

Application of Data-Driven Techniques for Continuous Emission Monitoring in WtE

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Continuous emission monitoring is essential in Waste-to-Energy (WtE) plants to ensure compliance with environmental regulations, optimize operational efficiency, and mitigate the impact of pollutants on air quality. Traditional monitoring systems rely on physical analyzers, which, while effective, can be subject to failures, maintenance downtime, or measurement uncertainties. In this context, data-driven techniques emerge as a potential tool for enhancing emission monitoring by using historical and real-time process data to develop virtual sensors. By using **data-driven methodologies**, virtual sensors provide an economical and **smart solution**, ensuring **continuous emission monitoring** and supporting decision-making in waste management, even under challenging conditions.

Mercury is one of the pollutants often associated with waste incineration, due to the presence of mercury-containing wastes such as batteries, paints, older light sources, and more (UNEP, 2015). Despite various restrictions, these materials can inadvertently end up in municipal solid waste streams, causing peak emissions even in WtE plants, which are typically characterized by very low mercury emissions into the atmosphere. To detect sudden changes in mercury emissions and implement appropriate control strategies to manage mercury emission peaks, it is essential for WtE plants to continuously monitor mercury (WI-BREF, 2019). When the continuous monitoring system face interruptions virtual sensors may hence present a valuable alternative, offering a reliable backup for such periods of downtime.

The present study investigated the **feasibility of developing a virtual sensor for backup monitoring of mercury** stack concentrations in the flue gas of a WtE plant. A **virtual sensor** is essentially an artificial dynamic system. It uses measurements from a set of known inputs and process outputs. The primary goal of this system is to provide an accurate estimate of an internal variable without the need for direct physical measurements, aiming to minimize the error between the actual value of the variable and its estimate (Figure 1). When the process model is unknown or only partially known, but measurements of the internal variable $v(t)$ are available, it is possible to estimate a virtual sensor from historical process data that provides an accurate estimation of $v(t)$. This approach is valid under the assumption that the set of known inputs and measured outputs $\{u(t), y(t)\}$ allows for accurately determining the internal state of the process in the absence of disturbances $w(t)$ and noise $n(t)$. The design of the **direct virtual sensor** involves identifying a dynamic system that takes the measured signals $\{u(t), y(t)\}$ as inputs and produces the estimated internal variable $\hat{v}(t)$ as the output.

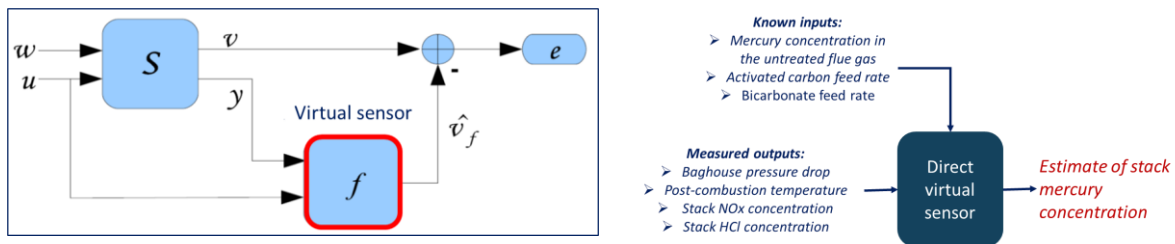


Figure 1. Schematics of a virtual sensor.

(u : known inputs; y : measured outputs; v : target variable; w : disturbance; e : error)

The study utilized several months of continuous real-plant data, collected from a facility equipped with a dry sorbent injection system using activated carbon. Mercury concentrations were monitored both before and after the flue gas treatment process. The plant was compliant with the authorized emission limit for mercury in flue gas. Although occasional inlet peaks reached $3000 \mu\text{g}/\text{m}^3$, the 90th percentile of the inlet concentration was $66 \mu\text{g}/\text{m}^3$. The plant's use of the best available technique (BAT31b) for mercury removal, as outlined in the WI-BREF (2019), ensured effective control of mercury emissions. The 90th percentile of the outlet mercury concentration was $3 \mu\text{g}/\text{m}^3$.

Several advanced data-driven methodologies were explored to develop and validate the virtual sensor (Figure 2), including system identification methods and machine learning approaches such as RNN (Recurrent Neural Networks) and LSTM (Long Short-Term Memory), while also utilizing feature selection techniques to identify the most significant variables.

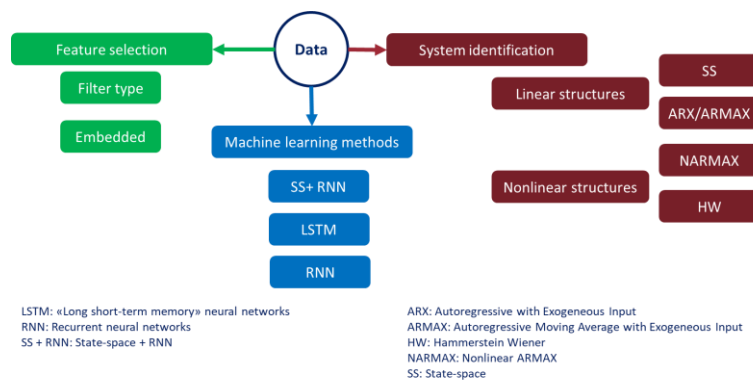


Figure 2. Overview of the data-driven methodology used in the study

The study provided insights into the complex dynamics of mercury removal, revealing that during periods when the mercury concentration in the flue gas is low, the data shows no significant correlation with input variables such as incoming pollutants, reagent dosing, and others. Each observed peak in the output, corresponding to a release event, presents a unique dynamic that differs from the others. Additionally, the system's memory influences these peaks in a non-systematic way. No coherent pattern emerged in the mercury emission peaks. The triggering factors for each release event could not be identified from the interactions of mercury concentrations with other gas species in the flue gas, nor from the control strategies involving temperature management and activated carbon dosing.

Given the lack of clear relationships between input and output variables in the available plant data, developing a virtual sensor for this specific setup proved to be challenging. However, these findings suggest that the feasibility of developing a virtual sensor may vary depending on the specific characteristics of the plant. For different plants with potentially more consistent data relationships, the development of a virtual sensor could be more achievable, and the results might differ. The study contributed to outlining the limitations of the investigated data-driven techniques when applied to systems with highly nonlinear and complex dynamics, suggesting the need for exploring new models or combinations of existing methods to improve simulation accuracy.

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