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Substation malfunction detection indicators to improve the operation of district heating networks

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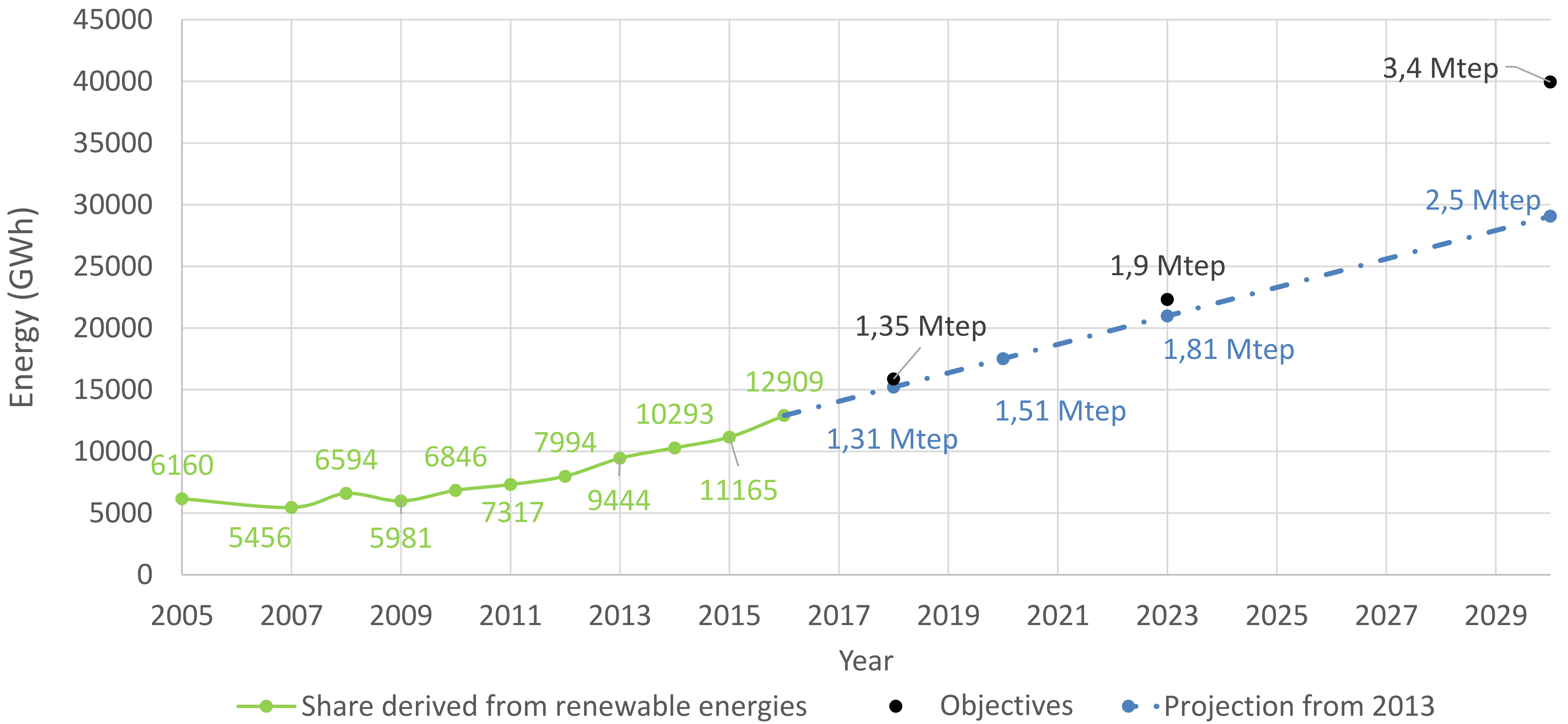
I. Introduction

- EU and France have enacted the development of district heating systems through European Energy Efficiency Directive and French « Energy Transition » law with the following objectives :
  - - 40% CO_2 emissions before 2030
  - - 30% final energy before 2030
  - - 30% fossil energy before 2030
  - +23% renewable energy before 2030



[Adapted from Cerema, 2016]

I. Introduction

Detection and cause of malfunctions of DH network

- How to improve the DH network performances ?

  → Decrease the return temperature by correcting the malfunctions

- Faults on a DH system are very common : for example among 135 substations of 2 Swedish DH networks only 26% of them worked correctly [Gadd & Werner, 2015]

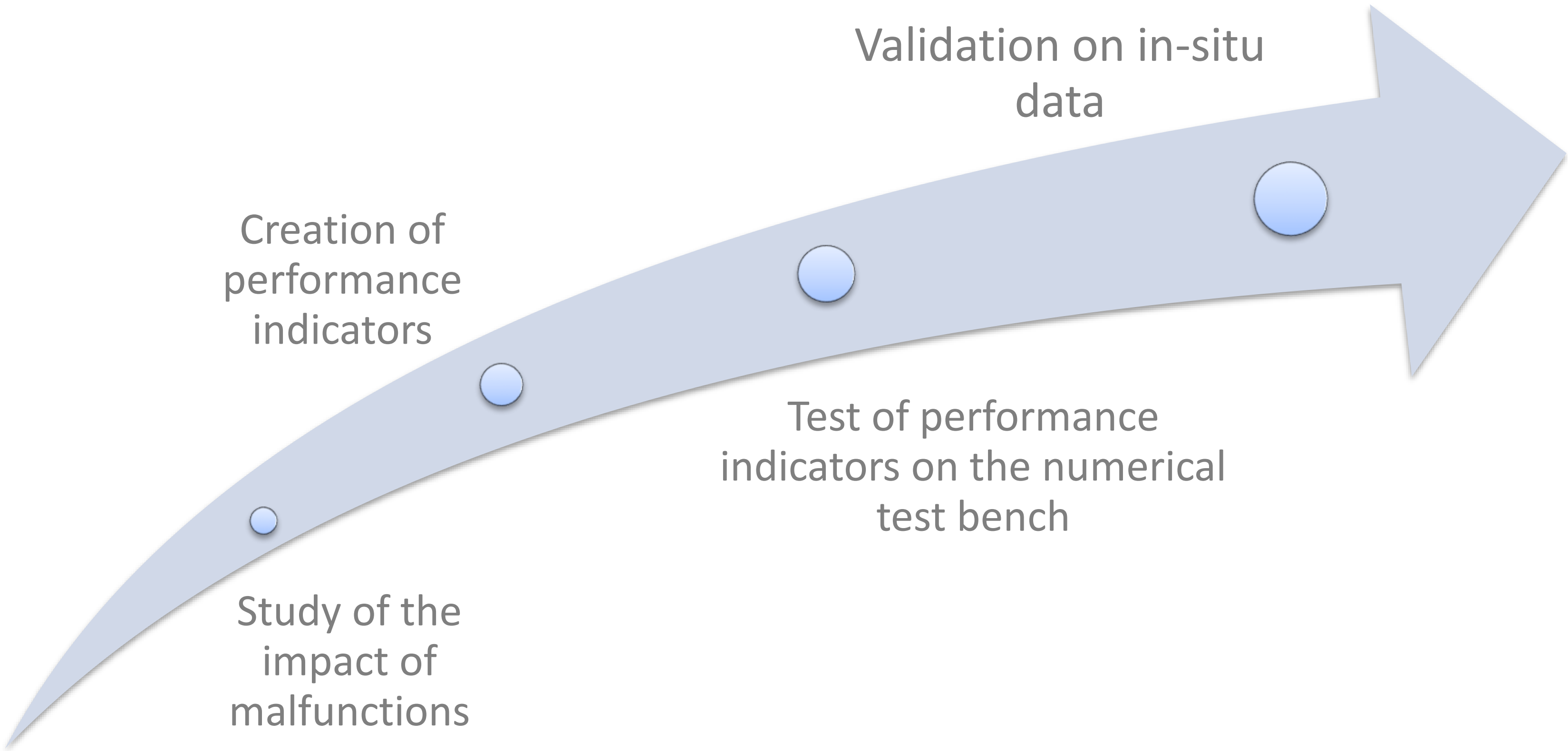
- The origins of malfunctions are numerous, the most usual ones are [IEA Annex VI, 2012]:
  - Damaged or manually adjusted valves
  - Poor substation control (Unsuitable water logic, sensor failure)
  - Unsuitable secondary systems

- Performance indicators have been developed [Zinko & al, 2005], [Gadd & Werner,2014], but none of them are able to detect the origin of the malfunctions

I. Introduction

Objectives and methodology

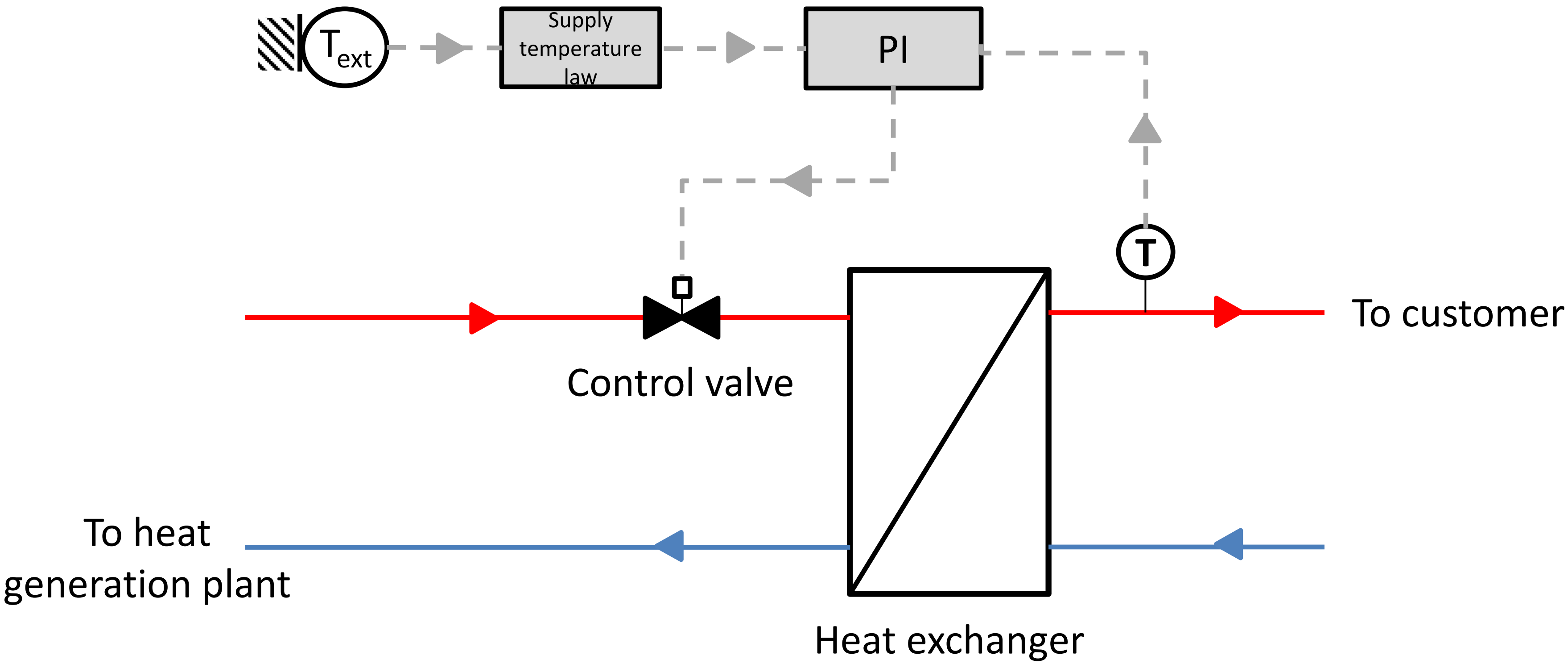
- Develop a DH model including the secondary side
- Assess the impact of usual malfunctions to create performance indicators able to distinguishing each of them



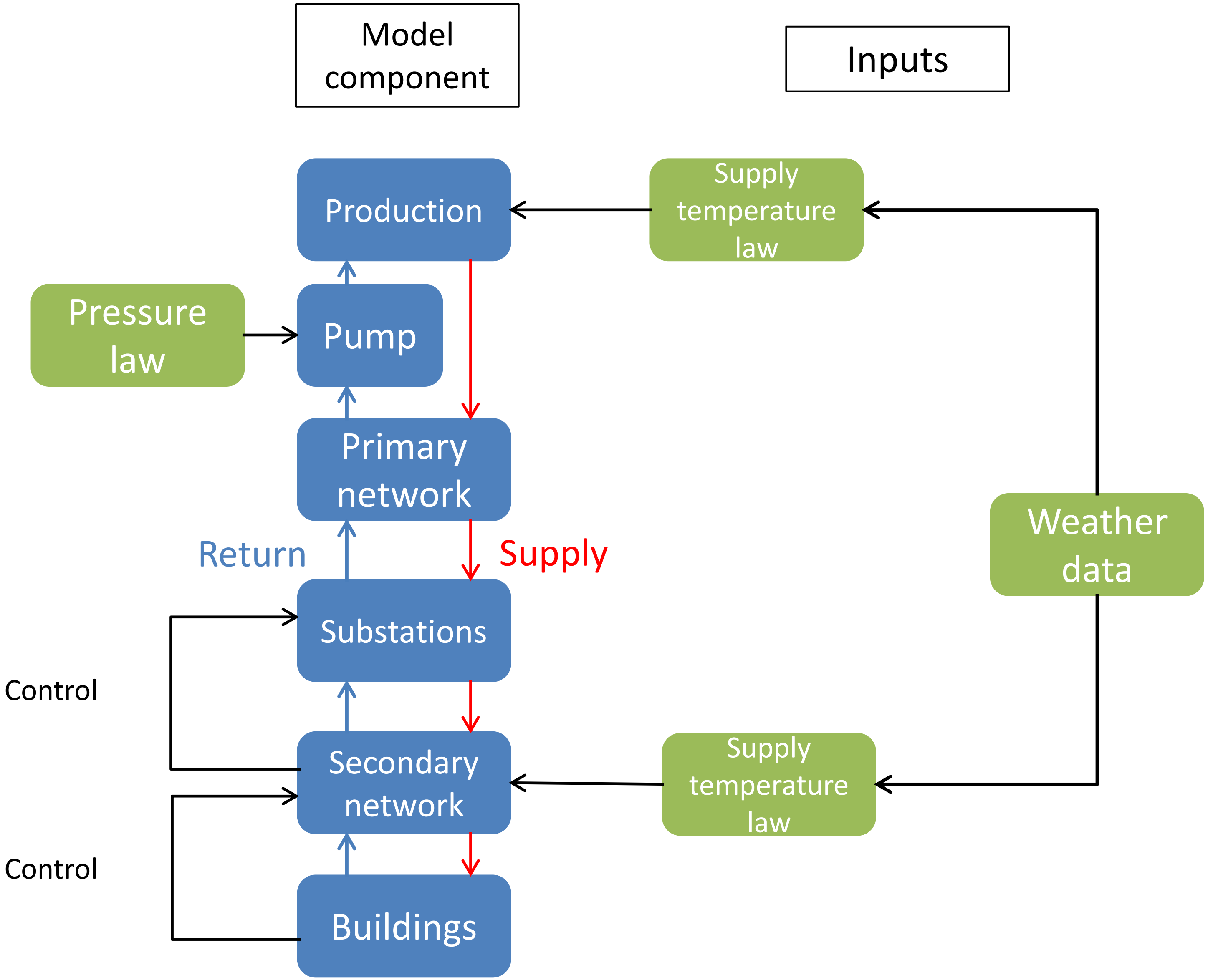
I. Introduction

Specific objectives

- Detection of blocked valves
- Detection of a fouled heat exchanger



II. Methodology: development of a numerical test bench

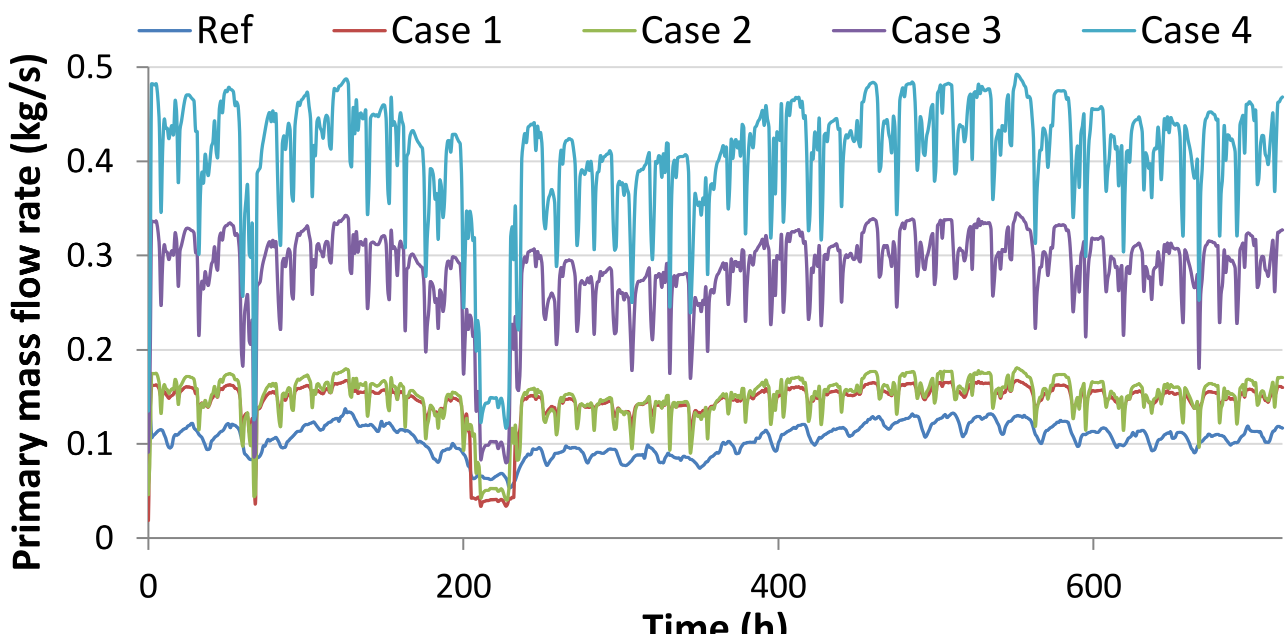


III. Detection of blocked valves

○ Consequence of a blocked valve

	Ref	Case 1	Case 2	Case 3	Case 4
Valve opening (%)	18 (average)	10	25	50	75

- Few substations with blocked valve (10%) impact significantly the performance
- Valve blockage leads to an instability of the flow rate

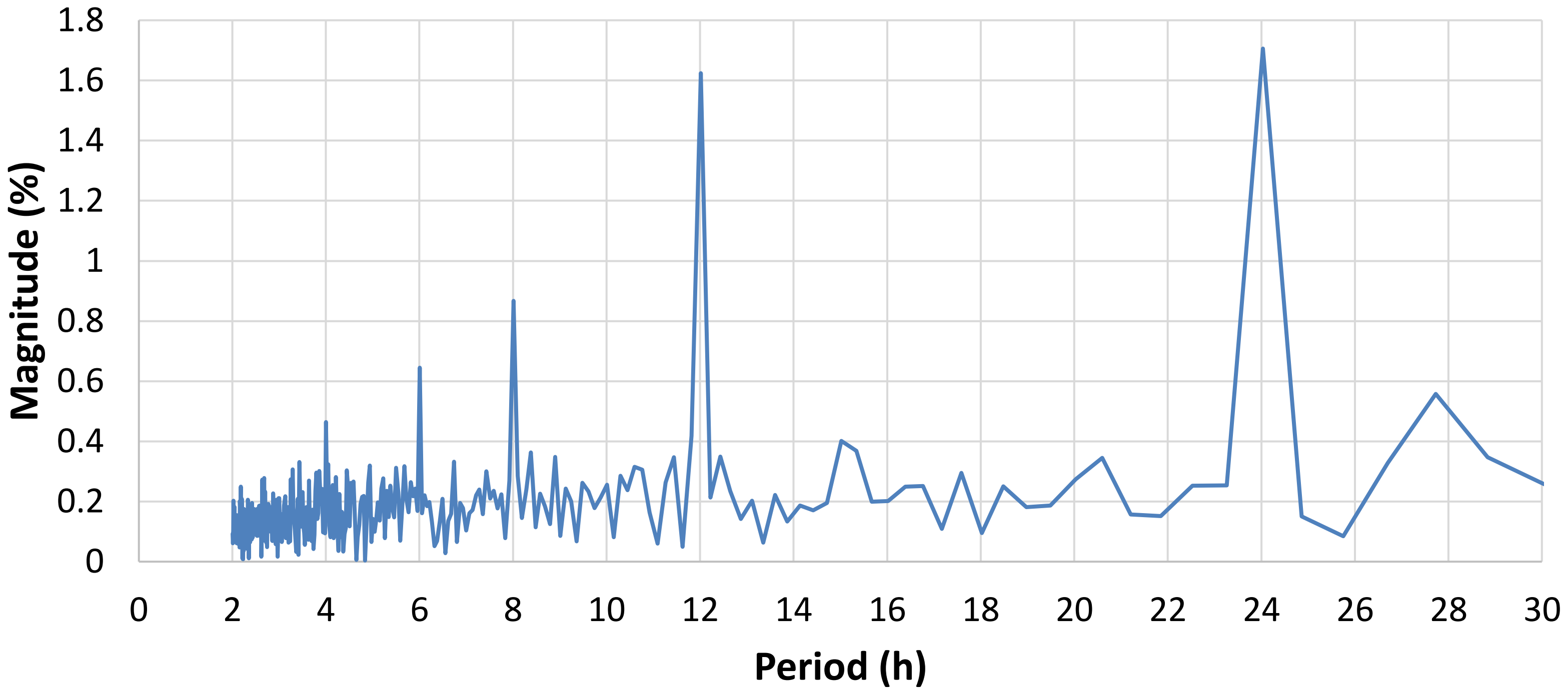


III. Detection of blocked valves

Frequency signal analysis for a non blocked valve

- The instability can be quantified through the relative mass flow rate variation:

$$D_m = \frac{\dot{m}_{t+\Delta t} - \dot{m}_t}{\dot{m}_{t+\Delta t}}$$



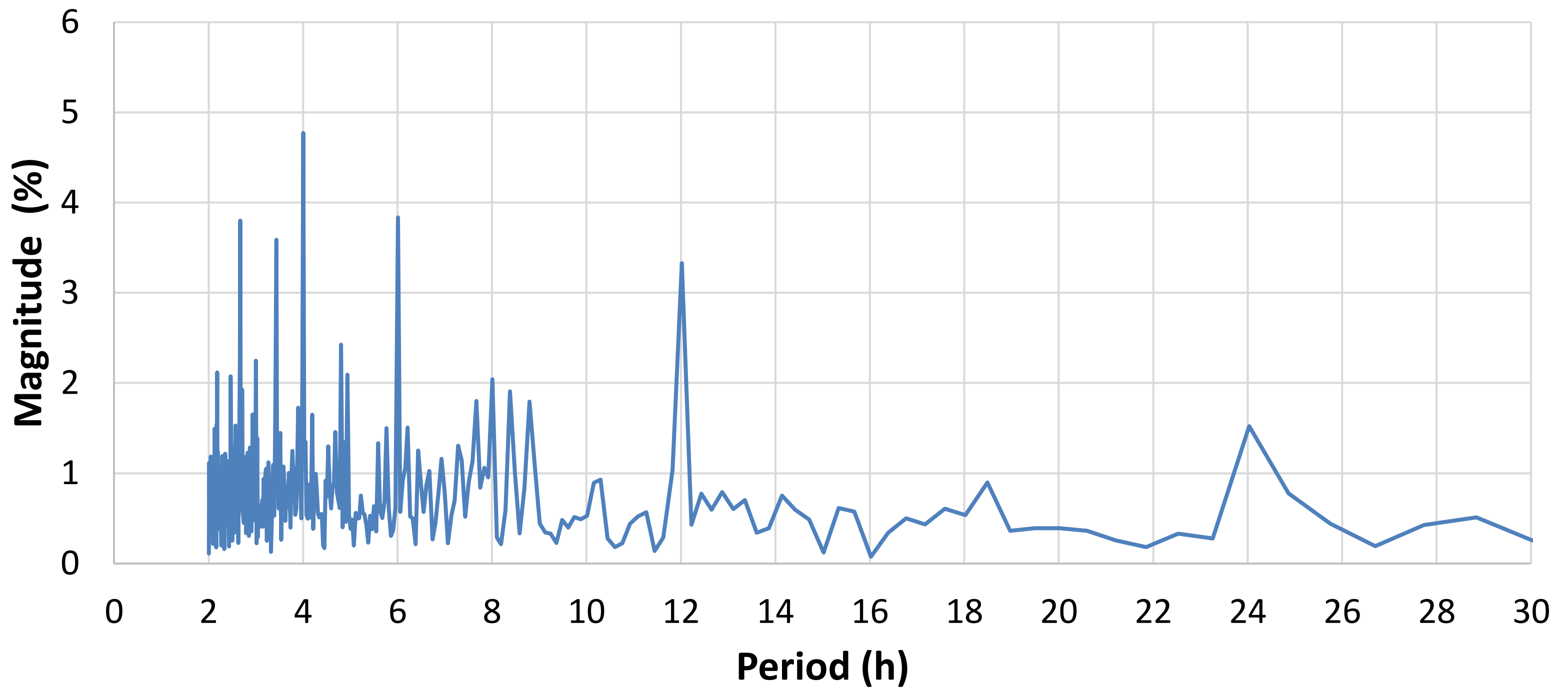
- Without valve issues, the biggest variations appear every 24h, 12h and 8h, so less than 4 times a day

III. Detection of blocked valves

Frequency signal analysis for a blocked valve

- The instability can be quantified through the relative mass flow rate variation:

$$D_m = \frac{\dot{m}_{t+\Delta t} - \dot{m}_t}{\dot{m}_{t+\Delta t}}$$

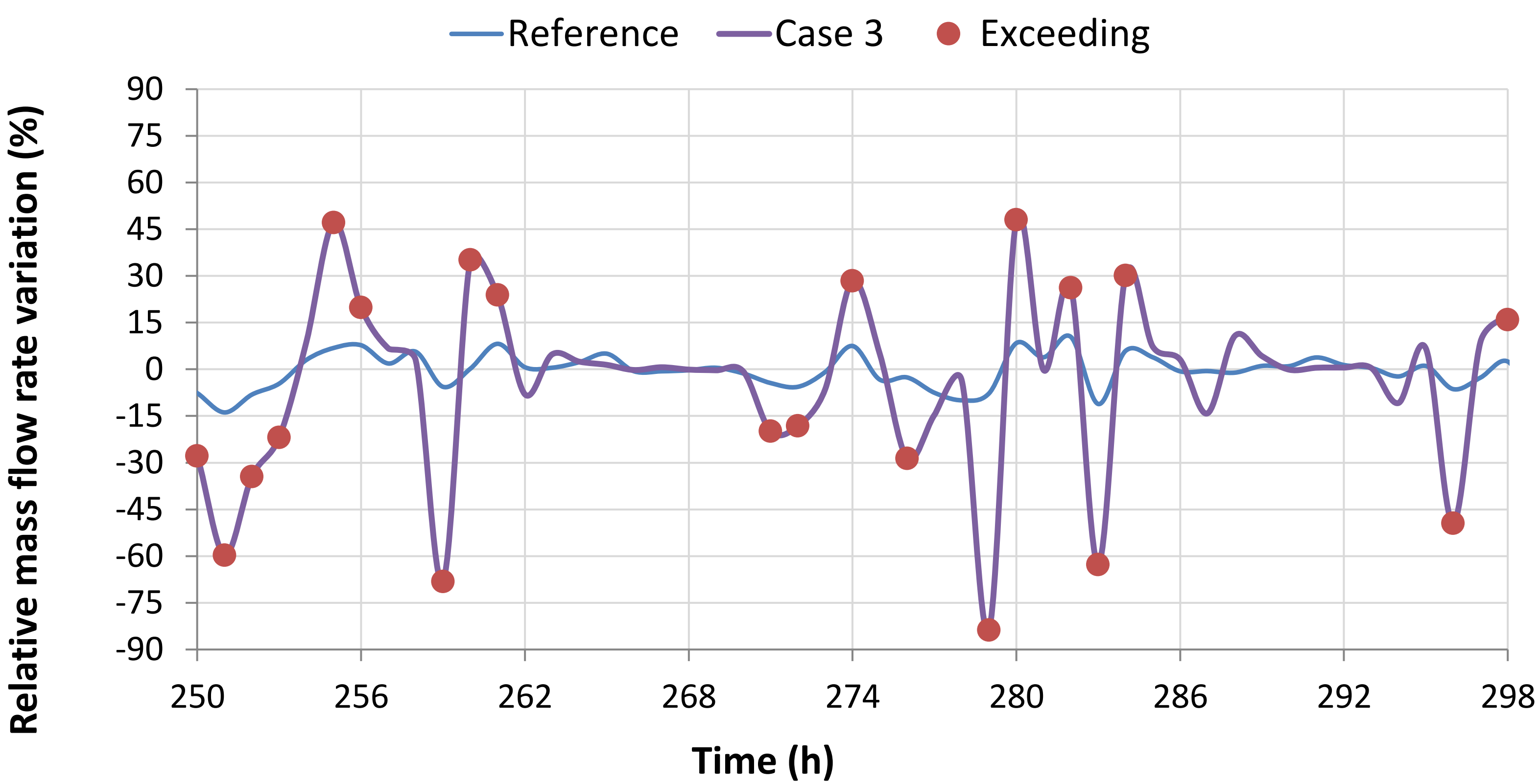


- With a valve blockage the biggest variations appear for periods inferior to 6h, so more than 4 times a day

III. Detection of blocked valves

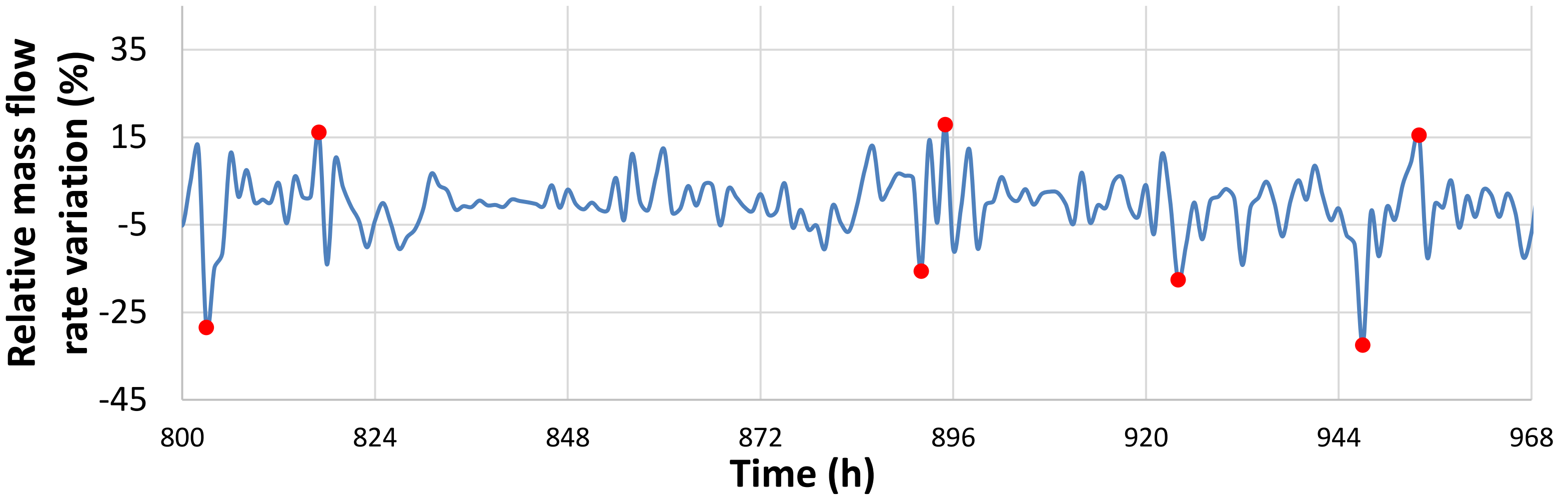
○ Numerical test

If $|D_m| > 15\%$ more than 4 times a day → Regulation issue

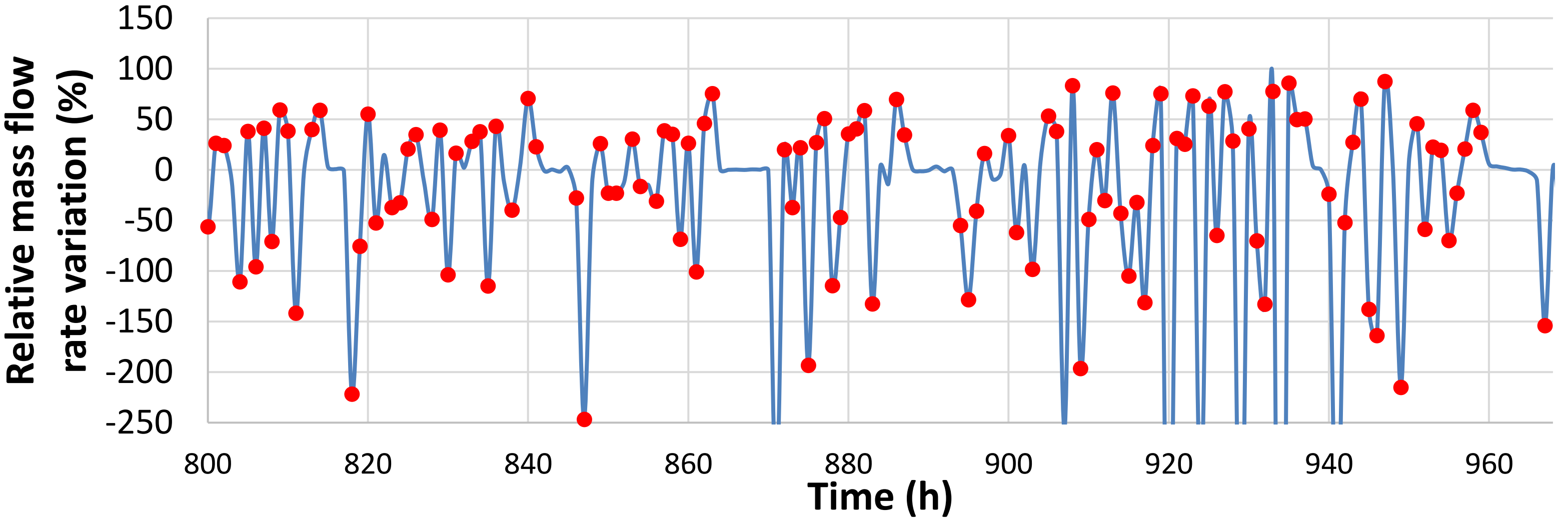


III. Detection of blocked valves

- Validation on in-situ data
  - Substation X with no specific malfunction



  - Substation Y with unsuitable regulation



IV. Detection of fouled heat exchanger

Consequences on thermal resistance

- Few substations with fouled heat exchanger (10%) impact significantly the performance
- Fouled heat exchanger leads to an increase of heat exchanger's thermal resistance
- The thermal resistance without fouling of an plate heat exchanger in counterflow only depends on mass flow rate (Dittus-Boetler)

$$R_{glob} = \gamma \frac{\dot{m}_p^{0,8} + \dot{m}_s^{0,8}}{\dot{m}_p^{0,8} \cdot \dot{m}_s^{0,8}} = \gamma \dot{M}$$

- The total thermal resistance including a fouling resistance (R_f) is :

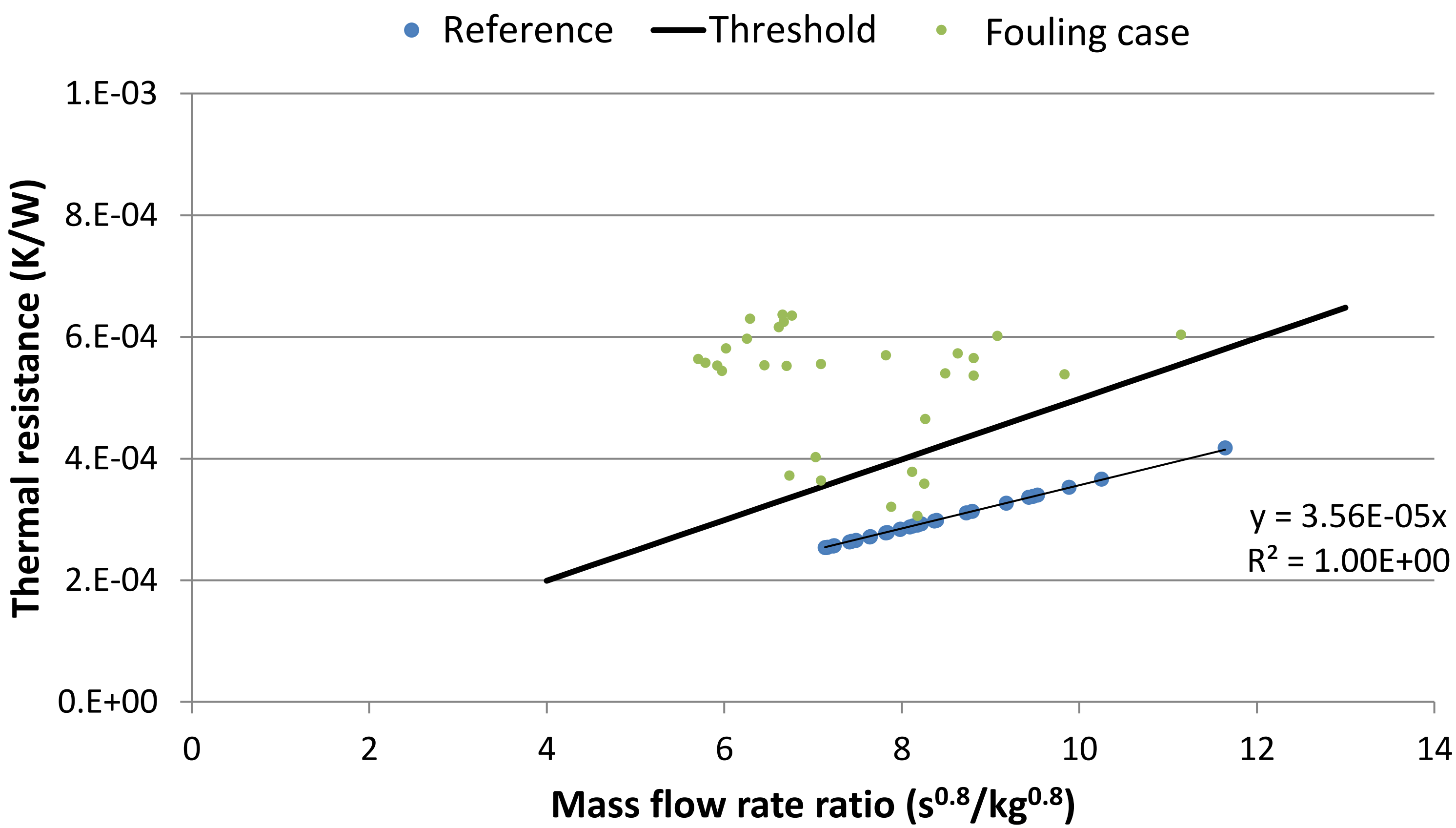
$$R_{tot} = R_{glob} + R_f$$

- The fouling downgrades significantly the return temperature when :

$$R_{tot} > 1{,}4\ R_{glob}$$

IV. Detection of fouled heat exchanger

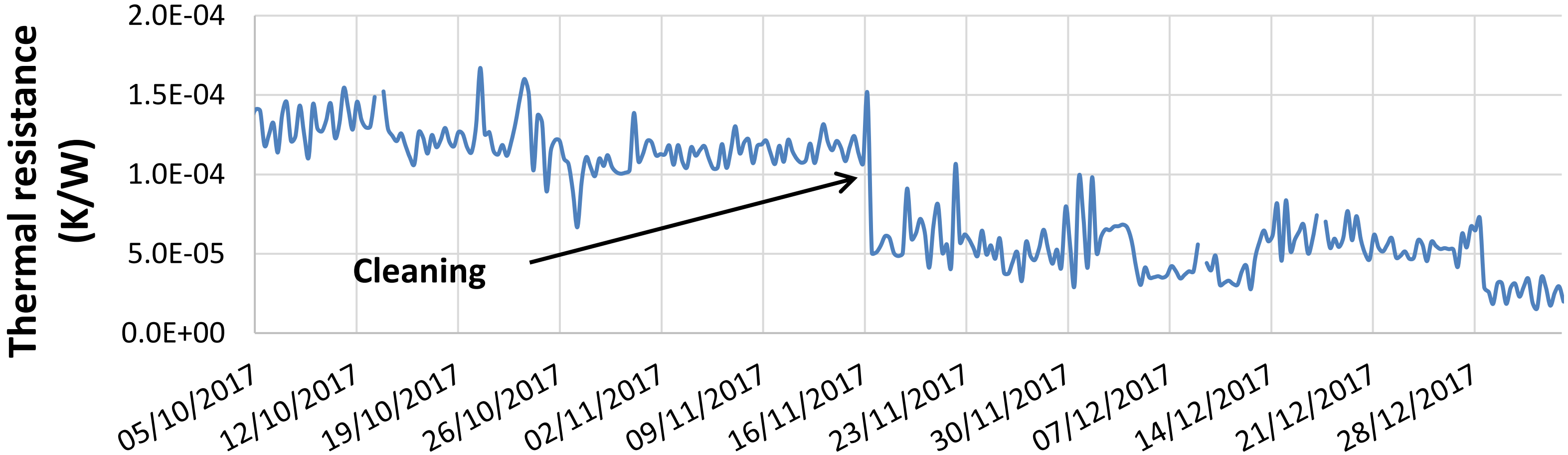
Numerical test

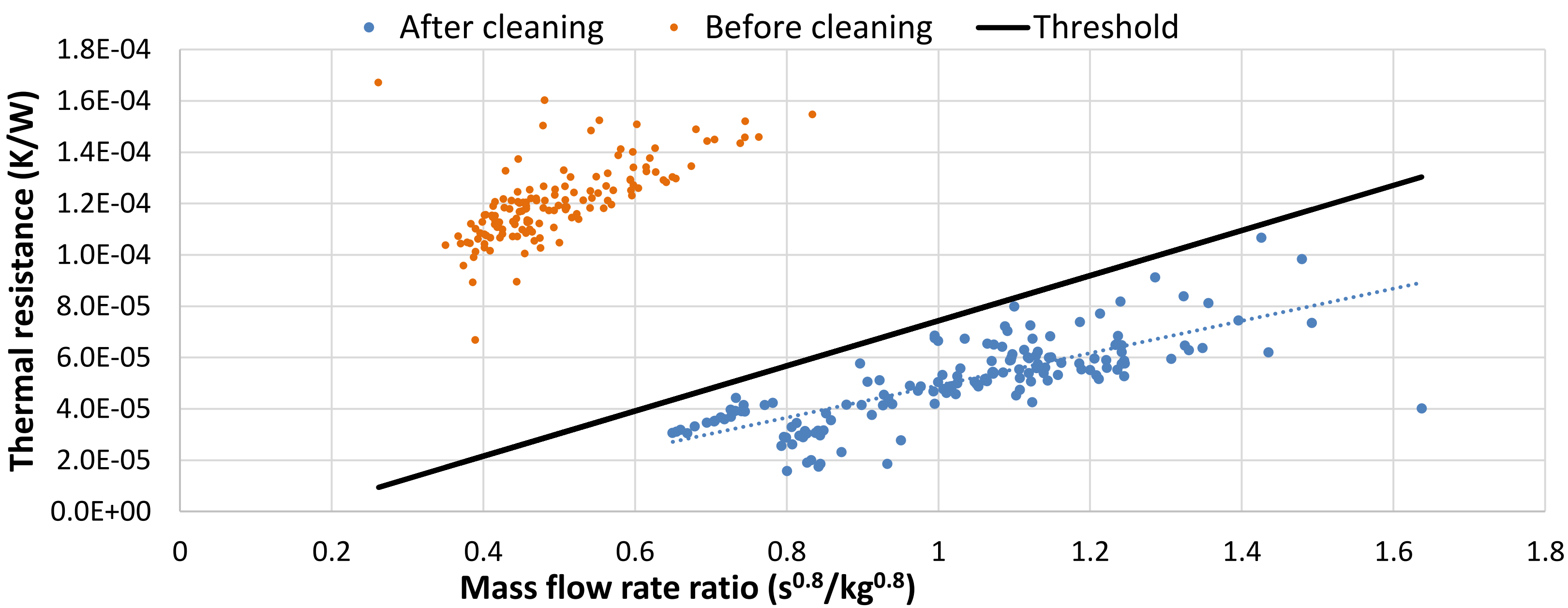


- Without fouling the evolution of thermal resistance is linear as expected
- An important fouling is detected

IV. Detection of fouled heat exchanger

- Validation on in-situ data





V. Conclusion

- A DH system model including the operation of secondary side has been developed

- 2 possible malfunctions have been tested:
  - Blocked valve
  - Fouled heat exchanger

- 2 specific indicators have been developed and validated:
  - The instability of mass flow rate at the primary side
  - The increase of the thermal resistance corrected from mass flow rates

- Other malfunctions must be studied such as unsuitable secondary side, defecting temperature sensor, …