Disposal of sludge from textile wastewater treatment in cement plants

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Abstract

Textile sludge can be disposed of in a cement kiln. Since some of the sludges contain a high percentage of organic compounds, they must never be mixed with the raw material, but must be incinerated. This means that such sludge must be added either to the primary or secondary firing. This requires, however, that the sludge used has certain homogeneity. Excessive fluctuations in the calorific value would cause disturbances in the kiln system.

With the exception of mercury, heavy metals are no problem with regard to emissions to air and the quality of the clinker. Some textile sludges can deliver a fairly large additional proportion of emissions. The mercury content of the sludges must therefore be monitored and sludges with excessively high contents excluded from use.

1 Introduction

In Asia, wastewater from wet processing of textile is increasingly treated. The reduction of the organic load is usually carried out by means of biological treatment, mainly in activated sludge systems. This is associated with significant amounts of sludge. As a rule of thumb, bacteria of activated sludge convert about half of the degraded organic compounds into biomass. This means that 1 kg of the biochemical oxygen demand results in about 0.5 kg of biomass (as dry matter). In plants with extended aeration, i.e. they are operated at low food-to-microorganism ratio (F/M) (< 0.05 – 0.1 kg BOD_5/kg MLSS x d), the biomass generation can be significantly lower (about 0.25 – 0.35 kg biomass (as dry matter) per kg BOD_5 degraded) and almost zero at F/M lower than 0.05 kg BOD_5/kg MLSS x d and at F/M lower than 0.1 kg BOD_5/kg MLSS x d if, at the same time, the wastewater temperature is high, i.e. higher than 30 °C. In addition, fibers present in textile wastewater can increase the sludge quantity. The same is true if organic agents for decoloration are used. In case a precipitation/flocculation stage using mainly inorganic chemicals (iron or aluminum salts) is applied prior to biological treatment, the additional sludge generation can be significant.

Against this background, increasing amounts of sludge have to be tackled in an environmentally-friendly manner. Repeatedly, the option of co-incineration in clinker[1] production plants is proposed for doing so. However, this option is often not well understood. Therefore, the subject of this study is to closely look into the possibility of disposing of textile sludge in a clinker (cement) production plant and to define adequate conditions concerned. For this purpose, it is assumed that this sludge should be used in a cement kiln system with a preheater but not in a wet or semi-wet kiln.

2 Relevant Data

2.1 Chemical data

The composition of textile sludge is determined by the manufacturing processes and treatment processes of textiles and the chemicals used.

As these processes are constantly changing, the concentrations of organic compounds, heavy metals and other compounds can vary over a wider range. For an assessment of an application in a cement plant, therefore, the analyzed contents of 21 textile sludges analyzed by EcoMetrix in April/May 2011 (EcoMetrix, 2011) are used.

[1] Clinker is produced by sintering of limestone and aluminosilicate materials such as clay and other materials in rotary kilns. Together with additives such as fly ash or blast furnace slag, it is ground to produce cement.

Tab. 1: Comparison of the analysis results of 21 textile sludge samples from Bangladesh (EcoMetrix, 2011) with analysis results from thousands of municipal sludge samples in Germany (UBA, 2018)

		Textile sludge - values from 21 Bangladeshi sludge samples (EcoMetrix, 2011)			Municipal sludge in Germany - ranges from (UBA, 2018) from thousands of samples
		Minimum	Maximum	Average	Minimum - maximum
Moisture	[%]	36.1	92.6	70.4	65 - 75
Dry Matter	[%]	7.4	63.9	29.6	30
Loss on Ignition	[%]			90*)	45 - 80
Ammonium-N	[%]	0.005	0.55	0.1	
TOC	[%]	1.1	44.7	11	33 - 50
AOX	[mg/kg]	4.3	2200	263	200 - 400
Arsenic	[mg/kg]	2	25	4.5	4 - 30
Cadmium	[mg/kg]	0.2	8.9	0.9	1.5 - 4.5
Chromium	[mg/kg]	17	140	56	50 - 80
Cobalt	[mg/kg]	3	21	10	6.5
Copper	[mg/kg]	9.2	1100	173	300 - 350
Lead	[mg/kg]	9	280	32	70 - 100
Manganese	[mg/kg]	43	2000	560	600 - 1500
Mercury	[mg/kg]	0.05	1.6	0.2	0.3 - 2.5
Molybdenum	[mg/kg]	2	3.8	2.2	3.9
Nickel	[mg/kg]	8.7	94	25	30 - 35
Thallium	[mg/kg]	0.1	0.2	0.1	0.2 - 0.5
Tin	[mg/kg]	1	44	9.2	30 - 80
Vanadium	[mg/kg]	3	100	26	10 - 100
Zinc	[mg/kg]	200	4100	916	100 - 300

*) Only one value

2.2 Chemical data

The term "textile sludge" is a collective term for sludges from the textile industry, whereby the composition of the sludges depends on the production process, the substances used, etc. The chemical composition of the sludges can therefore be quite different.

In a co-combustion of textile sludge, the organic substances of the sludge and thus also the organic pollutants must be destroyed. An important parameter is therefore the calorific value or the loss on ignition, which indicates a high organic content in the sludge. Another important parameter is the water content, since the water content reduces the calorific value of the sludge.

As Table 1 shows, textile sludges can have quite different moisture contents. The large proportion of dry sludge is volatile organic compounds and little ash, which is also confirmed by the published calorific value (Anwar et al., 2018) of 17.9 MJ/kg and the loss on ignition values ("weight loss") of 80 % (Iqbal et al., 2014).

The calorific value of the wet sludge is a function of the calorific value of the dry sludge minus the corresponding evaporation heat of the water. Figure 1 shows the calorific value in function of water content and for different calorific values (parameter) of the dry sludge.

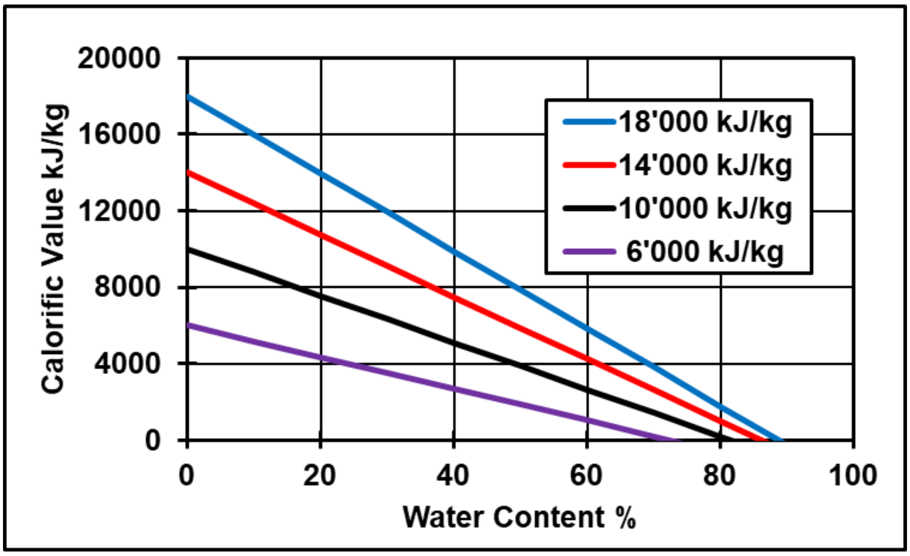

Fig. 1: Calorific value in function of water content and the caloric value of the dry substance (Parameter)

3 Suitability of sludges

3.1 Required homogeneity

In a cement kiln, the raw material used must have a certain homogeneity (chemical composition), and the same applies to all fuels used.

The required homogeneity of such sludge depends on the following factors:

1. Fluctuation of the heat value in the sludge (short term: minutes)
2. Fluctuation of the mass flow of the sludge into the kiln (given by the quality of the dosing system; short term: minutes)
3. Substitution rate

The combined influence of the first two factors produces the fluctuation of the heat input into the kiln by the sludge. The fluctuation of the total heat input into the kiln needs to be below a certain level.
As a rule of thumb, the following formula applies:

% Fluctuation (heat input) x % Substitution < 100 %
where:

% Fluctuation ~ (maximum – minimum) / average x 100
% Fluctuation (heat input) = fluctuation heat value + fluctuation mass-flow
% Substitution = % of heat consumption of kiln

If the fluctuations are higher, impacts caused by the inhomogeneity have to be expected (e.g. CO formation, increased heat consumption, reduced production capacity …)
Examples:

20 % Substitution: < 5 % fluctuation of heat input to avoid negative impacts
10 % Substitution: < 10 % fluctuation of heat input to avoid negative impacts
5 % Substitution: < 20 % fluctuation of heat input to avoid negative impacts

3.2 Homogeneity of the sludge

The measured dry matter and water content of the 21 samples from April/May 2011 vary in a very large range (EcoMetrix, 2011). However, this also means that the calorific values fluctuate accordingly.
This textile sludge with such a variation in the water content respectively in the calorific value must under no circumstances be placed in a cement kiln. Kiln fluctuations and disturbances are to be expected which would not be acceptable under any circumstances. The sludge should not be used without homogenization and/or prior drying.

3.2.1 Dry textile sludge

One possibility, however, would be to dry and homogenize this sludge to a residual moisture of 10% or less, whereby the fluctuation of the calorific value should be as small as possible.

3.2.2 Wet textile sludge

If this sludge is to be used wet, it must be homogenized. This means that sludge with acceptable average water or solids content must be formed and this value may only vary within a certain range, e.g. 20%. From the measured sludges, for example, a homogenized sludge of approximately 30 % dry matter (average value) could be produced without further heat and with some effort the variation respectively the calorific value could be kept below 20 %. Considering the input fluctuations (fluctuation of the input device) in a cement plant, an input of 3 to 4 % of the total heat consumption of the kiln could be possible. (cf. 3.1).

4 Disposal of the sludge in a cement kiln

The cement kiln has three input points for waste (Figure 2), namely:

- the main burner at the rotary kiln outlet end (1)
- the secondary firing (2) for which a number of different versions exist (see the list below)
- the raw material route (3)

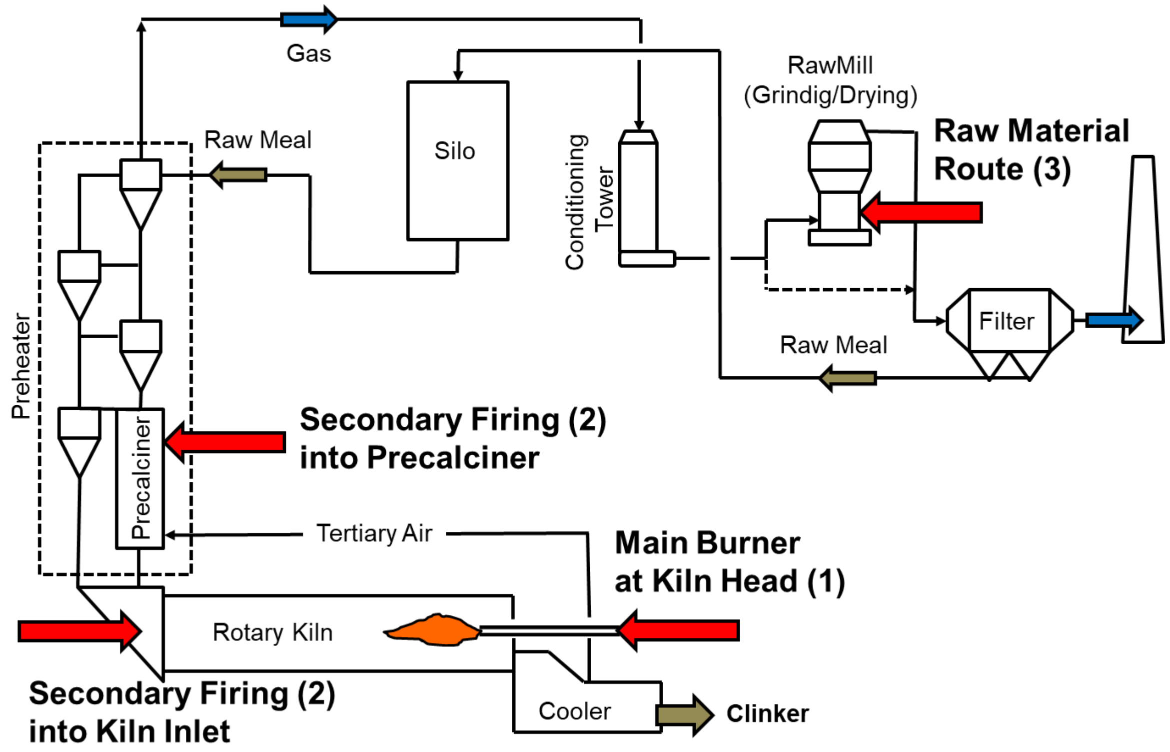

Fig. 2: Overview of a cement plant with the indication of the basic points (numbers 1, 2 and 3) for the feeding of waste-derived fuels and (waste-derived) raw materials.

Concerning the secondary firing, the following feeding points exist in practice:

- via a feed chute at the transition chamber at the rotary kiln inlet end (used for lumpy fuels such as waste tires)
- via secondary burners to the riser duct
- via a precalciner without a burner (so-called flameless combustion)
- via a precalciner equipped with a burner
- via a pre-combustion chamber, that is not equipped with a burner (so-called flameless combustion), prior to the precalciner
- via a combustion chamber, equipped with a burner, prior to the precalciner
- via circulating fluidized bed prior to the precalciner

4.1 Primary (or main) flame

4.1.1 Firing conditions

The maximum temperature in the flame is about 2000 °C and in the rotary part of the furnace the gas stays above 1200 °C for at least 6 seconds. Due to the clinker quality, the burning process in the area of the sintering zone (flame) must be operated with excess air. Therefore, it is expected that the organic substances in this zone will be completely oxidized.

Own investigations at the kiln inlet (transition part rotary kiln / preheater) at several furnaces without secondary firings have shown that all organic substances were oxidized and no organic compounds, in particular no chlorinated organic compounds, could be detected.

4.1.2 Incineration of dry textile sludge

It would be possible to burn this sludge via the main burner. This would have the advantage that all organic compounds would be oxidized and there would be no additional emission of organic substances at the stack.

The condition for an input on the main flame, however, would be that the sludge is dried in advance to a remaining water content of 10% or less and homogenized so that the fluctuations in the calorific value are less than about 5%. Wet textile sludge with high water content should not be fed to the main flame anyway. These fuels reduce the flame temperature due to their low calorific value and this can have a negative effect on the temperature required for clinker formation.

The amount of (dry) textile sludge that can be added via the main flame depends strongly on the burner construction. With an optimal construction, experience with dried sewage sludge has shown that up to about 10 % of the heat requirement can be burnt in the main flame. However, the mass flow of sludge with calorific values below approximately 10’000 kJ/kg] should be limited to approx. 4 t/h.

<u>Assumed kiln characteristic</u>

- Production: 2400 t/day or 100 t/h
- Raw meal mass flow: 165 t/h
- Heat consumption: 3.8 MJ/kg Clinker

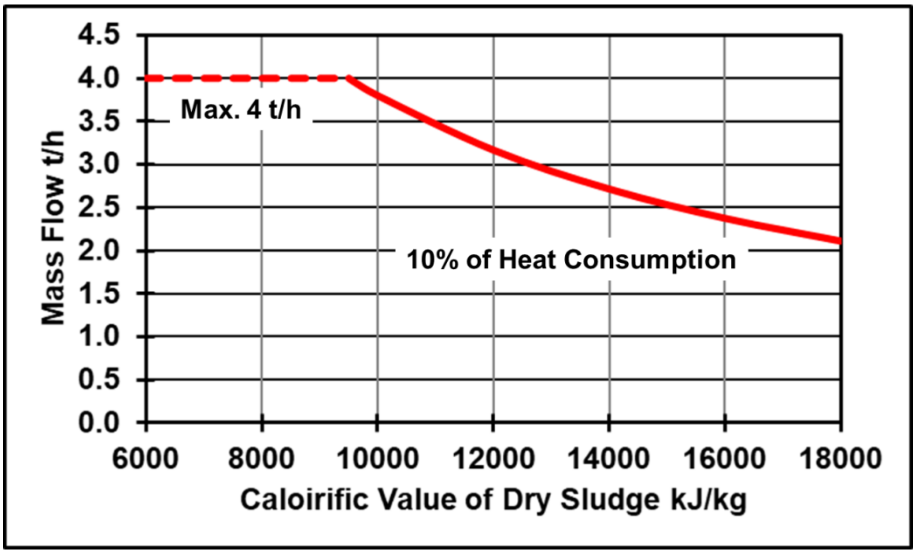

Fig. 3: Maximum input of dried sludge (water content < 10%) for a 10 % replacement of heat consumption of the kiln

4.2 Secondary firing

4.2.1 Firing conditions

In terms of secondary firing, a distinction must be made between the direct input of fuel to the kiln (e.g. tires) and the input of fuel to a special combustion chamber, the calciner. A maximum of about 20 % of the total heat consumption of fuels can be fed into the kiln inlet. The input to the calciner is 40 to 60 %, depending on the design.

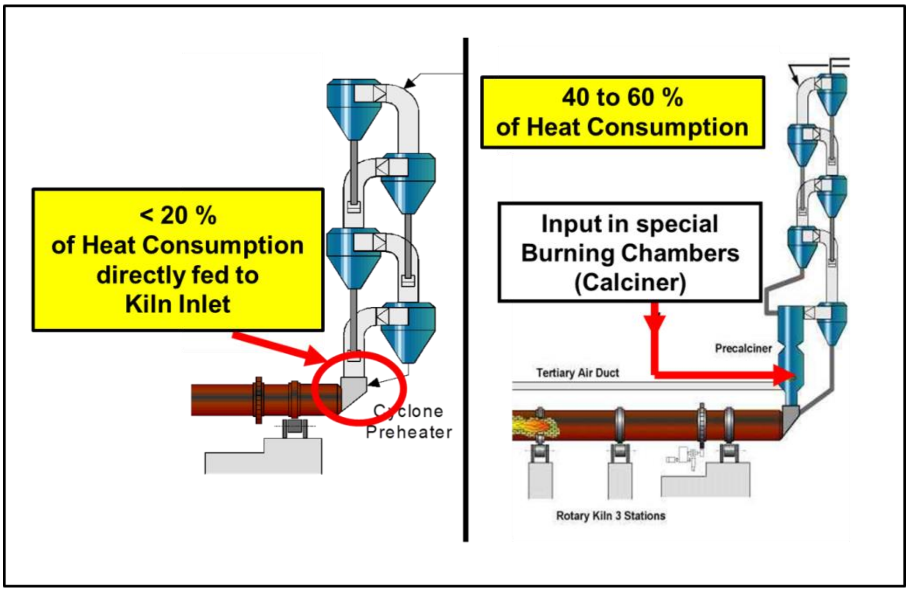

Fig. 4: Fuel Input in Secondary Firings

4.2.2 Co-incineration of textile sludge

Assuming that the sludge can be homogenized up to a variation of the water content below 20 % of the average and that the feed system causes few fluctuations, this corresponds to 3 to 4 %, in the optimal case 5 % of the heat consumption of the kiln. For a kiln described below, the possible mass flow (in t/h) of the textile sludge as a function of the heat input was calculated as a percentage of the total heat consumption of the kiln and as a function of the calorific value of the dry sludge and shown in Fig.4.

<u>Assumed kiln characteristic</u>

- Production: 2400 t/day or 100 t/h
- Raw meal mass flow: 165 t/h
- Heat consumption: 3.8 MJ/kg Clinker

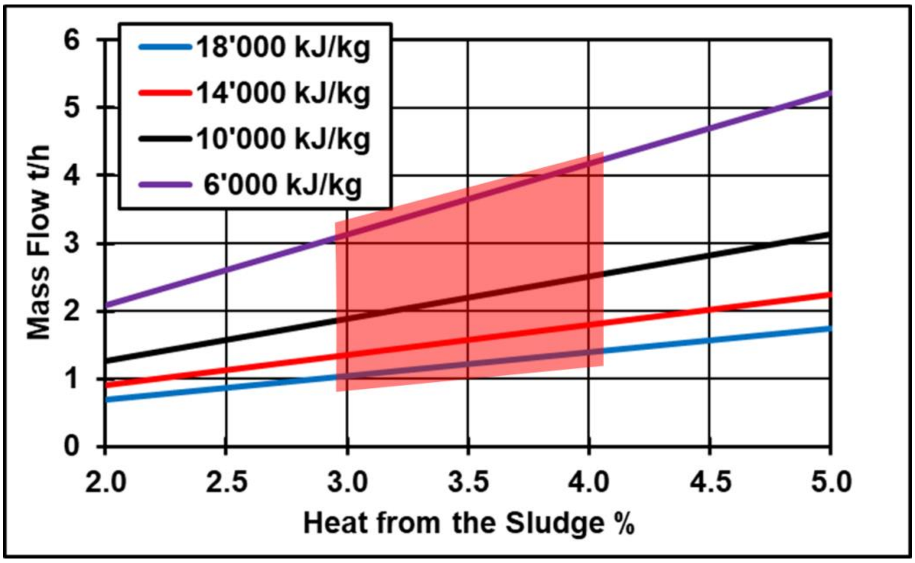

Fig. 5: Mass of sludge in function of heat input of sludge and calorific value of substance; red = recommended range fuel input in secondary firings

In secondary firing, the combustion conditions are much less rigid compared to the kiln when waste-derived fuels, such as sludge, are fed via the main burner. The gas temperature level is much lower (850 - 1100 °C) and the retention time can be less than one second. As a consequence, the incineration can be incomplete. There are cases known where the incineration conditions are highly incomplete resulting in high emissions of carbon monoxide, volatile organic carbon, also including hazardous substances such as benzene. However, in well-designed and well-operated calciners, the incineration conditions can be almost complete which is indicated by resulting carbon monoxide concentrations below 500 mg/Nm^3 and only traces of organic compounds at the outlet of this burning zone.

4.3 Input via raw material route

The addition of this sludge to the raw material would be the easiest way of disposal. **But this method is not a thermal disposal of the sludge and should not be made.**

The organic compounds in this sludge are only adsorbed. Adsorption is the attachment of atoms, ions or molecules from a gas, a liquid or a dissolved solid to a surface. That is, the organic substances are only slightly embedded in the base material. A reaction with the base material (absorption) usually does not take place. When such slurry is mixed in the raw material, it will be slowly heated in the kiln system and the organic compounds evaporate below about 400 °C and are emitted. So critical organic substances do not get into temperature zones where they are oxidized.

5 Heavy metals

The textile sludge contains some heavy metals. In the following, the emission factors EF published by the VDZ (VDZ, 2018) or my own factors (Mo and Zn) are used to calculate the possible emission and integration into the clinker for a sludge the maximum (dry) mass flow of 4 t/h.

Tab. 2: Emission and Input into the Clinker from the Textile Sludge

Heavy Metals	**Max. Content mg/kg**	**Factor EF %**	**Input g/h**	**Emission mg/m^3_N**
Arsenic	25	0.023	99	0.0001
Cadmium	8.9	0.17	260	0.0003
Chromium	140	0.012	288	0.0003
Cobalt	21	0.019	68	0.0001
Copper	1100	0.0093	1756	0.0018
Lead	280	0.05	2403	0.0024
Manganese	2000	0.018	6180	0.0062
Molybdenum	3.8	0.01	27465	0.0000
Nickel	94	0.03	7	0.0005
Thallium	0.2	1.3	484	0.0000
Tin	44	0.074	45	0.0006
Vanadium	100	0.052	559	0.0009
Zinc	4100	0.01	893	0.0070

5.1 Influence on stack emission and on clinker

The calculated emission is generally well below the detection limit of the corresponding element. The influence of the textile sludge is therefore marginal. Also an increase of the input over the assumed maximum mass flow of 4 t/h does not change this statement. A comparison of the influence of textile sludge with the detection limits (VDZ, 2018) and with the Swiss limits for clinker produced with waste (VVEA, 2018) shows a negligible influence. Quality problems with the clinker can thus be excluded, even if the input would be increased over the assumed 4 t/h.

Tab 3: Assessment of the calculated values

Assessment of Values	**Influence on Emission**		**Influence on Clinker**	
	Detection Limit mg/m^3_N (VDZ, 2018)	Emission mg/m^3_N	Limit mg/kg Clinker (VVEA, 2018)	Input mg/kg Clinker
Arsenic	0.0011	0.0001	15	0.0010
Cadmium	0.0001	0.0003	5	0.0004
Chromium	0.0017	0.0003	250	0.0056
Cobalt	0.0002	0.0001	125	0.0008
Copper	0.0013	0.0018	250	0.0440
Lead	0.0030	0.0024	250	0.0112
Manganese	0.0050	0.0062	---	0.0800
Nickel	0.0013	0.0005	250	0.0038
Thallium	0.0003	0.0000	---	0.0000
Tin	0.0001	0.0006	50	0.0018
Vanadium	0.0003	0.0009	---	0.0040
Zinc	0.0050	0.0070	750	0.1640

5.2 The emission of mercury

The element mercury is an exception. Here, influences of the textile sludge can be expected. The following values were calculated under the condition that all mercury is emitted and nothing is discharged from the system via a dust outlet.

Tab 4: Influence of Mercury (Hg)

Hg-Values	**Content mg/kg**	**Emission mg/m^3_N**
Maximum	1.6	0.0275
Average	0.2	0.0034
Minimum	0.05	0.0009

Compared with the German emission limit values (17. BImSchV, 2013) of 0.03 (daily average value) or 0.05 mg/m^3 (half-hourly average value), textile sludges can deliver a fairly additional large proportion of emissions; even exceeding the limit values is possible.
The mercury content of the sludges must therefore be monitored and sludges with excessively high contents excluded from use.

6 Conclusions and recommendations

Textile sludge can be incinerated in the cement plant, but the following conditions must be met:

- Use in the main flame: Only dry sludge (moisture < 10 %) can be used here and a maximum of about 10 % of the heat consumption of the kiln can be replaced. In any case this input point guarantees complete oxidation of all compounds.
- Use in secondary firing: Wet sludge can also be used here, but the humidity respectively the calorific value must not fluctuate by more than 20%. Under these conditions, a replacement of the heat requirement of 5% is then possible.
- Addition to the raw material: Under no circumstances must the sludge be disposed of via the raw material path. The organic compounds evaporate in this way and are emitted at the chimney.

With the exception of mercury and thallium, all heavy metals are largely incorporated into the clinker. Thus not only the calorific value of the sludge is used, but at the same time all heavy metals of the sludge are completely "disposed of".
Sludges with high mercury contents may cause emission problems and should not be incinerated.

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