

A methodology for the optimization of multi-stage abatement of acid pollutants in waste-to-energy plants

A. Dal Pozzo*, G. Antonioni, V. Cozzani*

a.dalpozzo@unibo.it

Dipartimento di Ingegneria Civile, Chimica, Ambientale e dei Materiali, Alma Mater Studiorum – Università di Bologna, Via Terracini 28, 40131 Bologna (Italy)

Abstract

Facing increasingly strict environmental regulations, waste-to-energy plants often rely on multi-stage treatment processes for the abatement of acid pollutants. In the multi-stage configuration, while the overall required abatement of pollutants is fixed by the emission limit values at stack, there are degrees of freedom in the repartition of abatement between stages, leaving room for process optimization. An optimal repartition of acid gas removal allows to reduce the consumption of reactants and the production of residues, with obvious economic and environmental advantages. The present study outlines a procedure for the identification of such optimal repartition, based on the analysis of process data by means of an empirical model.

Introduction

Acid gases, such as hydrogen halides (HCl, HF) and sulfur oxides (SO₂), are typical fuel-related pollutants. Cement production, steelmaking, ceramics and glass manufacturing, maritime transportation, biomass and waste combustion are all sectors in which the emission of acid gases is a known issue. In particular, waste-to-energy (WtE) facilities are subject to strict emission limit values and the upcoming revision of the BAT (Best Available Techniques) for waste incineration sets even higher standards for the emission control of these contaminants [1]. Therefore, in order to comply with the required high removal efficiencies, multi-stage acid gas treatment configurations are increasingly adopted in WtE plants, both in new installations and as retrofits.

Clearly enough, a multi-stage configuration introduces a degree of freedom in process control: the overall required removal of pollutants is fixed, but it can be achieved with different repartitions of the removal between stages. A well-balanced utilization of the treatment stages can minimize the consumption of reactants and the generation of process residues/wastewater, compared to an ill-balanced system with the same overall acid gas removal efficiency.

Nonetheless, in particular for dry multi-stage configurations (based on the injection of powdered basic reactants, like calcium hydroxide or sodium bicarbonate), systems are often operated far from the optimal conditions. The selection of the

operating parameters is typically done on conservative assumptions, without the support of an adequate understanding of the reaction process. The gas-solid reaction process is strongly dependent on a variety of plant-specific parameters (operating temperature, gas composition, solid residence time), which would require a plant-specific process optimization. In the present study, a simple methodology, generally applicable to dry multi-stage acid gas removal configurations, is proposed to identify the optimal operating point of a treatment system, starting from its performance data registered by the plant control system.

Examples of dry multi-stage acid gas removal configurations

Dry systems are the most widespread approach for acid gas abatement in countries such as Italy, France or UK [2]. A multi-stage configuration can be generally realized as shown in Fig. 1.

In the first case (Fig. 1a), acid gas removal takes place downstream of the heat recovery section of the WtE plant, in two consecutive reaction stages where a solid reactant is first injected in the flue gas ductwork and then the solid products of the neutralization reaction are captured by a fabric filter. Typically, the first stage employs a cheap reactant like calcium hydroxide, $\text{Ca}(\text{OH})_2$, while the second stage relies on a more performant, yet expensive sorbent like sodium bicarbonate, NaHCO_3 .

In the second case (Fig. 1b), deacidification starts directly in the combustion chamber via the injection of a reactant such as calcined dolomite ($\text{CaO}\cdot\text{MgO}$). Then, the heat recovery section of the WtE plant acts as particulate collection device for the reaction products. Downstream, the second stage of acid gas removal generally consists in a sodium bicarbonate injection.

In both cases, the operating costs consisted in the purchase cost of reactants and the management cost for the solid process residues, which have to be sent to specific landfilling sites or recycling facilities.

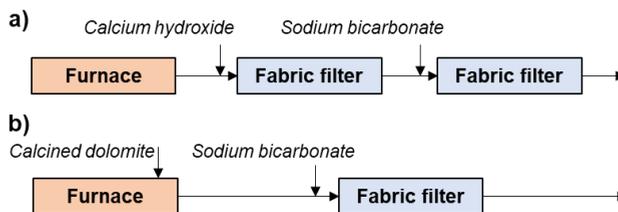


Figure 1. Two-stage dry acid gas removal systems.

Methodological approach and simplified process modelling

We propose a plant-specific approach to optimize the operation of a multi-stage system, based on the following steps:

1. Collection of plant-specific process data;
2. Calibration of a performance model for each acid gas removal stage;
3. Simulation of different multi-stage configurations to identify the optimal repartition of acid gas removal between stages that minimizes operating costs.

Core of the methodology is the use of a simple semi-empirical model for the description of the reaction between acid pollutants and solid reactants [3]:

$$X_{i,j} = \frac{SR_j^{n_{i,j}} - SR_j}{SR_j^{n_{i,j}} - 1} \quad (1)$$

where the conversion of the acid pollutant i by the reactant j is a function of the stoichiometric ratio SR , i.e. the ratio of the actual feed rate of reactant to the amount of reactant theoretically required to convert all the acid pollutants in the inlet flue gas. The model offers a simplified approach to the description of acid gas removal, by lumping the influence of all the variables affecting the reaction (sorbent properties and flue gas operating conditions) in a set of empirical parameters $n_{i,j}$, which can be tuned by calibration with plant-specific data. The calibration dataset can be obtained either by analyzing the past performance of a treatment unit (calibration through process data analysis) or by performing test runs at controlled feed rates of reactants (calibration through dedicated test runs).

Model calibration through process data analysis

If an acid gas removal stage is equipped with gas composition measuring devices both upstream and downstream, the conversion of the acid pollutant in the stage can be monitored continuously and put in relation with the concurrent feed rate of solid reactant. However, the raw data retrieved from the plant has to be properly processed to be used as calibration dataset. For example, Fig. 2 sketches the procedure for a $\text{Ca}(\text{OH})_2$ -fed treatment unit, with reference to HCl removal. The performance data of the unit (HCl conversion vs. SR) are collected as hourly averages for an entire year of operation, obtaining over 7500 data pairs. The performance is highly variable (see e.g. how an 80% HCl removal efficiency has been obtained during the year with widely different SR , ranging from 1 to 5), as a consequence of the highly fluctuating conditions of WtE operation. This cloud of data can be processed by cataloguing data pairs in clusters according to the most relevant operating conditions (temperature and inlet HCl concentration) registered during their collection. More details regarding the classification procedure can be found in [4]. Hence, in the example, by considering the average data point for each cluster, the dataset was reduced to 16 points, on which it was possible to identify a clear effect of operating temperature on lime performance. At lower temperature, the reactivity of lime increases, arguably due to an increase of relative humidity that reduces the diffusional limitations in the gas-solid reaction process [5]. Therefore, in this case, the tuning parameter $n_{\text{HCl,Ca}(\text{OH})_2}$ for the model in eq. 1 was obtained as a function of temperature.

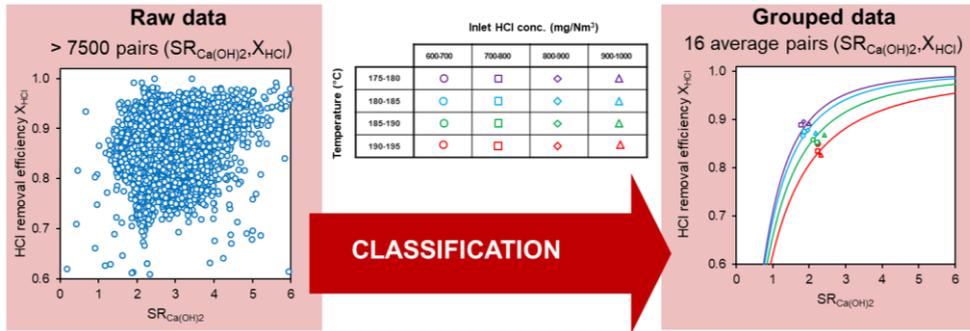


Figure 2. Classification of raw process data for $Ca(OH)_2$ injection.

Model calibration through dedicated test runs

If an acid gas removal stage is not equipped with upstream and downstream measuring devices, it is not possible to retrieve performance information from historical process data. The data gap can be filled with a dedicated experimental campaign. For example, in the case of calcined dolomite injection directly in the combustion chamber (see again case b in Fig. 1), the concentration of acid pollutants in the flue gas can be measured only downstream of the furnace. Therefore, in order to assess the effect of the injection of reactant in terms of acid gas removal, “on/off tests” have to be performed, by alternating periods of injection and interruption of the reactant feed rate, as shown in Fig. 3a. Then, the removal efficiency of calcined dolomite towards HCl or SO_2 at different feed rates can be calculated considering the reduction in acid gas concentration at the downstream measuring point, compared to the periods without injection of reactant. With a sufficient number of experiments, a neat calibration set for the model of eq. 1 can be obtained (see Fig. 3b).

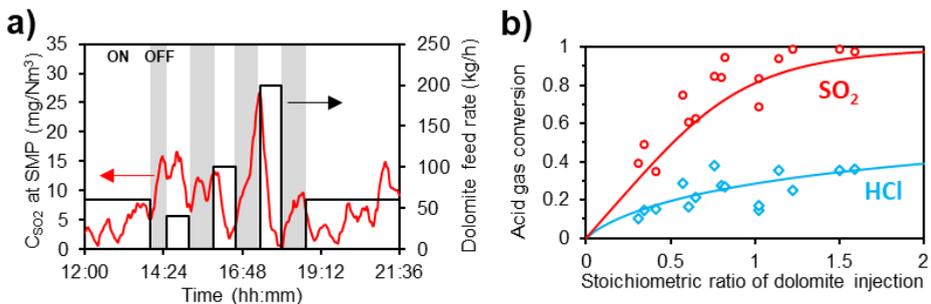


Figure 3. a) Dolomite feed rate and SO_2 concentration varying during a test run. b) Calibration of the empirical model on experimental data point from test runs.

Identification of the optimal operating point

Once calibration has been performed for each removal stage in the plant, the model can be used for process optimization. Different repartitions of acid gas removal between stages are simulated to identify the one that achieves cost minimization.

For example, here we consider a two-stage acid gas treatment system, with a 1st stage based on $\text{Ca}(\text{OH})_2$ injection and a 2nd stage based on NaHCO_3 injection (case a in Fig. 1). The target is to minimize the overall operating cost given by:

$$C_{TOT}(SR_{\text{Ca}(\text{OH})_2}, SR_{\text{NaHCO}_3}) = C_{\text{Ca}(\text{OH})_2} + C_{\text{Ca residues}} + C_{\text{NaHCO}_3} + C_{\text{Na residues}} \quad (2)$$

where the costs for both purchase of reactants and disposal of process residues are taken into account. This function can be minimized by varying the acid gas conversion in the two stages ($X_{\text{Ca}(\text{OH})_2}$ and X_{NaHCO_3}), keeping constant the overall removal efficiency:

$$X_{\text{overall}} = X_{\text{Ca}(\text{OH})_2} + X_{\text{NaHCO}_3} - X_{\text{Ca}(\text{OH})_2} \cdot X_{\text{NaHCO}_3} = \text{constant} \quad (3)$$

Fig. 4 shows the outcome of this analysis for a plant equipped with the considered two-stage system, assuming an inlet concentration of HCl and SO_2 of 800 and 100 mg/Nm^3 , respectively. Different repartitions of acid gas removal between stages were explored by varying $X_{\text{Ca}(\text{OH})_2}$ in the range 0-80%. A minimum for the operating costs can be identified at a 30% HCl conversion in the $\text{Ca}(\text{OH})_2$ -fed stage. Variations in the unit costs of reactants supply and residues disposal or in the emission limit values imposed at stack for HCl and SO_2 can influence significantly the position of the optimal operating point, which is clearly a plant-specific and condition-specific result.

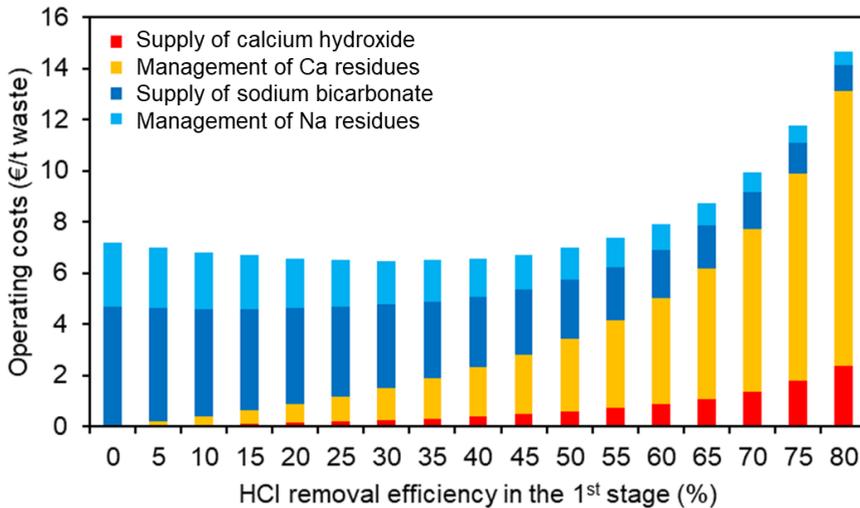


Figure 4. Operating costs as a function of HCl conversion in the $\text{Ca}(\text{OH})_2$ stage.

The proposed methodology is an easy and effective approach to the performance analysis of multi-stage acid gas removal systems. The result of the analysis, i.e. the optimal repartition of acid gas abatement between treatment stages, represents useful information for plant managers, since a properly optimized multi-stage system can achieve significant cost savings compared to non-optimized operation. Once the optimal removal repartition between stages is known, it can be actively pursued through process control, e.g. by imposing the value of optimal acid gas conversion at the 1st stage as setpoint in a feedback control logic for reactant feed rate regulation (see the scheme of Fig. 5).

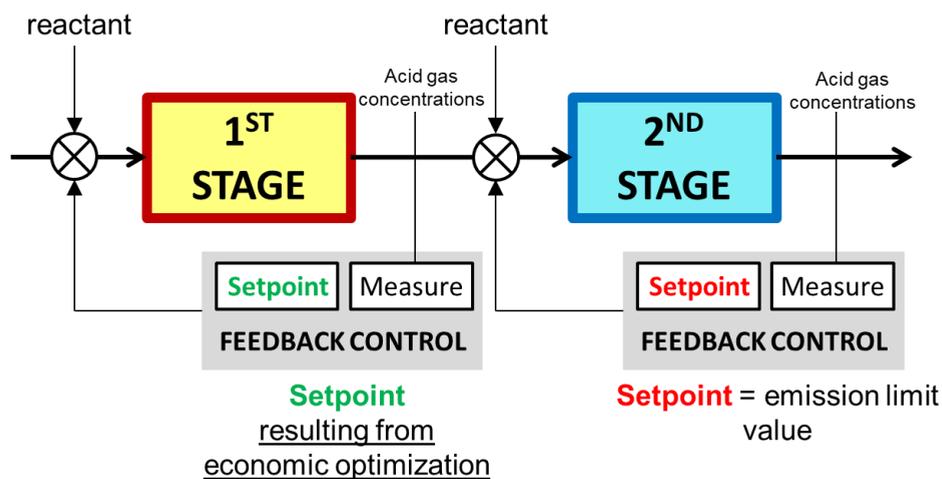


Figure 5. Example of process control using as intermediate setpoint the optimal operating point identified by the process optimization analysis.

References

- [1] European Commission, BREF Waste Incineration (draft), Dec 2018. Available at: <https://bit.ly/2UTDHhl>
- [2] Vehlow, J. Air pollution control systems in WtE units: An overview. *Waste Manage.* 37: 58-74 (2015)
- [3] Dal Pozzo, A., Antonioni, G., Guglielmi, D., Stramigioli, C., Cozzani, V. Comparison of alternative flue gas dry treatment technologies in waste-to-energy processes. *Waste Manage.* 51: 81-90 (2016)
- [4] Dal Pozzo, A., Giannella, M., Antonioni, G., Cozzani, V. Optimization of the Economic and Environmental Profile of HCl Removal in a Municipal Solid Waste Incinerator through Historical Data Analysis. *Chem. Eng. Trans.* 67: 463-468 (2018)
- [5] Chisholm, P.N., Rochelle, G.T. Dry absorption of HCl and SO₂ with hydrated lime from humidified flue gas. *Ind. Eng. Chem. Res.* 38: 4068-4080 (1999)