Assessment of Uncertainty Quantification Methods with Application to the Design of Organic Rankine Cycles

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Abstract:

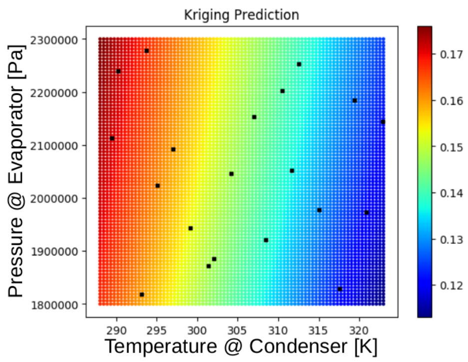
The subject of this work is the robust design (RDO) of Organic Rankine Cycles (ORCs), used for power generation from renewable sources. ORCs are Rankine Cycles employing as working fluid complex organic compounds (hydrocarbons, silicon oils or refrigerants), instead of steam: they are closed cycles involving at least a pump, that compresses the working fluid, a hot heat exchanger, known as evaporator where the working fluid is heated by an external heat source to become vapour, a turbine, that converts the thermodynamic power of the fluid in mechanical one, and a condenser, where the residual heat is released at the environment allowing the fluid to come back to the liquid status. The mechanical power at the turbine shaft is converted in electricity by a generator. Nowadays, ORCs represent a viable technology for the exploitation of energy from low/medium temperature sources, as they are usually preferred to classic steam cycles because of their simplicity, the lower operational costs and a good thermodynamic cycle efficiency [1].

Despite these advantages, ORCs have the drawback that they are by nature subject to several forms of uncertainty [2]. In fact, they are usually adopted in renewable applications (concentrated solar power, geothermal plants, biomass) or waste heat recovery, which are aleatory by definition. Furthermore, because of their high molecular complexity, it is difficult to characterize their properties reliably: sometimes the only information available comes from non-rigorous tests and they can lead to wrong estimations having a huge impact on the whole ORC design. Moreover, due to the small size of ORC (in comparison with the big steam Rankine cycle), machining tolerances in its equipments may be large and have a great influence on the general performance of the system.

As a consequence of this, robust design is nowadays more and more required, in order to avoid an "over-optimization" of the system that can be too sensitive to small changes. Due to the several sources of uncertainties, the design problem must be solved in a highly multi-dimensional space. In addition, the performance of ORC components (in particular heat exchangers and the expander) is often assessed by means of complex and costly models such as computational fluid dynamics (CFD). Thus, in order to perform RDO in this field, the employment of surrogate models is mandatory, like already done for example in [3, 4].

In the present work the quantification of the uncertainty on system performance is carried out by using surrogate models based on Gaussian processes (specifically Bayesian Kriging [5]). This approach drastically reduces the number of (costly) function evaluation compared to other techniques (like polynomial chaos expansion, see e.g. [4]). Still the average cost remains too high for routine application in the ORC industry, especially if massively parallel computers are not available. Thus, in order to further decrease the required computational resources, in the present work CoKriging [6] and the General Method of Moments [7] are also considered. At the present stage, these models are assessed for selected analytical functions and for an inexpensive ORC model, for

which comparisons with the Montecarlo Method are possible [8]. Results in terms of mean value prediction and error (relative to the computational cost) will be presented at the meeting. Furthermore a multivariate parametric study and a sensitivity analysis of the ORC will be provided. Figure 1 depicts a preliminary result for the ORC efficiency as function of 2 variables (pressure at the evaporator and temperature at the condenser).



ORC Efficiency	Kriging (20 samples)	MCM (1e4 samples)
Mean value	14.6 %	14.5 %
Max Value	17.6 %	17.6 %
T_cond@ MaxValue	288 K	288.1 K
P_eva@ MaxValue	23.0 bar	22.9 bar

Figure 1: Kriging prediction of ORC efficiency (left) and comparison with Montecarlo method

This work represents the preliminary step of a wider project, having the goal of performing the RDO of the ORC system using advanced models. More precisely, we aim at developing an accurate and computationally affordable RDO tool for ORC expanders, modelled by means of 3D CFD.

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Short biography – After the M.Sc. in Mechanical/Energy Enegineering at Politecnico di Milano and more than 5 years working as Turbine Design R&D Engineer for an ORC supplier, Aldo Serafino began a PhD on methodologies for RDO of an ORC turbine at Arts et Métiers ParisTech in 2017. This thesis is funded by Enertime, a French company manufacturer of ORC.