**An eXplainable AI Framework for Hybrid Modelling and Optimization of Marine Scrubber Systems**

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Artificial Intelligence (AI) today is widely spreading across different sectors such as the automotive, robotics, healthcare/diagnostic, and cybersecurity. These sectors look at accuracy as the most important metric to evaluate the goodness of the results provided by the AI systems. On the other hand, other sectors, such as the process industry, need these technologies in order to discover and insert second-order effects which are not considered with the classical first-principle models related to the specific system. For this reason, the eXplainable AI (XAI) can help the stakeholders to build new hybrid approaches for controlling, designing, and modelling the processes and equipment by respecting at the same time ethical and safety matters.

This work, considering a case study based on the marine scrubbers’ functioning, aims to develop an XAI framework able to improve the design and functioning of these systems, and also to follow an “explain-to-discover” approach to investigate the second-order effects that impact the system’s functioning. Marine scrubbers are essentially absorption towers aimed at removing acidic gas content from flue-gas to be compliant with the environmental regulations defined by the field authorities. The framework was developed on real data provided by ship companies and aggregated with other data from satellites, technical documents, and mass balances. Through a supervised learning approach and testing different kind of AI algorithms, the framework was able: (i) to develop a digital twin of the system aimed to model and optimize its functioning; (ii) to develop a hybrid model aimed to improve the design equations of these systems by reducing the design errors from the conventional first-principle models; (iii) to discover second-order effects investigating the outcomes from the AI decision making-process through the use of XAI post-hoc explainability analysis.

The results obtained are largely attributable to the dataset construction strategy, where several data were available only in a partial or an approximated way, but correctly aggregating them makes it possible to obtain a dataset where the explainability is introduced from “the cradle”. The work demonstrates that, upon training, AI models can be a valuable tool to sustain conventional analytical models without losing the designer's capacity to model, control, and describe the process. The low computational costs and improved performance of the proposed AI framework justify further research and development efforts aimed at optimizing marine scrubber performance and ensuring compliance with evolving environmental regulations.

**Keywords**: *Marine Scrubbers, Digital Twin, Hybrid Model, eXplainable Artificial Intelligence (XAI)*