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Minimizing Emissions
to air, water and soil!
Flue Gas Cleaning in Waste-to-Energy  – Best Available Technology –

Christian Fuchs

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Focusing on flue gas cleaning for Waste-to-Energy it can be noticed that the development of technology is regularly pushed by legislation, which usually is reflecting the public demand and public support.

Minimizing the emissions was prime target in the nineties of the last century, minimizing invest and operational costs at the beginning of the new millennium. Today energy efficiency whilst maintaining low emission levels gets more and more demanded.

What are the technologies of today, saving energy and highly efficient at the same time? What is the best technology in 2017?

1. Available flue gas cleaning technologies

As usual in these discussions we will focus on the treatment of acid gas components like SO₂, HCl and HF of the flue gas only. We do not discuss about treatment of the pollutants like Heavy Metals, Dioxins/Furans or NOₓ, which naturally require different technologies to be combined with acid gas cleaning or which result in an additional cleaning stage.
The actual cleaning effect when treating acid gas components is a chemical reaction between these and an alkaline additive, which is injected into the gas flow.

There are differences how to inject the additive, so we make a difference between dry, semidry or wet technologies. There are as well many Hybrid-Technologies, which combine at least two technologies to a multistage cleaning system. Multistage cleaning combines the advantages of individual technologies to achieve an improved efficiency or/and economy.

Energy optimization can be implemented in any of these technologies, but we will focus here on the dry technology and the possibilities to improve the energy production.

2. Presentation of the dry sorption technology

The Dry Sorption consists of an architecture as described below:

- Evaporation cooler for the conditioning of the flue gas to reach the required reaction temperature and to increase the humidity of the gas. Alternatively a heat exchanger package to cool down the gas to reach optimum process conditions and thereby produce a significant amount of low pressure steam, which may be utilized for activation of the residues (VapoLAB Technology),
- Reactor to intensively mix additive and gas,
- Fabric Filter to separate fly ash and additive from the flue gas flow,
- Recirculation of the filter residues to enhance efficiency of the system,
- Ventilator to convey the flue gas from incineration to the stack,
- The stack,
- Peripheral installations to support the process like storage and preparation of the sorbents, residues storage, compressed air preparation.

To treat acidic components of the flue gas additives like hydrated lime or sodium hydrogen carbonate are injected into the flue gas and are thoroughly mixed by means of static or mechanical mixing devices, depending on the manufacturers technology. The efficiency of the reaction of sorbents with acid gas is strongly dependent of contact duration, sorbent distribution in the gas flow, reaction temperature and humidity. This is the reason why all variations of the Dry Sorption Technology aim to optimize above mentioned conditions as much as possible.

An evaporation cooler is adjusting the temperature to the optimum for the reaction of hydrated lime, which is approximately 140 °C and represents the best compromise between efficiency and safe distance to the acid dew point, which mainly is depending on the HCl concentration of the gas.

As a secondary effect the relative humidity of the flue gas is increased by evaporation of water, which also has a very positive effect on the efficiency of the process. The presence of water (e.g. the partial pressure of steam) is essential for the chemical reaction of acidic gas with hydrated lime.
Alternatively the flue gas may be cooled down to the reaction temperature using a heat exchanger to recover additional energy from the incineration to achieve a better thermal efficiency of the complete incineration system. The produced steam may be used in the boiler circuit, as city heating or utilized in the dry sorption technology, which is described later. Nevertheless, 140 °C will be the temperature of the gas leaving the process and therefore a lot of energy will be lost.

The influence of reaction time and particle distribution of additives in the flue gas is self-explaining. To reach better efficiencies there are various components used between injection of additives and the filter, which are static mixers, turbulence generators and mechanical reactors.

Recirculation of the fly ash and reaction salts separated in the fabric filter has a major effect on the efficiency of the Dry Sorption Process. Not all injected sorbent had a chance to react in the time between its injection and the separation in the fabric filter. A certain amount of unused, still reactive sorbent is present in the filter ash. The unused amount of hydrated lime, in relation to the injected amount increases the stoichiometric ratio of the process above 1.0, which would be at 100 % reaction. If all injected hydrated lime has reacted and there is no unused lime in the residue, the stoichiometric ratio would be 1.0. For dry systems the ratio is usually between 2 and 3, depending on whether there is recirculation or not and whether there is additional humidification (water injection) of the residues while recirculating or not. To our experience the best stoichiometric ratio can be achieved by steam injection to the residues while recirculating.

Recirculation also has another positive effect: Acid gas concentration resulting from a waste or RDF- incineration is never homogenous, there are always high concentration peaks possible. Recirculating offers the benefit that the sheer mass of active sorbents in the flue gas flow is increased by dimensions – therefore the stability of such a system against peaks is by far higher than without recirculation.

In particular applications the use of sodium hydrogen carbonate instead of hydrated lime as a sorbent may also be also advantageous.

Here a cooling system is also required in most cases, in particular in existing incineration plants, to achieve a reaction temperature of approximately 170 °C to 180 °C. This requirement is not resulting from the properties of sodium bicarbonate, but of additional system requirements like the use of activated carbon, which limits the temperature to approximately 200 °C.

Sodium hydrogen carbonate is highly reactive, but usually requires in situ grinding of the granules to a very fine powder to achieve this high reactivity. Therefore grinding stations consisting of two or three special mills to be able to treat peaks and always have one mill available as being redundant for regular cleaning or unplanned downtimes.

When injecting the freshly ground powder into the hot flue gas actually the disodium carbonate is created out of sodium hydrogen carbonate by losing carbon dioxide and water. This explains that this technology produces less residues than the comparable process with hydrated lime and makes it attractive at high disposal costs.
Latest development is an already ground to specification sodium hydrogen carbonate delivered to site by tanker truck which may be used without further treatment. The manufacturer claims this product does not change properties like particle size due to agglomeration and is as efficient as the freshly ground product without any side effects, this has to be monitored.

![Process diagram dry sorption using steam activation](image)

Figure 1: Process diagram dry sorption using steam activation

### 3. Today’s improvement on Flue Gas Cleaning Technologies

Comparing and selecting Flue Gas Cleaning Technologies can only be complete under consideration of many conditions, which may be different at all possible locations. Principally every installation will be different, which explains also the variety of technologies available.

For example, an existing installation with grown infrastructure, limited space available and an existing permit describing certain emissions will surely build different compared with a new installation on green field, which is under planning only. Also availability, investment costs and operating costs as well as residues have to be considered. Both Capex and Opex determine if a technology is attractive or not.

If we look at low investment and low maintenance costs, we clearly have to decide for a simple dry system. Taking low emissions and low operational costs into the equation, it becomes more difficult, because that is the domain of wet technology.
Energy efficiency is achievable with both systems, depending on the energy extraction system installed.

For our discussion we will focus on dry technology and will compare different ways of improving the energy efficiency.

**4. High efficiency dry sorption technology**

Above we have mentioned that there are many factors determining the performance of a dry sorption system. Besides adjusting the optimized reaction temperature and thorough mixing of gas and additive recirculation and *activation* is essential for the performance. Recirculation offers a complete new level of performance boosting the dry technology and enabling the use of it even in highly demanding applications like waste or RDF incineration compared biomass incineration, which was the main application for dry systems in the past. Recirculation offers the possibility to even increase the performance by activation of the unused lime particles, which are then re-injected into the gas flow.

Activation is the opening of the surfaces of used additive by an exchange of ions to re-introduce active surfaces into the process. This is how the amount of captured HCl can be optimized.

The actual equations are as follows:

\[
\text{Ca(OH)}_2 + 2 \text{HCl} \rightarrow \text{CaCl}_2 + 2 \text{H}_2\text{O} \quad \text{in the gas flow}
\]

\[
\text{CaCl}_2 + \text{Ca(OH)}_2 \rightarrow 2 \text{CaClO}H \quad \text{during activation}
\]

\[
2 \text{CaClO}H + 2 \text{HCl} \rightarrow \text{CaCl}_2 + 2 \text{H}_2\text{O} \quad \text{recirculated in the gas flow.}
\]

Activation is based on the ion exchange in the particles, until today there are three ways to reach an activated product.

Maturation of the recirculated filter ash is not using any additive or any reactor which might lead to process instabilities like scaling or crusting. This means that this technology works reliable, without any process issues but it requires a large buffer volume. The recirculated filter ash is buffered in a dedicated silo for a short time period to allow for the ion exchange to take place, then it is re-injected into the gas flow again.

![Activation process](image)
Moisturizing the recirculated filter ash with the injection of a small amount of water is a way which saves the space of the silo and the maturation time, it is a process taking place in a specific reactor mixing the dry fly ash and injecting water at the same time. This is a very efficient activation technology and has only one drawback: In case the mixing is uneven or the amount of water injection is increasing above a maximum level there is the risk of forming a slurry which tends to create crustings and operational problems.

A particular new development utilizes low pressure steam for the activation. The recirculated filter ash is fed to an external reactor which intensely mixes ash and steam to achieve the activation in a short time, without requiring a silo for storage and without the risk of forming a slurry leading to process problems. This technology is the latest development, but there are already more than ten references in operation, the first one since 2011.

<table>
<thead>
<tr>
<th>Year of Com.</th>
<th>Plant</th>
<th>Country</th>
<th>Fuel</th>
<th>Plant status</th>
<th>Flue gas flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>2019</td>
<td>Wheelabrator, Kemsley</td>
<td>UK</td>
<td>Waste</td>
<td>New</td>
<td>2 x 170,000 Nm³/h</td>
</tr>
<tr>
<td>2017</td>
<td>Viridor, Beddington</td>
<td>UK</td>
<td>Waste</td>
<td>New</td>
<td>2 x 100,000 Nm³/h</td>
</tr>
<tr>
<td>2017</td>
<td>MVV Leuna</td>
<td>D</td>
<td>Waste</td>
<td>Retrofit</td>
<td>2 x 145,000 Nm³/h</td>
</tr>
<tr>
<td>2016</td>
<td>SITA, Wilton</td>
<td>UK</td>
<td>Waste</td>
<td>New</td>
<td>2 x 161,000 Nm³/h</td>
</tr>
<tr>
<td>2015</td>
<td>Veolia, Shropshire</td>
<td>UK</td>
<td>Waste</td>
<td>New</td>
<td>1 x 63,000 Nm³/h</td>
</tr>
<tr>
<td>2015</td>
<td>Viridor, Cardiff</td>
<td>UK</td>
<td>Waste</td>
<td>New</td>
<td>2 x 145,000 Nm³/h</td>
</tr>
<tr>
<td>2014</td>
<td>MVV, Mannheim</td>
<td>D</td>
<td>Biomass</td>
<td>Retrofit</td>
<td>1 x 82,000 Nm³/h</td>
</tr>
<tr>
<td>2014</td>
<td>Vantaa, Helsinki</td>
<td>FIN</td>
<td>Waste</td>
<td>New</td>
<td>2 x 145,000 Nm³/h</td>
</tr>
<tr>
<td>2014</td>
<td>MVV, Ridham Dock</td>
<td>UK</td>
<td>Biomass</td>
<td>New</td>
<td>1 x 118,000 Nm³/h</td>
</tr>
<tr>
<td>2013</td>
<td>Brive</td>
<td>F</td>
<td>Waste</td>
<td>Retrofit</td>
<td>1 x 65,000 Nm³/h</td>
</tr>
<tr>
<td>2011</td>
<td>SITA, Teesside</td>
<td>UK</td>
<td>Waste</td>
<td>Retrofit</td>
<td>2 x 80,000 Nm³/h</td>
</tr>
</tbody>
</table>

5. Performance

Above we have mentioned that there are many factors determining the performance of a dry sorption system. Emissions are not an issue any more for a steam based dry sorption system. This year a waste incineration plant in Germany with very high concentrations of SO₂ and HCl has installed the first line with VapoLAB, the second line still is equipped with the original spray absorber system. Without going into details it can be stated that the lime consumption for the converted line was reduced by 59 % down to approximately 500 kg/h and the consumption of sodium hydrogen carbonate, which is injected to treat occasional high peaks of acid gas components was reduced by 80 % down to approximately 40 kg/h. The same reduction can be monitored for the residues generated, which are reduced by the same amount.

The challenge of reaching low emissions at high inlet concentrations is usually very demanding for a dry sorption system. The above mentioned technology is reliably reducing daily average values of 1.800 mg/Nm³ tr. HCl down to 8 mg/Nm³ tr. and 650 mg/Nm³ tr. SOₓ.
down to $40 \text{ mg/Nm}^3$. These setpoint values are perfectly met to optimize the additive consumption to the lowest level while safely maintaining the required emissions, lower emission levels are adjustable in the controls.

The influence of the steam can be displayed and reproduced by checking emissions and consumption of lime when turning the steam off and on again.

![Influence of steam to the lime consumption](image)

**Figure 3:** Influence of steam to the lime consumption

Low pressure steam is injected in the ActiLAB mixer at a rate of approximately 150 kg/h, process conditions are stable. When turning the steam off the emissions of $\text{SO}_x$ are slowly rising, but at the same time the amount of added lime is increased from 500 kg/h up to 1,200 kg/h, until the steam is switched back on again. Then the lime consumption slowly drops again and is falling even below the initial value of 500 kg/h, because the unused lime in the system is used up before dosing fresh lime again.

$\text{HCl}$ does not play a role at all, because the raw gas level of $\text{SO}_x$ is relatively high.

The Figure below indicates a daily average of $\text{SO}_x$ of approximately 1,000 mg/Nm$^3$ and of $\text{HCl}$ of 1,500 mg/Nm$^3$. What can also be monitored at Figure 4 is that the relation between $\text{SO}_x$ and $\text{HCl}$ is not perfect for a good performance, nevertheless the technology works extremely stable even with these high concentrations and these adverse conditions.
6. Energy recovery

The advantage of the dry sorption technology is clearly that the process works reliable and highly efficient with minimum of components and costs.

Now, after the stoichiometric ratio is improved to an optimum value for the reaction, while still being able to handle the residues without any problems it has to be considered how to improve the energy efficiency of the overall system. The exhaust gas still has approximately 140 °C and could be cooled down to extract more heat.

7. Condensation

There are two principal concepts of energy recovery by condensation, which are used in industry: Direct condensation and assisted condensation.

Direct condensation extracts the energy out of the scrubber recirculation water using a water/water heat exchanger and feeding directly into a heat distribution system, in general the district heating grid. This is an easy way utilizing the energy of the flue gas, but only possible when the temperature requirement is not high.

Assisted condensation is working in the same principal, but transforms the recovered energy to a higher temperature level using heat pumps.

Figure 4: Raw gas values related to the lime consumption described in Figure 3
Both systems can work independently and only the temperature requirements of the district heating grid determine if a heat pump is necessary.

Heat pumps are used to transform the temperature level of the water to a higher level. Here we can use absorption heat pumps with saline brine or compressor heat pumps using ammonia as a transfer fluid.

8. Combustion air humidification

Increasing the moisture in the combustion air also boosts the possibility of energy recovery. The condenser recirculation water is passing a water/water heat exchanger feeding the district heating system. Depending on the water level in the condenser the water is partially diverted to the humidifier, where it is sprayed on a packing humidifying and saturating the combustion air passing through here.
Figure 7: Condensation and humidification

A typical humidifier is shown underneath. It is a vessel similar to a scrubber containing a large packing giving an intense area of particle exchange. Liquid distribution is done without using pressure by a perforated plate above the packing. The packing usually is a loose packing with form pieces.

Figure 8: Humidifier and loose packing
The advantage of humidification is that the energy recovery out of the flue gas can be increased by approximately fifty percent in our example. In this case we have exact values from a realized plant in Denmark using the humidification to improve the energy recovery in particular for district heating.

Table 2: Energy recovery with condensation and with humidification

<table>
<thead>
<tr>
<th>Example of biomass plant in DK</th>
<th>Unit</th>
<th>With humidification</th>
<th>Without humidification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flue gas flow</td>
<td>Nm³/h</td>
<td>121,400</td>
<td>114,711</td>
</tr>
<tr>
<td>Flue gas temperature</td>
<td>°C</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Moisture content in flue gas</td>
<td>Vol.-%</td>
<td>28.8</td>
<td>22</td>
</tr>
<tr>
<td>District heating water return</td>
<td>°C</td>
<td>51</td>
<td>51</td>
</tr>
<tr>
<td>Flue gas saturation temperature</td>
<td>°C</td>
<td>70.6</td>
<td>62</td>
</tr>
<tr>
<td>Heat recovery</td>
<td>MW</td>
<td>15.3</td>
<td>9.8</td>
</tr>
</tbody>
</table>

9. Comparism of technologies

As usual there are no two identical plants you can compare. Even if you have two identical lines within one installation there will always be different behavior and different parameters of the two lines.

Therefore the comparism below works on calculated values and shall display the differences of different stages of energy optimization with a standard VapoLAB system as the basis, with no energy recovery.

The magnitude of energy recovery is directly linked to the magnitude of the investment, so it depends on the actual situation of the plant and the plant location which technology and investment is the best and which amount of energy can be used locally.

Table 3: Energy recovery and condensate production of different process constellations

<table>
<thead>
<tr>
<th>FGC type</th>
<th>Conditions</th>
<th>Heat recovery MW</th>
<th>Flue gas temperature °C</th>
<th>Condensate m³/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>VapoLAB</td>
<td></td>
<td>0</td>
<td>138</td>
<td>0</td>
</tr>
<tr>
<td>VapoLAB + Condenser (direct)</td>
<td>DH: 50 °C, DH flow: 800 m³/h</td>
<td>6.29</td>
<td>51.5</td>
<td>4.1</td>
</tr>
<tr>
<td>VapoLAB + Condenser (Packing)</td>
<td>DH: 50 °C, DH flow: 800 m³/h</td>
<td>5.84</td>
<td>52.5</td>
<td>3.8</td>
</tr>
<tr>
<td>Economizer + VapoLAB + 2 steps condenser (Packing + HP)</td>
<td>DH: 50 °C, DH flow: 800 m³/h, CW flow: 330 m³/h</td>
<td>14.91</td>
<td>31.0</td>
<td>11.5</td>
</tr>
<tr>
<td>Economizer + VapoLAB + 2 steps condenser + humidifier</td>
<td>DH: 50 °C, DH flow: 1,000 m³/h, Combustion air: 80,000 Nm³/h dry, T in = 20 °C, T out = 49 °C</td>
<td>9.61</td>
<td>36.5</td>
<td>9</td>
</tr>
</tbody>
</table>

Generally speaking, the most energy efficient installation may not be the best choice for the individual installation because they cannot use the recovered heat, because there is no district heating system.
But it makes sense to plan the location of incineration plants producing power and heat in the neighborhood of a heating grid or an industrial facility requiring.

However, waste incineration serves many different important responsibilities for the society: The waste produced by the community is treated in a safe way and can be landfilled and deposited safely. This important task is done not wasting energy, it produces energy helping to save fossil fuels and preserve the environment.