Genetic Algorithm for Pollutant Emission Minimization in Coal Power Plants

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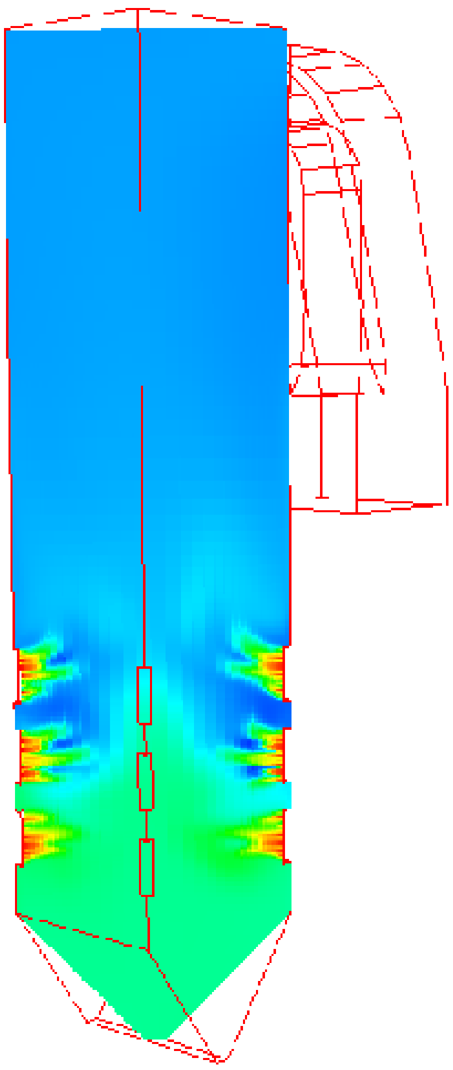
Plan

1. Pulverized Coal Boilers
2. Use of Genetic Algorithm
3. Some results
4. Conclusion

Pulverized Coal Boilers

- In France, coal power plants produce about 4% of global electricity production
  - Flexible production essential to meet peak demand
- The boiler is the location where the combustion takes place
- Feeded by six pairs of mills with associated burners
- Two air inlets associated with each burner
- Each pair of burner has a given tilt

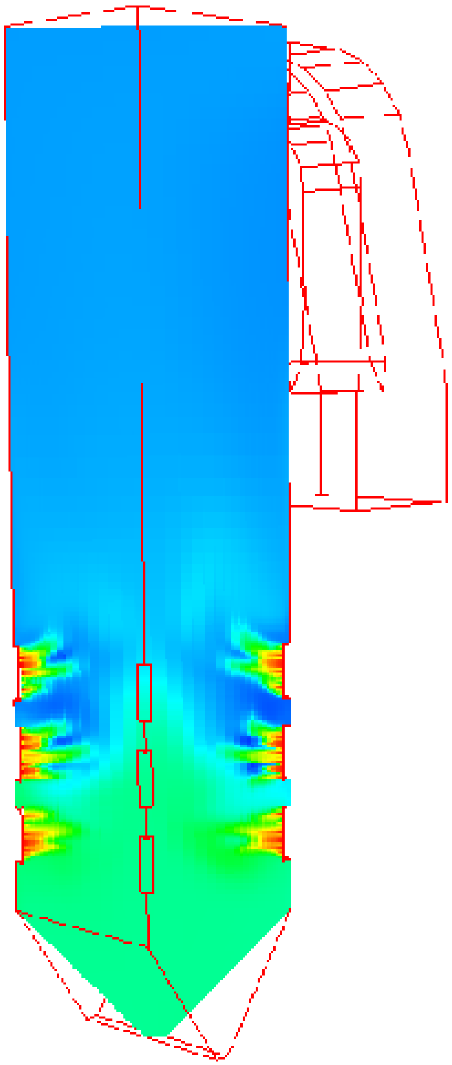


Pulverized Coal Boilers

- Boiler parameters:

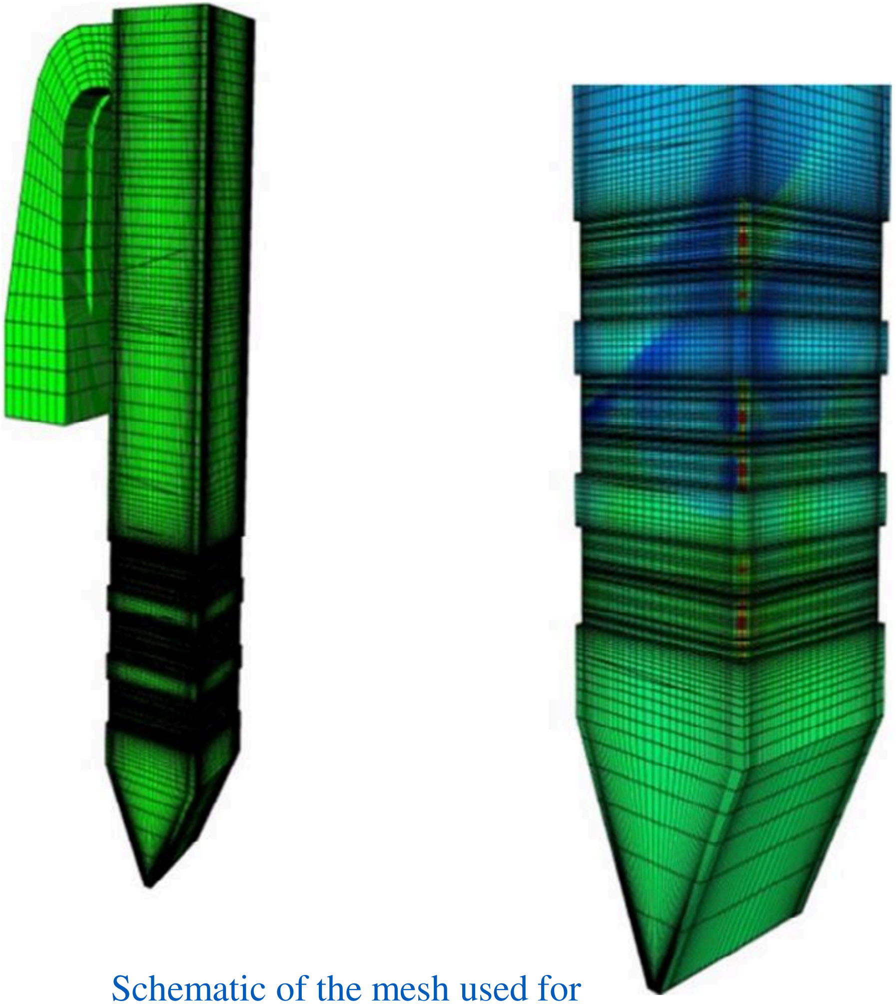
- Imposed
  - Global coal load (216 tons / hour)
  - Coal quality (e.g. low sulphur / low Nox)

- To be adjusted
  - Load distribution on mills and burners
    - At least 4 pairs of burners used out of 6
  - Air staging
    - Open/closed air inlets
  - Tilt angles
    - Ranging from –30° to +30° wrt the horizontal for upper burners
    - Ranging from –15° to +30° wrt the horizontal for middle burners
    - Ranging from 0° to +30° wrt the horizontal for lower burners



Pulverized Coal Boilers

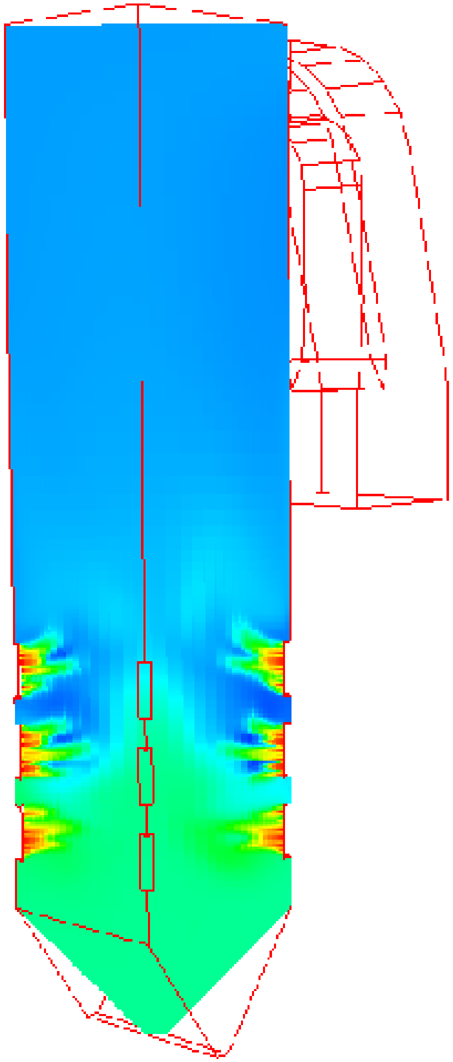
- How to assess a configuration setting ?
- Use of a fluid dynamics software developped at EDF R&D : Code_Saturne®
  - Finite volume code
  - Boiler modelled by a mesh made up of half a million octahedra



Schematic of the mesh used for CFD simulations

Pulverized Coal Boilers

- How to assess a configuration setting ?
- Use of a fluid dynamics software developped at EDF R&D : Code_Saturne®
  - Finite volume code
  - Boiler modelled by a mesh made up of half a million octahedra
  - Running time : about 12 hours on a 8-core computer (shared memory parallelization)
  - Computes chemical compositions and physical characteristics
    - O_2 rate (percentage)
    - CO rate (percentage)
    - NOx production (mg/Nm^3)
    - Unburnt carbon (percentage of ashes)
    - Inner area prone to corrosion (m^2)
    - Thermal flux homogeneity (ratio)



Optimization goal

- Finding innovative boiler settings to :

  - Minimize pollutant emission
    - NOx
    - CO
    - ashes
  - Maximize boiler lifespan
    - Corrosion
    - O_2
    - Thermal flux

  - Combined in a single function, sum of non-linear costs associated to each output characteristic
    - Typically, the cost is
      - 0 if inside a tolerance interval around the nominal value
      - Constant plus proportional costs otherwise

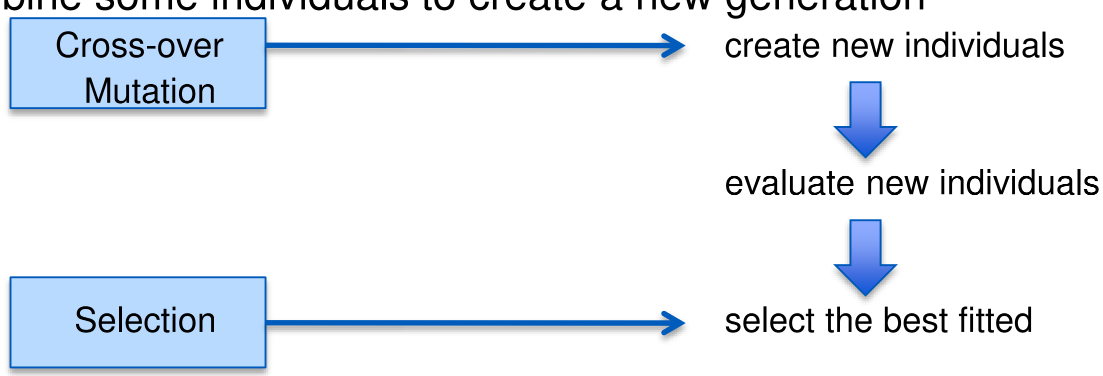
How to optimize ?

Problem difficulties

- Huge search space
- No direct link between inputs and outputs
  - Cannot express direct constraints binding input and output values
  - Combustion is a dynamical process
- Non-linearities
- Evaluating a configuration is expensive in terms of time and memory

use of a Genetic Algorithm

- 1 - Start from an initial population
- 2 - Combine some individuals to create a new generation



- 3 - go to step 2

Genetic Algorithm

- Advantage
  - The evaluation step is clearly separated from the cross-over / mutation / selection processes
  - Allows us to use Code_Saturne® separately from the GA itself

- But…
  - GA efficiency typically relies on :
    - Population size
    - Number of generations

- So…
  - Trade-off between population size and running time needed to evaluate a whole generation
    - Initial population of 52 individuals
    - No population size increase through generations
    - Use of a cluster of several hundred nodes
    - Use of a small database storing already evaluated configurations

Implementing the Genetic Algorithm

- The chromosome
  - 6 real values :
    - 6 Burners loads, at least 4 non-zero
    - Sum equals 216 tons/hour
  - 24 boolean values :
    - opening of 24 air inlets
      - 1 : open
      - 0 : closed
  - 2 integer values :
    - Burners tilts on the 2 diagonals
      - Upper level : -30°, -15°, 0°, 15°, 30°
      - Middle level : -15°, 0°, 15°, 30°
      - Lower level : 0°, 15°, 30°

⇒ Easy to compare 2 configurations

- avoid unnecessary computation
- equality is defined as an ε–approximation for real values

Implementing the Genetic Algorithm

- Use of ParadisEO Library

  - Crossover : a one-gene exchange
    - generated configurations have to be post-processed to fulfill operating constraints (e.g. mandatory opening of some air inlets if associated burners are on)

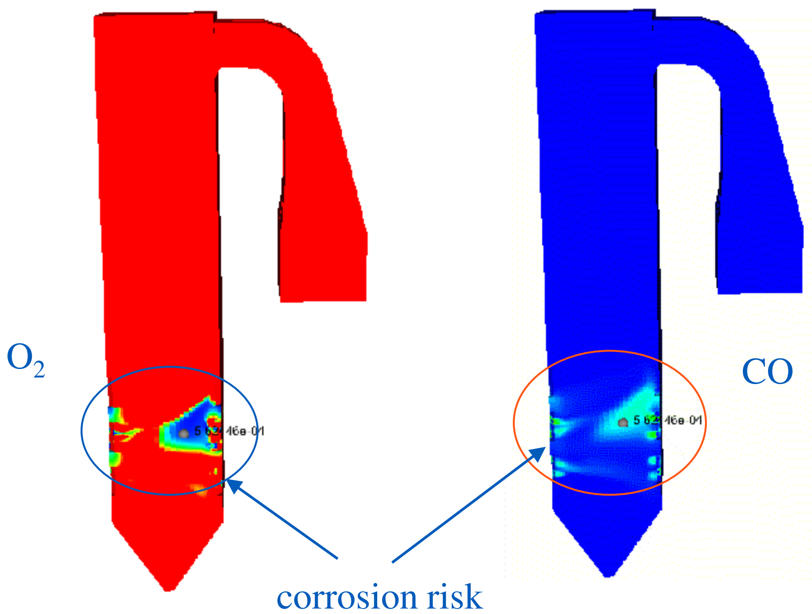
  - Mutation :
    - First select the gene undergoing mutation
    - Second change its value depending of his type
      - Swap for binaries
      - Random assignement for the others

  - Selection
    - EP stochastic tournament

Some results

- About 1300 different configurations generated so far
  - General comment : some optimisation criteria are contradictory (e.g. NOx level and corrosion risk)

A generated configuration :



At the same location lack of O2 and excess of CO higher corrosion risk

But lower temperature and thus lower quantity of NOx produced

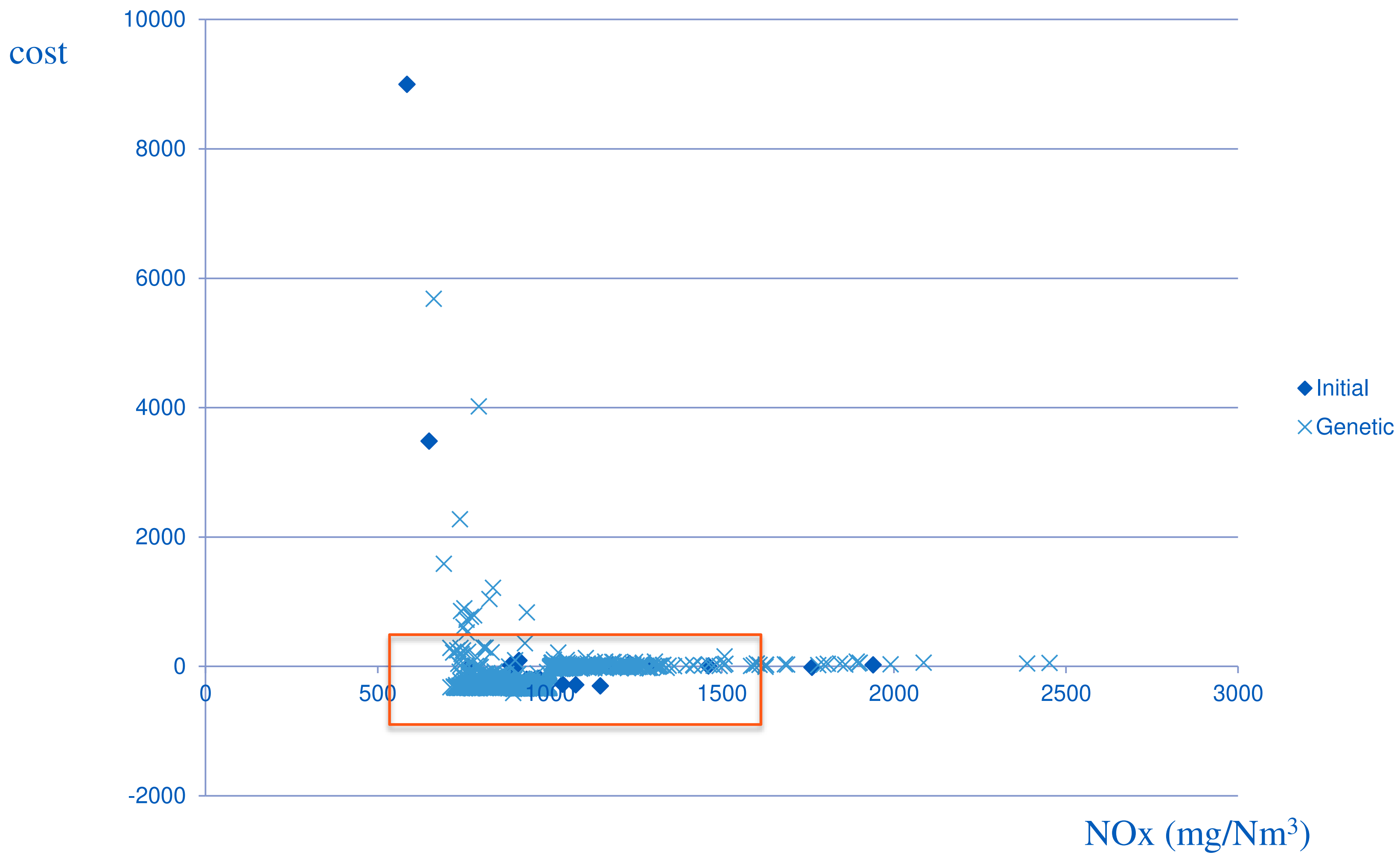
Nevertheless, bad configuration cost because NOx emission gain is overwhelmed by the corrosion risk cost

Some more results

- The automatically generated population
  - How does it compare to initial population
    - NOx emission
    - Unburnt ashes
    - Area at corrosion risk

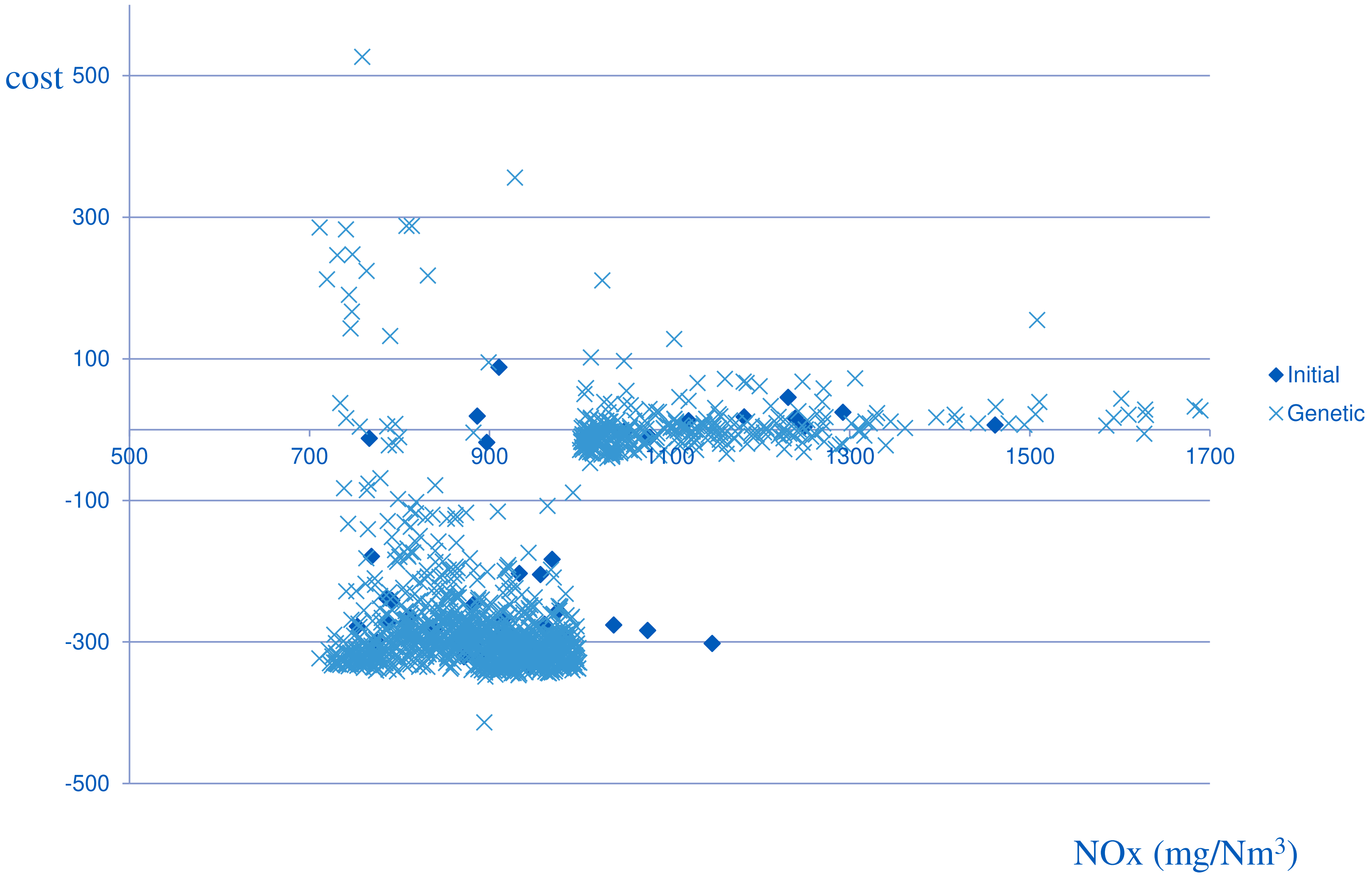
Some more results

- The automatically generated population : NOx emission



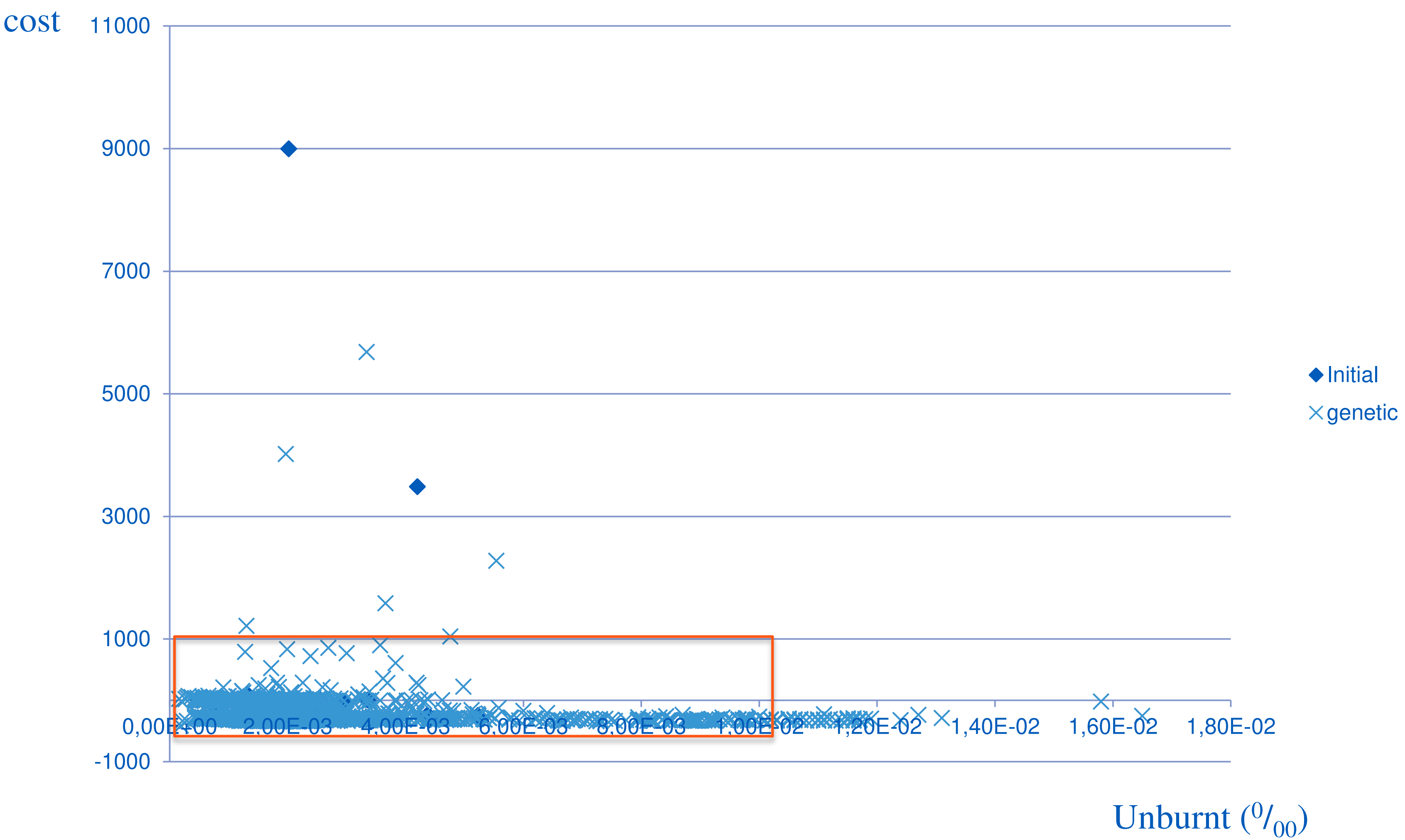
Some more results

- The automatically generated population : NOx emission



Some more results

- The automatically generated population : unburnt ashes



Some more results

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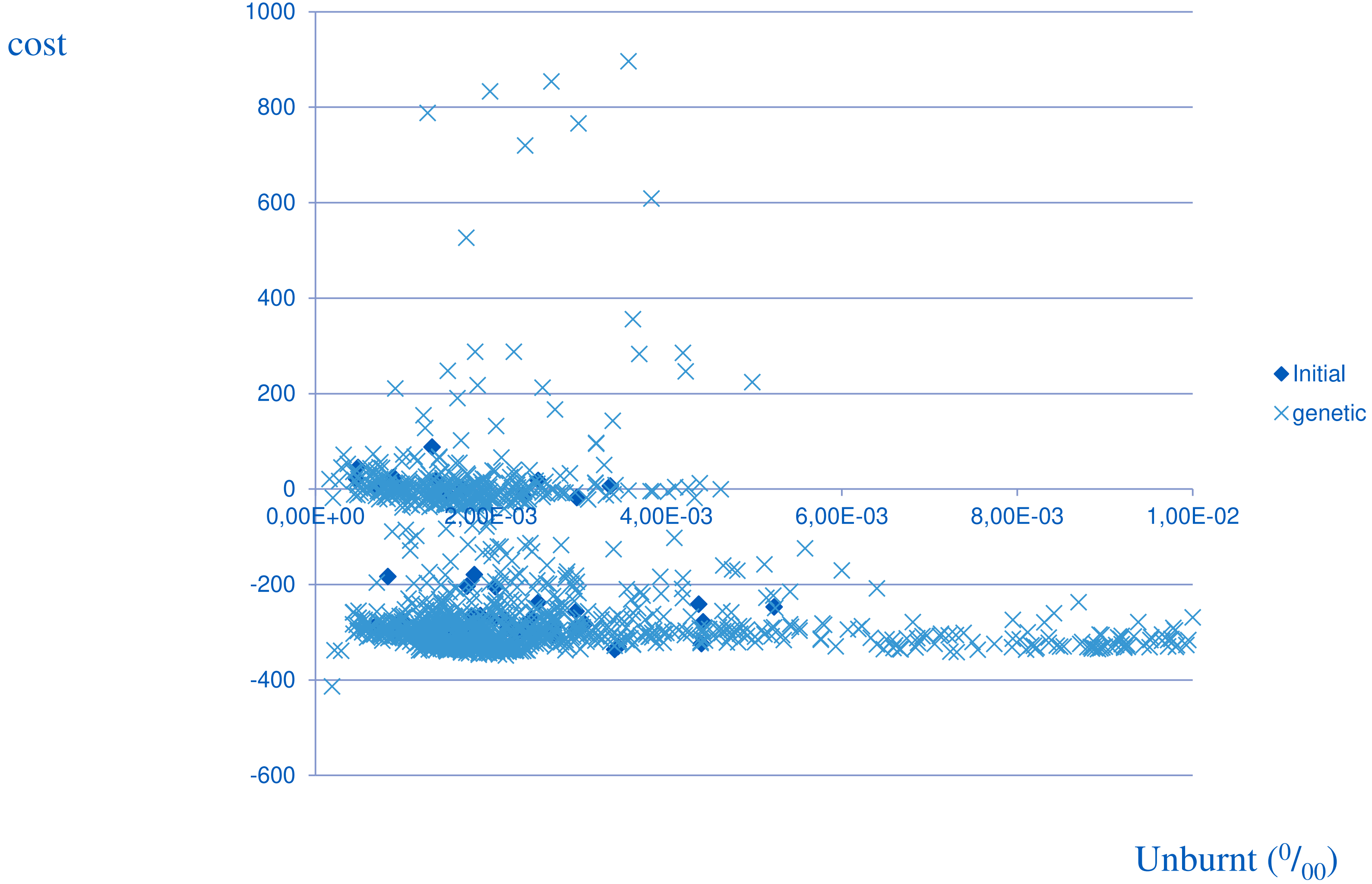
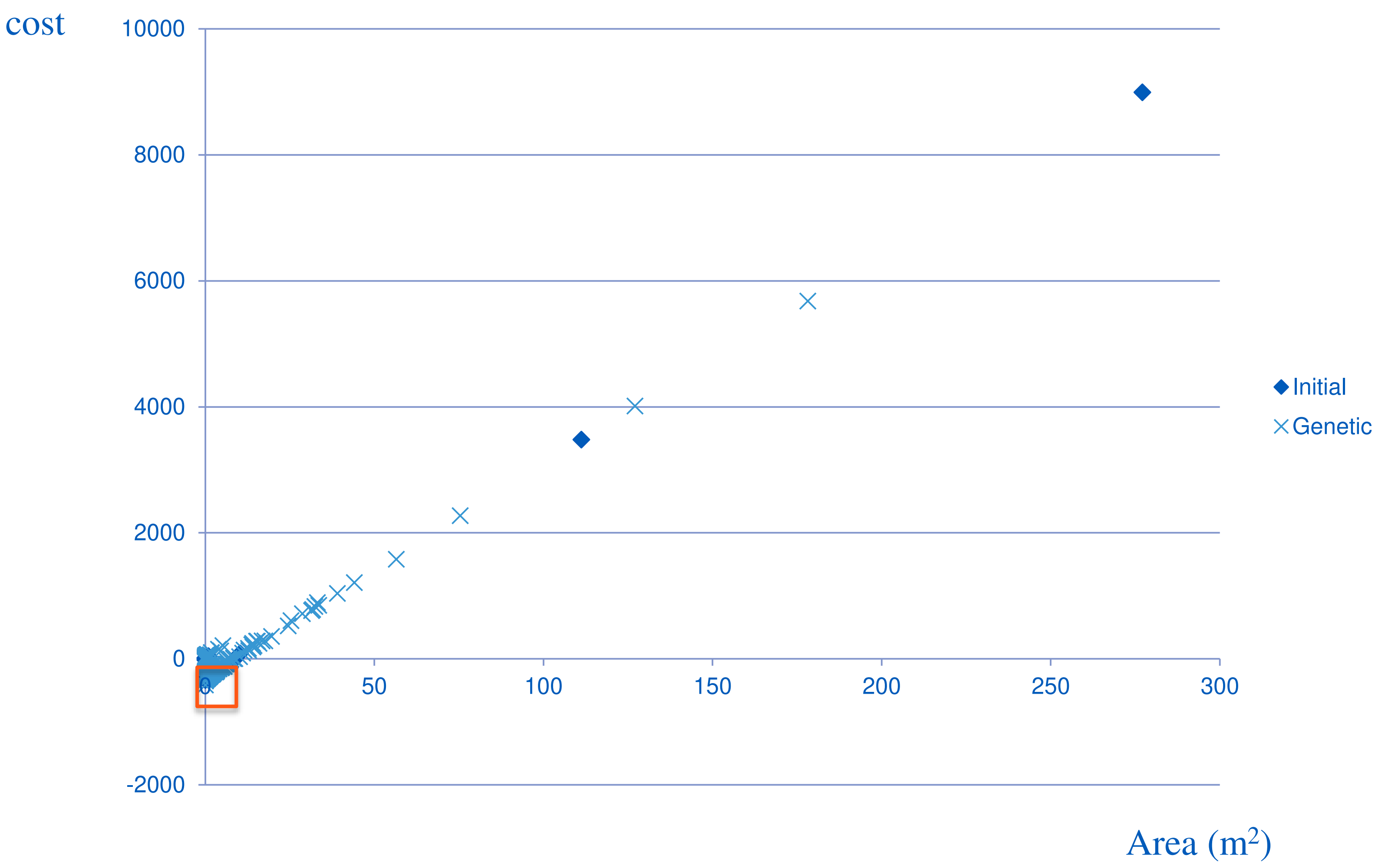


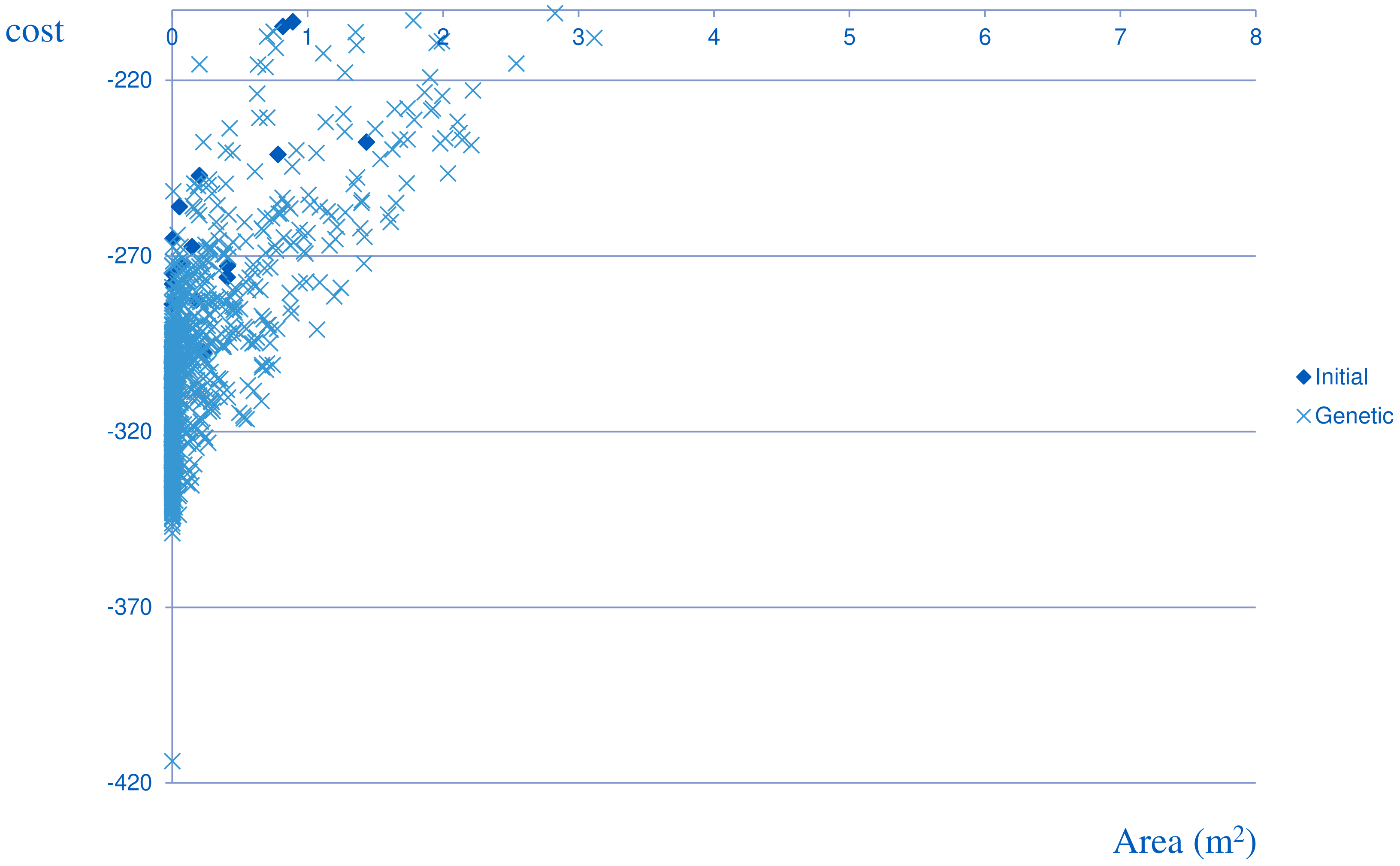
Some more results

- The automatically generated population : corrosion risk



Some more results

- The automatically generated population : corrosion risk

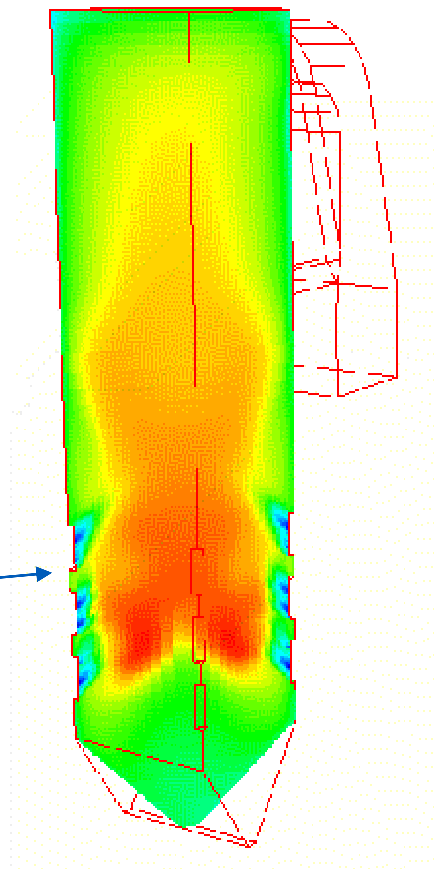


Some results

Reduction of 22% of Nox level
compared to reference case
Unburnt : 1%

An innovative configuration

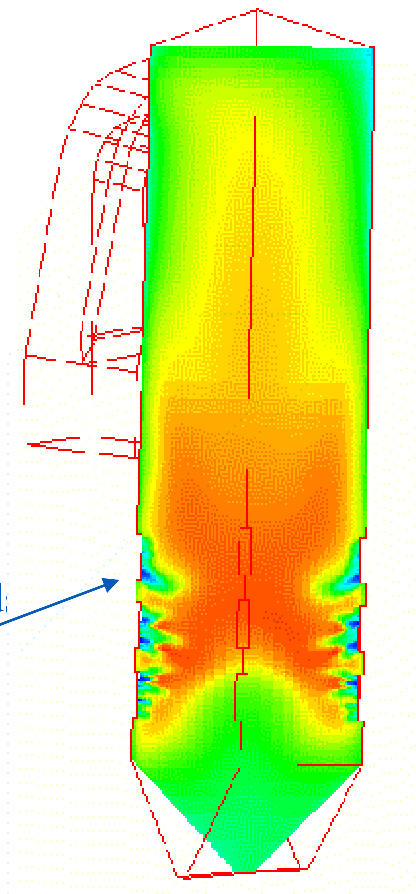
Meets the forthcoming regulation on NOx emission



tilt
30° upwards
Angles 1 & 3

Secondary air
inlets open on
one diagonal

tilt
-30° downwards
Angles 2 & 4



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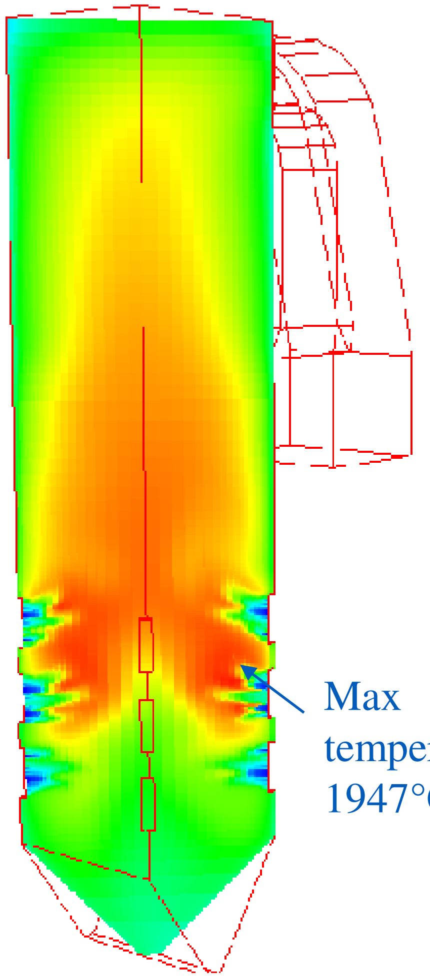
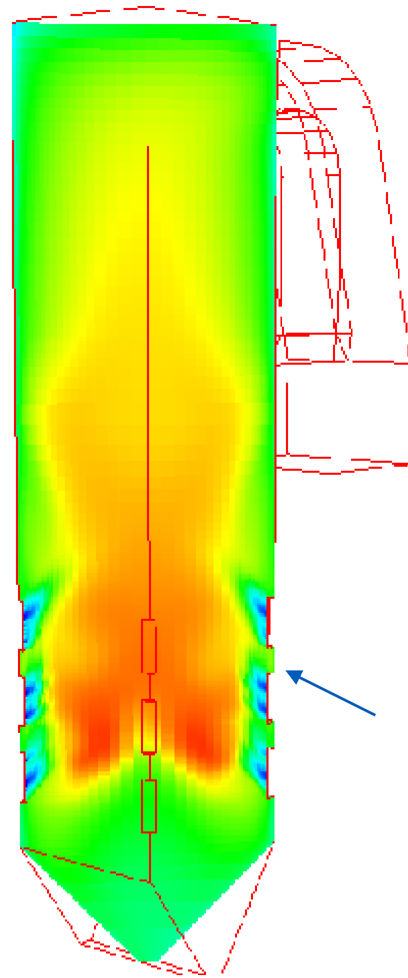
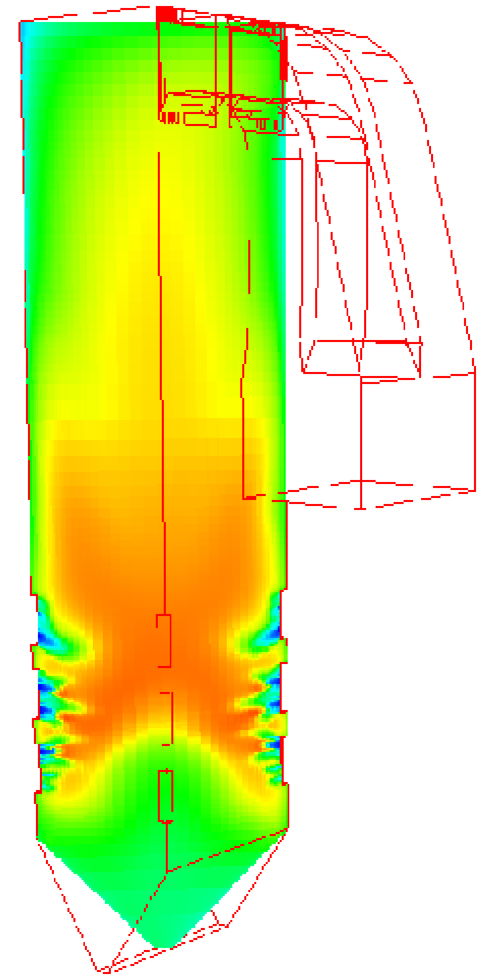


Max
temperature
1947°C

Reference case

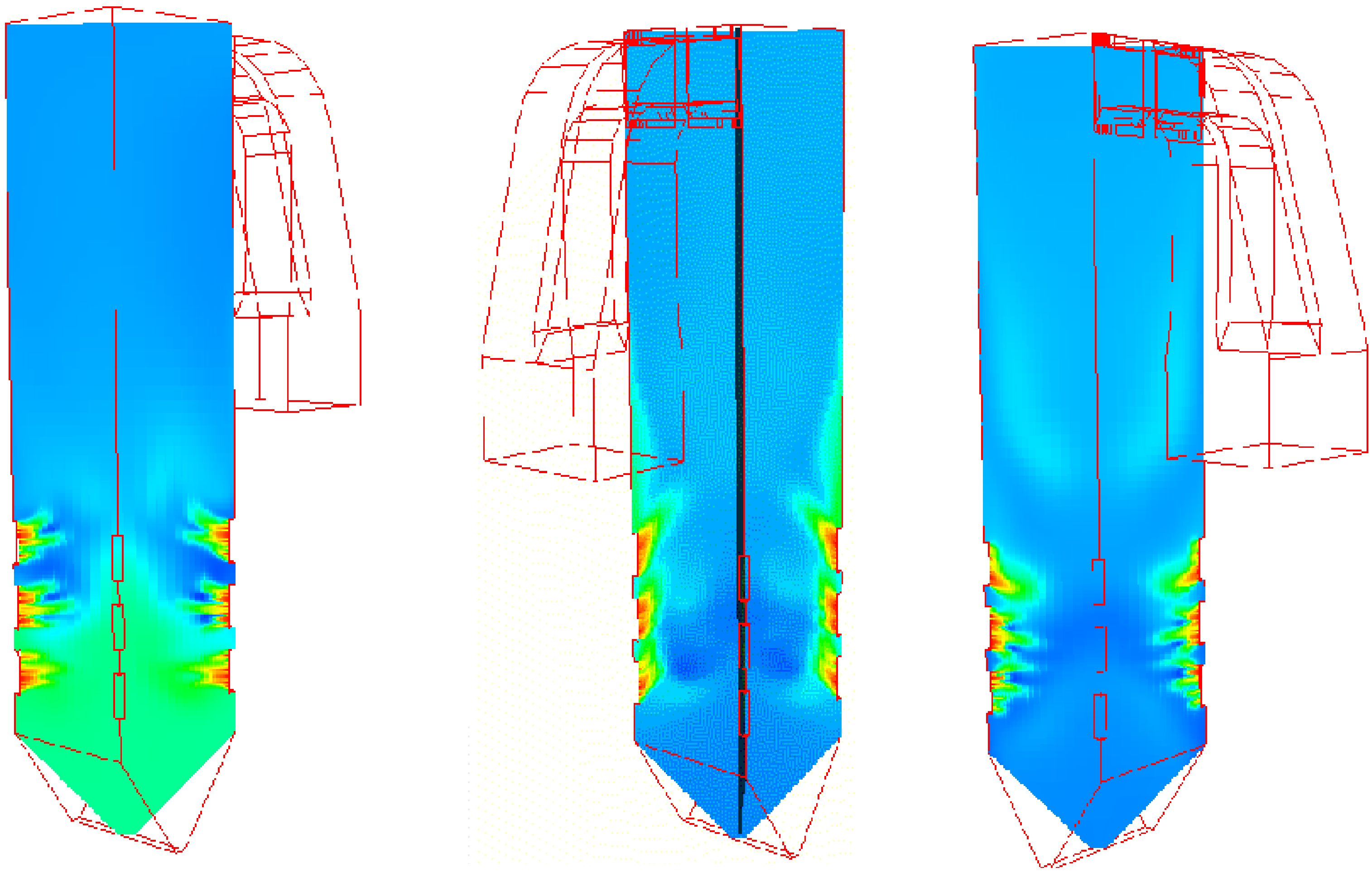


Max
temperature
1900°C



Serie7-624

Some results



Reference case

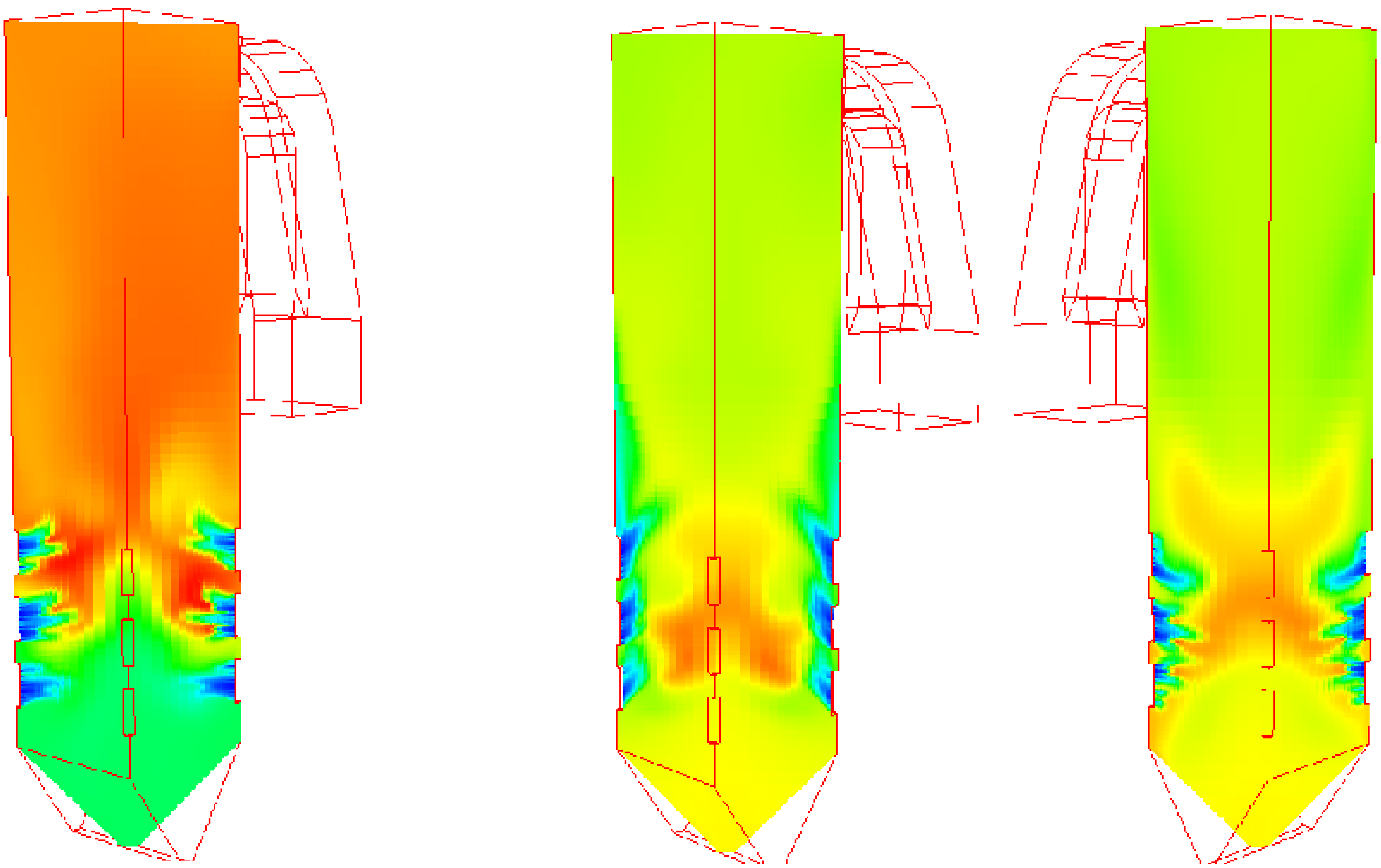
Individual 7-624

O_2 distribution

Some results

Reference case

Serie7-624



NO distribution

Conclusions

- We implemented a genetic algorithm to tackle the problem of finding innovative settings of a coal boiler
  - Minimizing pollutant emission (NOx, CO)
  - Maximizing lifespan (reduced corrosion risk)
- Innovatice coupling of a CFD code with Genetic Algorithm
- We found a satisfactory configurations
  - Best configuration are not those with lower NOx level
- Tested at Le Havre and Cordemais
- We identified some possible drawback in objective function (corrosion risk)
  - Taking into account the transient phases when modulating
  - Metal loss in µm : $M=6.10^5(\sqrt{to\ kpo} + \sqrt{tr\ kpr})e^{123500/RT}$
    - Kpo and Kpr corrosion rates under oxydizing and reducing conditions in cm^2/s, to and tr durations of exposition in both conditions, T metal temperature
- Switching to multi-objective optimisation