Evolutionary Algorithm for Pollutant Emission Minimization in Coal Power Plants

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1 Introduction

In order to limit the impact of thermal electrical power plants on environment (nitrogen and sulphur oxides, flying ashes; effect of green house gas is, so far, out of the scope), producers can use secondary exhaust gas treatment (catalytic removal, washing) or primary measures (fuel composition, air staging). EDF as the largest electricity producer in Europe, manages some thermal plants fed with pulverised coal, heavy fuel oil or natural gas. Nitrogen oxides (NOx) reduction can be obtained using recently designed burners (inducing expansive investment) or using suitable fuel and air staging mimicking their behaviour. This study is devoted to pulverised coal boiler settings.

2 Context

Even with a specified coal load and an excess air imposed by/for thermal efficiency considerations, a lot of parameters have to be adjusted: load distribution on mills and burners, burners tilt, and air staging. The latter is obtained through opening air registers of burners, even if not used (burner used as tertiary air inlet) or opening auxiliary air inlet (associated with start burners). User's manual and best practices collector are known, used, yet they have not been designed to face the new pollutant regulations. The behaviour of a coal boiler is complex, non-linear and there is no simple relation between input and output data. For any settings, we use a Computational Fluid Dynamics tool (Code_Saturne®, a finite volumes tool developed at EDF R&D) to evaluate its quality in terms of combustion, unburnt carbon in ashes, NOx emission, area prone to corrosion risk, and thermal flux. We needed an optimization method that explores the search space extensively, able to enumerate a scattered population of potential solutions and that can use an external tool to evaluate any individual. This and the previous work of [1] led us to consider genetic algorithms (GA). The capacity of GA to handle heterogeneous populations, yet fulfilling safety rules, was an important characteristic to produce unusual settings minimizing pollutant formation.

3 Genetic algorithm

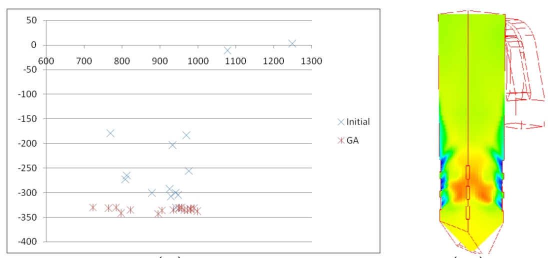
We use the ParadisEO [2] library developed by INRIA to implement the GA. This library provides a simple and flexible environment to experiment on the crossover/mutation/selection steps. For the selection step, we use the EP stochastic Tournament method already implemented in ParadisEO (each individual competes against n opponents and the best scores survive). As for crossover and mutations steps, they are carried out as follows. Each individual is a direct representation of the configuration parameters of the coal boiler: binaries for the air inlets (open/closed), integers for the burners vertical tilts (angles from -30° to 30°), and continuous values for the burners load. Because we have to post-process the chromosomes, modifying some gene values to fulfil physical constraints (e.g. constant global coal load, mandatory opening of operating burners air inlets), we implemented a simple one-gene exchange crossing procedure. Combined with mutations, it leads to a satisfactory variability in the successive populations. The mutation step is two-fold. First we randomly select the gene that will undergo the process. Second we change its value depending on the gene type: swap for binary, random assignment for others. Finally, the fitness of an individual is obtained by running Code_Saturne® and then by combining five physical/chemical indicators (combustion regularity, unburnt carbon in ashes, NOx emission, surface prone to corrosion risk, and thermal flux) into a single economical value.

4 Experiments

Code_Saturne® uses a mesh made up of 500 000 hexahedra to model the 3D volume of the boiler. To compute chemistry and fluid dynamics, Code_Saturne® runs on an 8-core machine in approximately 14 hours per individual. This significant running time was an obstacle since the efficiency of GA is related to the size of population and the number of generations. To overcome this difficulty, we distributed the execution of Code_Saturne® on a fifty-two 8-core node cluster which is equivalent to reducing the average evaluation time down to fifteen minutes per individual. To avoid unnecessary re-evaluation, we built a database of all already assessed chromosomes. We started from an initial population of fifty two individuals reflecting best-practice and standard configurations. We run the GA for fifty generations on a constant population. As a result, we obtained several interesting boiler settings minimizing the global economic cost. Among the best configurations that we found so far, some are particularly promising. For instance see figure 1 for NOx emission. As shown on the plot, there is always a generated configuration which has a better fitness than the initial settings.

	initial	individual_624
O_2	4.62e-02	4.75e-02
NOx	928.52	722.84
unburnt	1.35e-03	1.14e-02
corrosion area	0	3.55e-03
flux homogeneity	1.187	1.186

(i)



(ii) (iii)

Fig. 1. (i) Tabular: indicators comparison of first generation vs. 624th generated individuals. (ii) Plot: distribution of the individuals either from initial generation (blue) or from the best automatically generated (red). On the x-axis, the NOx emission level. On the y-axis, the fitness. (iii) Image: NOx emission along one diagonal of the coal boiler.

They have a much better behaviour both from environmental point of view (Low NOx and unburnt) and from an industrial sustainability (no corrosion risk, homogeneous thermal flux). The best one innovates by using opposite tilts of burners for the two diagonals. As a consequence of this orientation, and of a detailed air staging, the fuel air ratio is very regular, allowing a diminution of temperature and oxygen. Both of theses effects reduce the NOx formation. Due to the new air injection and orientation, the global oxygen excess diminution is obtained without significant wall oxygen lack (corrosion risk).

5 Conclusion and future work

We successfully used genetic algorithms to automatically generate innovative configurations of coal boiler. Although the results obtained so far are promising, they have to be confirmed and tested on a real boiler to account for model limitations. However the relevance of theses first results induces EDF R&D to apply this approach to similar setting optimisation (e.g. flow parameters in carbon capture process for coal and fuel boiler).

References

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