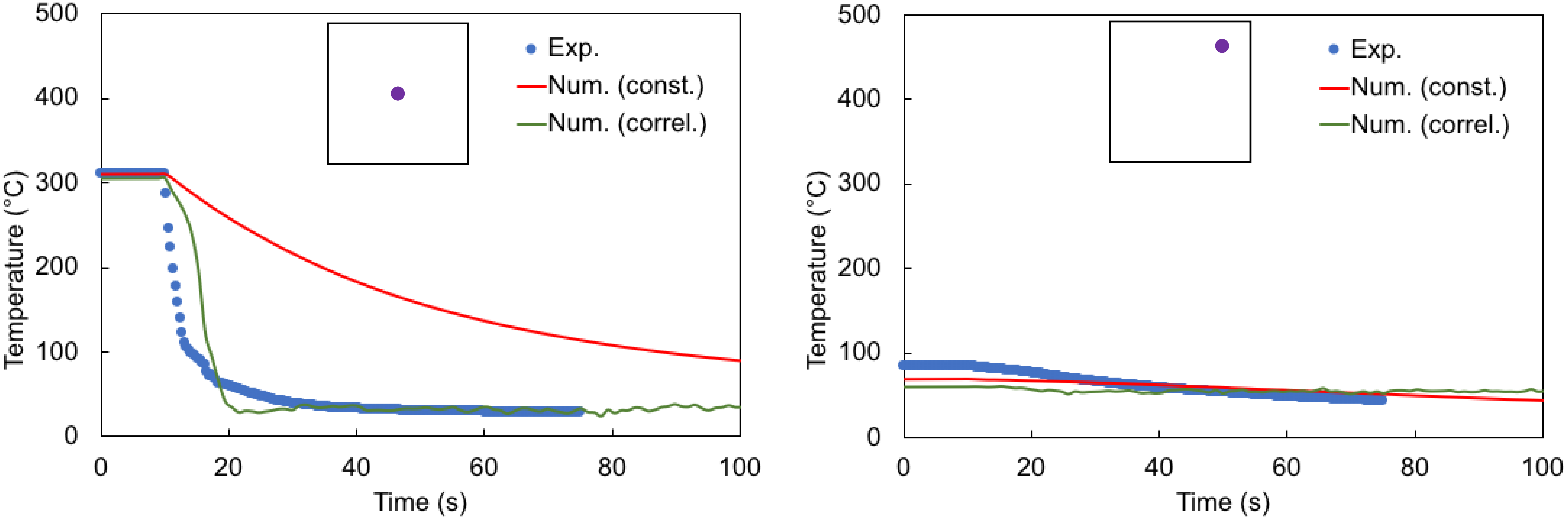
TEST 1

Gas flow rate = 0.25 g/s and Water flow rate = 5 L/min



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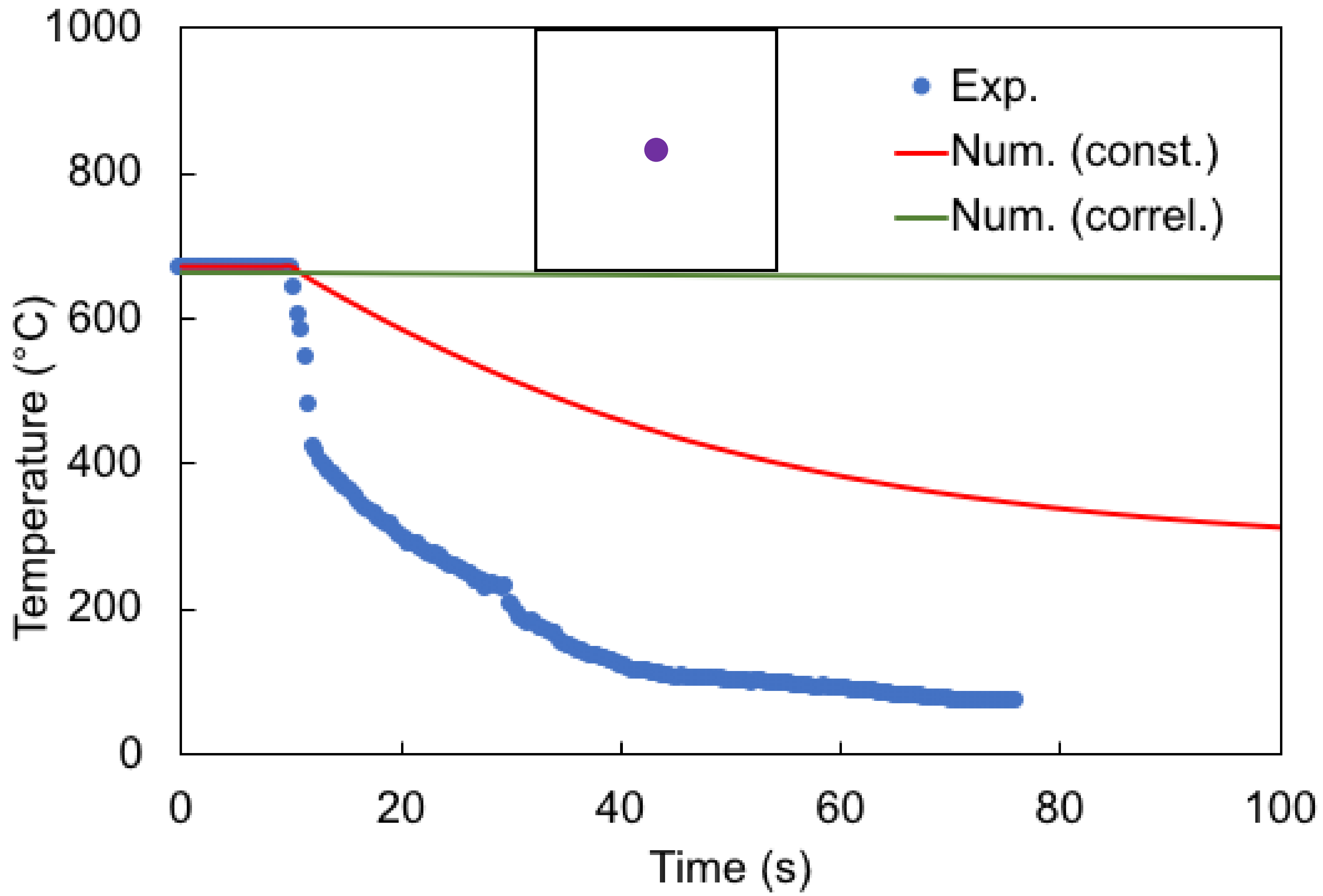
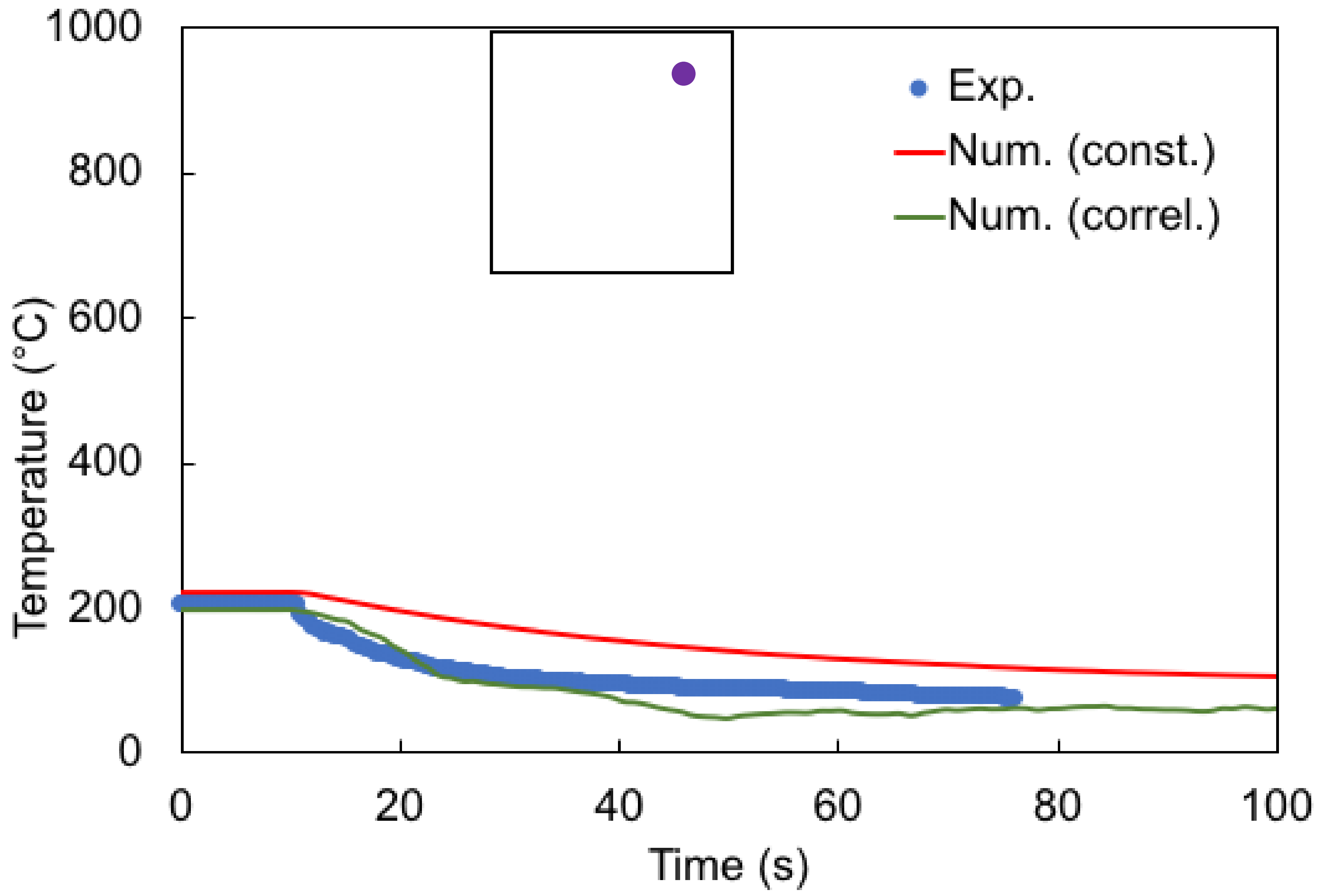
TEST 2

Gas flow rate = 1.40 g/s and Water flow rate = 5 L/min





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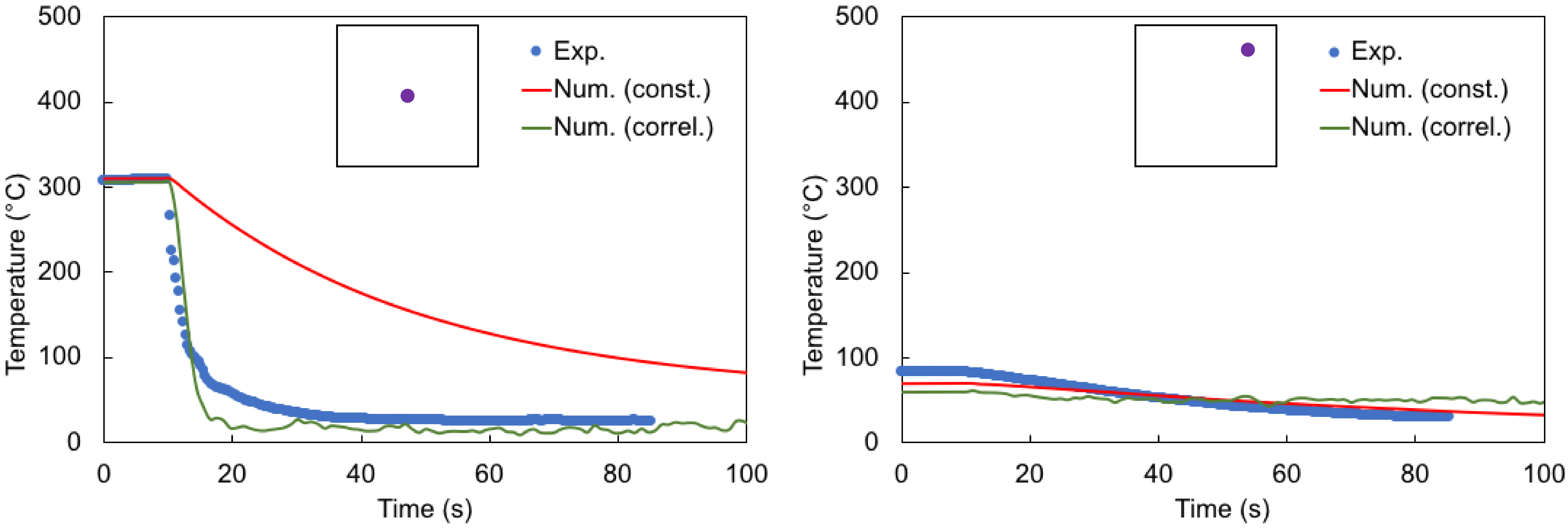
TEST 3

Gas flow rate = 0.25 g/s and Water flow rate = 10 L/min



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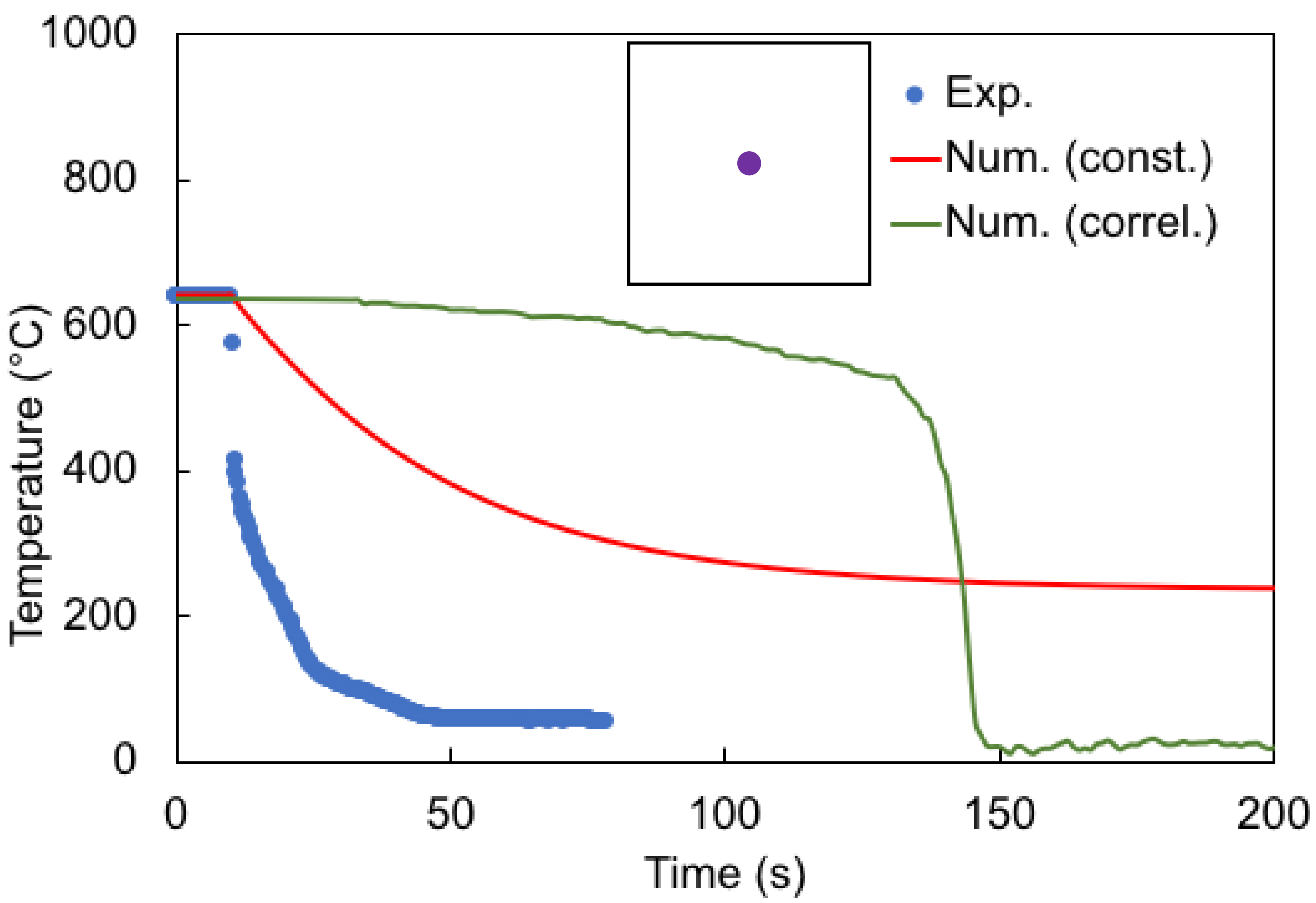
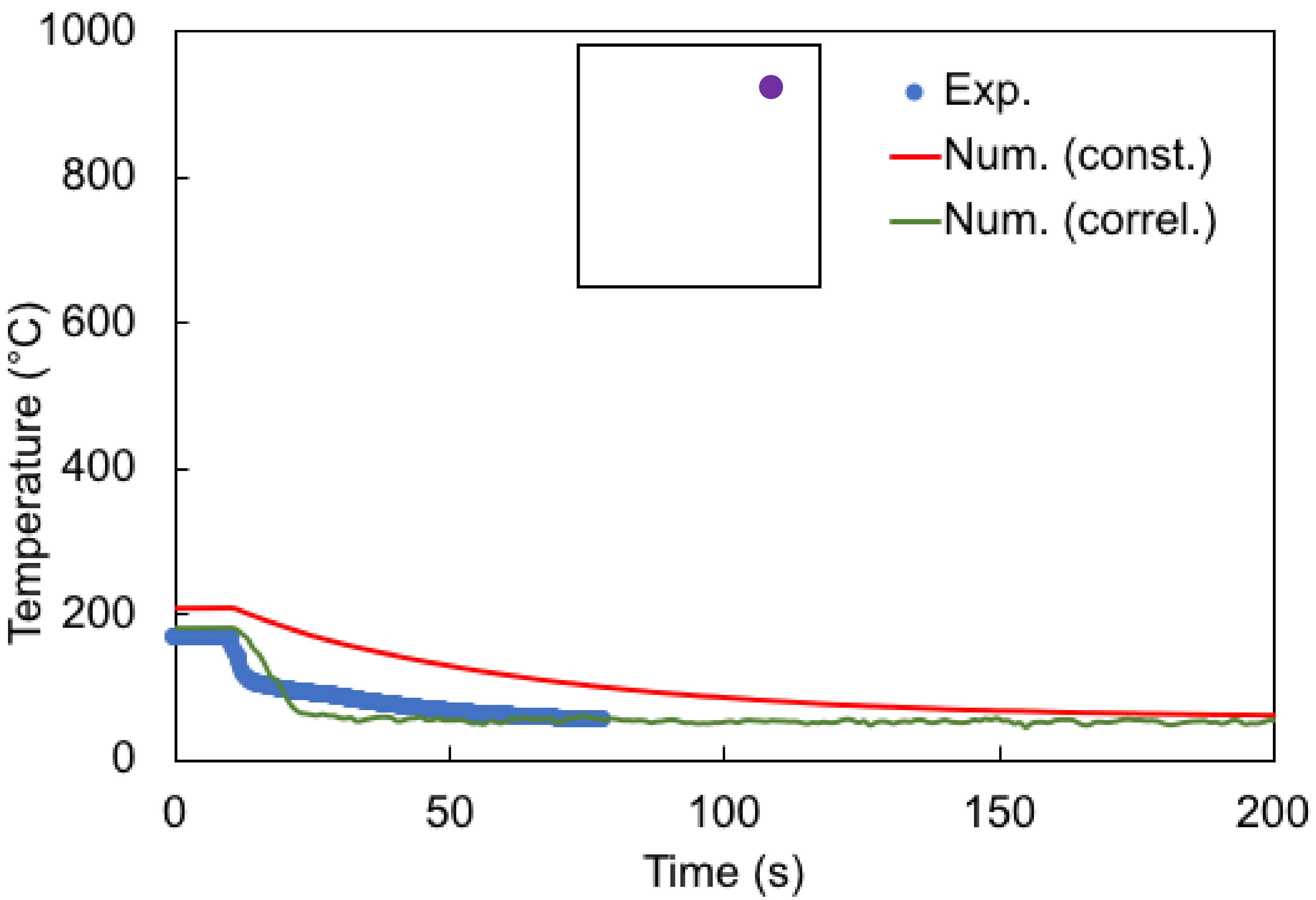
TEST 4

Gas flow rate = 1.00 g/s and Water flow rate = 10 L/min





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CONCLUSIONS AND FUTURE WORK

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CONCLUSIONS

- Good performance of the correlation for steel temperatures of 200 – 300°C.
- Issue with high steel temperatures (above 550°C): → no or delayed cooling.

Current model in FDS:

$$h_s = \max\left(100, 0.0296\,\mathrm{Re}_L^{\frac{4}{5}}\,\mathrm{Pr}^{\frac{1}{3}}\,\frac{k_p}{L}\right) \quad ; \quad \mathrm{Re}_L = \frac{\rho_p \|\mathbf{u}_p\| L}{\mu_p}$$

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FUTURE WORK

- Explore different other available correlations.
- More experimental and validations studies.

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