Modelling of Hg adsorption on activated carbon in WtE plant fabric filters

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Waste incineration is applied to non-recyclable or potentially hazardous solid wastes to reduce their volumes destined to landfill and, through energy generation in waste-to-energy (WtE) plants, provides an alternative to non-renewable energy sources. Mercury is one of the pollutants often associated with waste incineration given the presence of several mercury containing wastes such as batteries containing mercury, paints, older light sources etc. (UNEP, 2015) which despite restrictions can inadvertently end in municipal solid waste streams causing peak emissions even in WtE plants usually characterized by very low mercury emissions into the atmosphere.

Such as for many other pollutants from waste-to-energy plants, also the emission limit values for mercury become stricter with time. The latest emission limit values associated with best available techniques (BAT) are set to average daily limits for Hg mercury emissions at 5-20 μg/Nm^3 depending on the flue gas treatment technology used and the mercury content in the incoming waste stream (WI BAT[1], 2019). WI BAT also requires continuous mercury measurement at the stack in order to be able to promptly detect increasing mercury concentrations in the flue gas and put into action proper control strategies to control the mercury emission peaks. Many WtE plants have already implemented continuous mercury measurement at the stack. Some of them have installed mercury analyzers also in the process (i.e., upstream mercury emission control unit) and sometimes downstream the mercury emission control unit. Several mercury control units are indicated as BAT for mercury emission control (BAT 31 – low pH wet scrubber, dry sorbent injection, injection of special highly reactive activated carbon, boiler bromine addition, fixed- or moving bed adsorption). The feeding of activated carbon in a duct or in a reactor tower before a fabric filter is one of the most common flue gas treatment configuration for mercury removal in WtE plants.

Given the enhanced monitoring capabilities more and more WtE plants implement mercury control strategies based on the increased dosage of activated carbon when certain concentration thresholds are reached in the stack and/or the raw gas upstream the mercury removal. However, control strategies based on fixed setpoint values may not be able to cope with the great variability in the mercury concentrations due to the variations in the composition of the fuel (i.e., municipal solid wastes) and so some under/over dosage may happen. Advanced data-driven control strategies based on gray box modelling[2] approach would make use of plant real-time data to calibrate properly the reactant dosage. In this context the availability of a model able to dynamically estimate the mercury removal in the system would be very useful.

With this in mind, the present study investigated the development of a model using a kinetic approach to describe the mercury adsorption process on activated carbon based on data from a full-scale solid waste incineration plant equipped with a dry flue gas treatment line.

Approach:

The mathematical model developed is based on Langmuir equation and on material balance on mercury, in both gaseous and adsorbed phases, along the growing filter cake and inside the activated carbon particles. The real-world plant data came from an Italian WtE plant. Several plant operation information was available (e.g., average fabric filter operation temperature, operating pressure drop in the fabric filter) as well as continuous mercury measurement data in the inlet and outlet of the fabric filter and reactant feed data (i.e., activated carbon for mercury and alkaline reactant for acid gas removal). The overall data set has been divided in calibration and validation datasets. Different subsets were chosen to include, in both calibration and validation, as many various mercury inlet-outlet conditions as possible to represent mercury variability in the real plant data to allow the model to learn

[1] Frederik Neuwahl, Gianluca Cusano, Jorge Gómez Benavides, Simon Holbrook, Serge Roudier; Best Available Techniques (BAT) Reference Document for Waste Incineration; EUR 29971 EN; doi:10.2760/761437
[2] i.e., a hybrid of data driven and physio-chemical phenomena based models where, coefficients of the equations from physio-chemical based models are learned using data.

and perform in all the possible operating conditions occurring in a WtE plants. The activated carbon properties and the Langmuir isotherm parameters have been obtained by fitting the model to the selected dataset. The estimation capability of the model was then tested, on validation dataset. MAPE (Mean Absolute Percentage Error) metric is used to identify the overall deviation of estimated values from the observed ones, and to test the goodness of the model.

Preliminary results

After having calibrated different Langmuir isotherm constants, for different level of Hg concentration, model estimations of the Hg removal efficiency fall within ±3% error band and with an average absolute deviation equal to 0.87%. Figure 1 shows an example of preliminary results on the real-world WtE dataset.

Scientific innovation and relevance:

The work is **scientifically relevant** under three aspects:

- Diversly from several earlier literature studies that modelled the filter cake as a fixed bed reactor, the present study introduces the filter cake growth into the model through moving boundary condition.
- It takes into account the copresence of different kinds of activated carbon as well as alkaline reactant usually present in flue gas treatment plants dealing simultaneously with mercury, acid gas and organic micropollutants abatement.
- It can serve for example as a part of the data-driven activated carbon feed control strategy towards increasing the economic and environmental sustainability of WtE plants or for the development of virtual sensors to use when the stack mercury analyzers fail, so that the use of virtual sensors may fill in the gap for monitoring until the physical analyzers are reinstated.

Beyond-the-state-of-the-art: The model's main **novel characteristic** is that, diversly from many modelling approaches that can be found in literature, it delves with dynamically changing mercury inlet concentrations to the fabric filter, a common situation for real-world WtE plants.

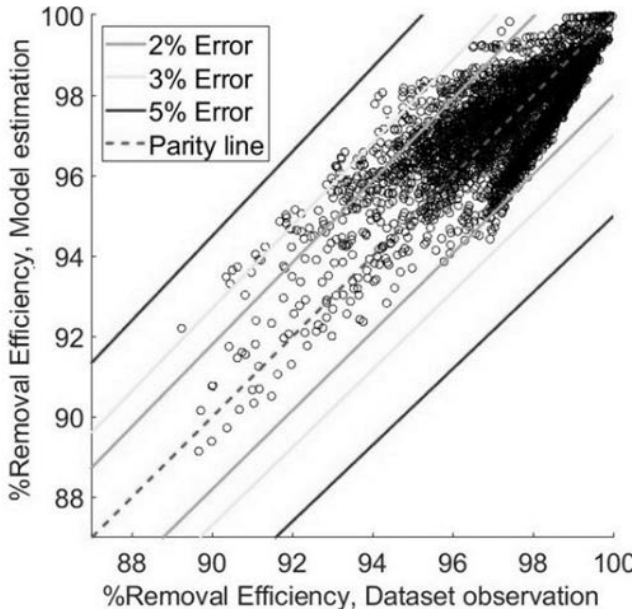

Figure 1. Parity plot for the observed and modelled Hg removal (on validation data)