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## Characterization of ash deposits from municipal solid waste (MSW) incineration plants

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### Abstract

In this work, chemical compositions and micro morphologies and structures of ash deposits from two municipal solid waste-to-energy (WtE) plants in Norway were analyzed and characterized. The ash deposits were sampled from different locations in the combustion chamber. The samples were analyzed by a combination of a scanning electron microscopy equipped with energy dispersive X-ray spectroscopy (SEM-EDX) and X-ray fluorescence (XRF). The samples collected from locations close to the grate contain high concentrations of Ca and Si. Concentrations of K, Na, Cl and S in the deposits sampled from the top of the combustion chamber are significantly high. A layered structure can be seen from the deposit samples. The inner layer closer to or directly in contact with a heat transfer tube surface can be considered as primary deposits that have high concentrations of Cl, S, K and Na. The primary deposit layer has dense and compact structure due to the sintering and melting of deposited ash particles and grains. Together with XRF analysis, the SEM-EDX analysis revealed that the primary deposits are probably formed due to deposits of fused sulfates and chlorides on the heat transfer tube surfaces. The outer layer of the ash deposits has more loose structure formed due to agglomeration of smaller size grains. SEM-EDX and XRF analyses showed that the Ca, Si, Al and S are dominant elements in these large grains, indicating existence of calcium sulfates, silicates and calcium and silicon oxides.

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## 1. Introduction

Incineration with energy recovery is currently the most important and efficient way to dispose and manage Municipal Solid Waste (MSW) worldwide [1]. The volume and amount of MSW can be significantly reduced through incineration. It preserves landfilling space and limits the negative effects of MSW to environmental and water systems. The MSW incineration is often combined with heat and power production and material recycling, which maximizes the valorization of MSW. However, MSW is a mixture of inhomogeneous materials with high ash content and complex chemical compositions. MSW usually contains high concentrations of chlorine, sulfur and alkali metals, and minor concentrations of heavy metals like lead and zinc. During transportation and storage, MSW is often contaminated by soil, sand and stone, which enhances the Si content in the MSW. During incineration, a large fraction of the inorganic elements in the MSW will volatilize and transform through complex chemical reactions. Part of the MSW, its combustion residues and generated ashes will be entrained by inlet air through the fuel bed, into finally the flue gas. These volatiles and entrained fine fuel/ash particles in the flue gas can lead to formation of deposits on heat transfer surfaces [2]. With accumulation and sintering of the ash deposits, the heat transfer can be significantly hampered, decreasing the energy conversion efficiency of the WtE plant. Additionally, certain elements (mainly Cl and S) and chemicals in the ash deposits attack the heat transfer tube, leading to corrosion and thinning of the tubes. This requires costly cleaning and maintenance for the heat transfer tube surfaces and therefore reduce the economic viability of WtE. It is necessary and important to perform detailed characterization and analyses of deposits collected from the MSW incineration plants in order to understand ash deposition formation processes, to be able to propose effective mitigation measures.

## 2. Materials and Methods

### 2.1. Sample

Four ash deposit samples in total were collected from two Waste-to-Energy (WtE) plants in Norway. The first two ash deposit samples were collected from Heimdal WtE plant operated by Statkraft Varme AS. The other two ash deposit samples were collected from Haraldrud WtE plant operated by EGE Waste to Energy Agency in Oslo. All ash deposits were sampled directly from the heat transfer tube surfaces during planned shutdown and maintenance periods. In both WtE plant, the combustion system is based on a moving inclined grate with two-stage air injection. The primary air is preheated and distributed throughout the grate in several separately controlled zones. The secondary air is injected from top of the combustion chamber. The bottom ash is discharged to a chain conveyor at the far end of the grate. The four ash deposit samples were collected from vertical surface locations from close to the grate to the top of the right side wall of the primary combustion chamber. From the Heimdal WtE plant, the ash deposit sample #1 was collected at a position 2 meters above the grate. It means that this sample was exposed to a higher temperature and probably direct flame contact as well. The ash deposit sample #2 was collected from a position 10 meters above the grate, which is at the top of the combustion chamber. This is the zone where the flue gas turns and flows into the superheater section. In the Haraldrud WtE plant, the ash deposit sample #3 was also collected from a position about 2 meters above the grate. The ash deposit sample #4 was collected from a position below the flue gas entrance to the superheater section, which is about 8 meters above the grate. The four collected ash deposit samples were photographed and labelled right after collection. In order to analyze the deposition formation mechanisms, two sub-samples were obtained from the inner and outer layers of the original ash deposit samples. A similar sampling method and procedure can be found in our previous work [2, 3]. Therefore, in total eight samples were analyzed.

### 2.2. Sample analysis

The two sub-samples were carefully cut from the inner and outer layer of an original ash deposit sample respectively, in order to retain their initial rather dense structure and compact surface. Each sub-sample was divided into two parts for further chemical composition, microstructure and chemistry analyses. A portion of the sample was crushed into a fine powder and analyzed by an X-ray fluorescence (XRF) analyser (Bruker, S8 Tiger) for quantifying concentrations of elements in a sample. The XRF analyses results are presented as oxides. The other part of the sample

(with its original dense structure) was examined by a scanning electron microscopy (SEM) to investigate its microstructure and morphology. The scanning electron microscopy (SEM) was coupled with energy dispersive X-ray analysis (EDX), enabling to determine elemental concentrations in selected spots and areas.

### 3. Results and Discussion

#### 3.1. Chemical composition analysis

Fig. 1. shows the chemical compositions of the ash deposits sample #1 and #2. It is clear that the ash deposit sample #1 contains high concentrations of Ca, Si, Al and Fe. The sample #1 was collected from the lower section of the combustion chamber, close to the grate. Entrainment of ash particles from the fuel bed on the grate will occur, and they will attach to, accumulate and sinter on the combustion chamber wall. The four dominant elements in the ash deposit sample #1 are non- or less volatile chemical elements. Therefore, detection of these four elements in the ash deposits sample #1 is probably mainly associated with deposition of entrained fuel/coarse ash particles. On the other hand, the ash deposits sample #2 contains high concentrations of S, Cl, K and Na. These are elements with high volatility, which will be released and evaporate during devolatilization and further combustion of MSW to form vapors, aerosols and/or fine particles. The gas flow will transport the vapors, aerosols and/or fine particles from the bottom up to top section of the combustion chamber. As the gas reaches a lower temperature zone in the combustion chamber, the vapors, aerosols and fine particles will condense on colder heat transfer tube surfaces and act as a sticky layer [4] favoring further deposition.

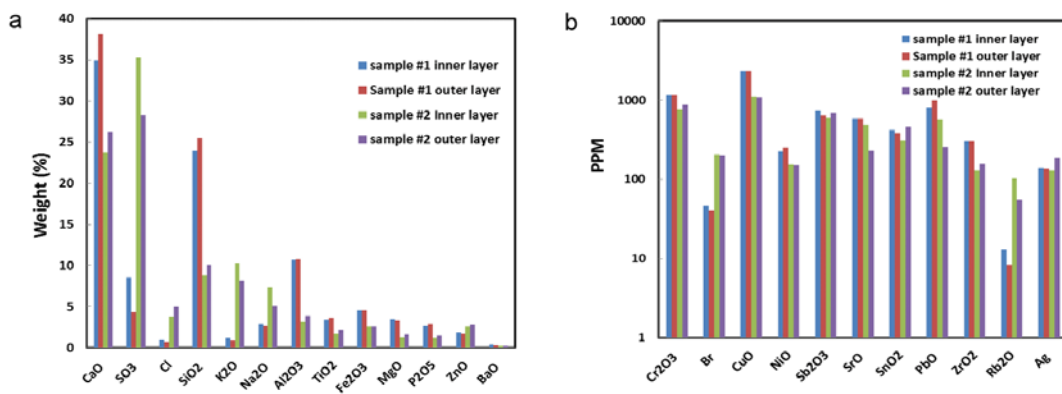


Fig. 1. Chemical composition of deposit sample #1 and #2 (a) main elements; (b) minor elements.

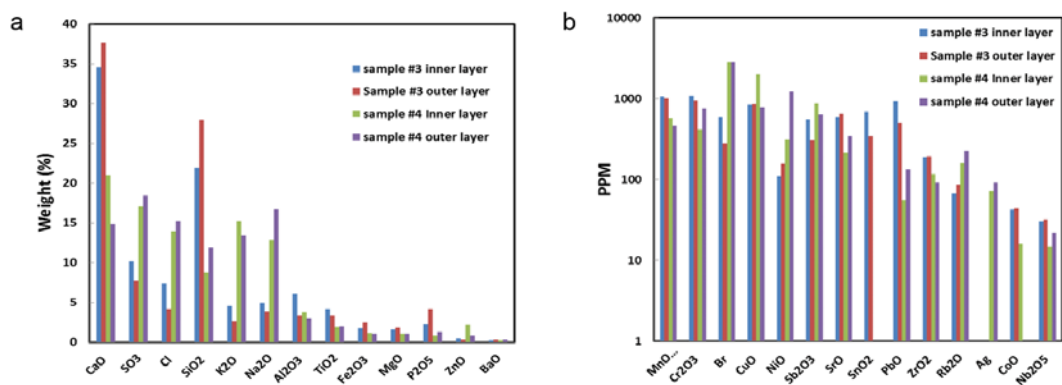


Fig. 2. Chemical composition of deposit sample #3 and #4 (a) main elements; (b) minor elements.

With time, more aerosols and fine particles in the flue gas will be captured by the primary sticky layer, resulting in further formation of bulky and denser deposits. Fig. 1 (a) also displays considerable differences in chemical compositions of inner and outer part deposits. High concentrations of Ca, S, Cl, K and Na are detected in the inner layer deposits close or in direct contact with heat transfer tube surfaces. It indicates that primary deposits on the heat transfer tubes consist of mainly calcium sulfates, alkali sulfates and chlorides. These sulfates and chlorides have low melting temperatures and are present as vapors, aerosols and droplets in the flue gas [4]. After reaching the heat transfer tube surfaces, they will condense and act as a glue to bind impacting fly ash particles. In Fig. 2 (a), similar element distributions in the inner and outer part of the ash deposit sample #3 and #4 are displayed. Fig. 1 (b) and 2 (b) show that the concentrations of minor elements in the samples collected from the lower and higher section of the combustion chamber are rather different. Such differences are mainly associated with different volatilities and further reaction of them under different conditions [5]. Currently, landfilling is the most common way to dispose of the fly ash from MSW incineration plants. Therefore, fly ash from different sections of one MSW incineration plant should be treated differently, considering their different concentrations of harmful minor elements.

### 3.2. SEM-EDX analysis

Fig. 3 and 4 show SEM images of the inner and outer layer of ash deposit sample #1 to #4. It can be clearly seen in Fig. 3 (a) that the inner layer of ash deposit sample #1 has intact and smooth surface, indicating intensive melting of the material in the scanned area. Ca, S, K and Na are the main elements detected by EDX from this area, indicating formation and subsequent melting of Ca and alkali sulfates.

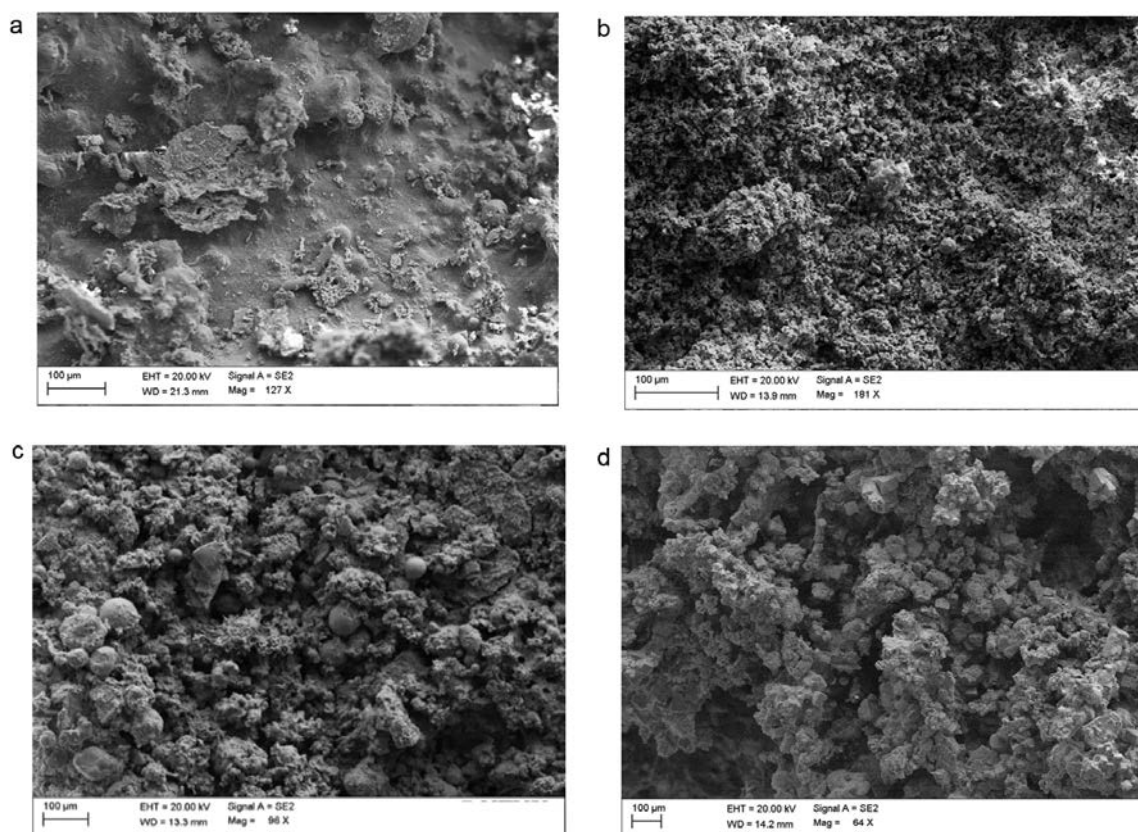


Fig. 3. SEM image of (a) ash deposit sample #1 inner layer; (b) ash deposit sample #1 outer layer; (c) ash deposit sample #2 inner layer; (d) ash deposit sample #2 outer layer.

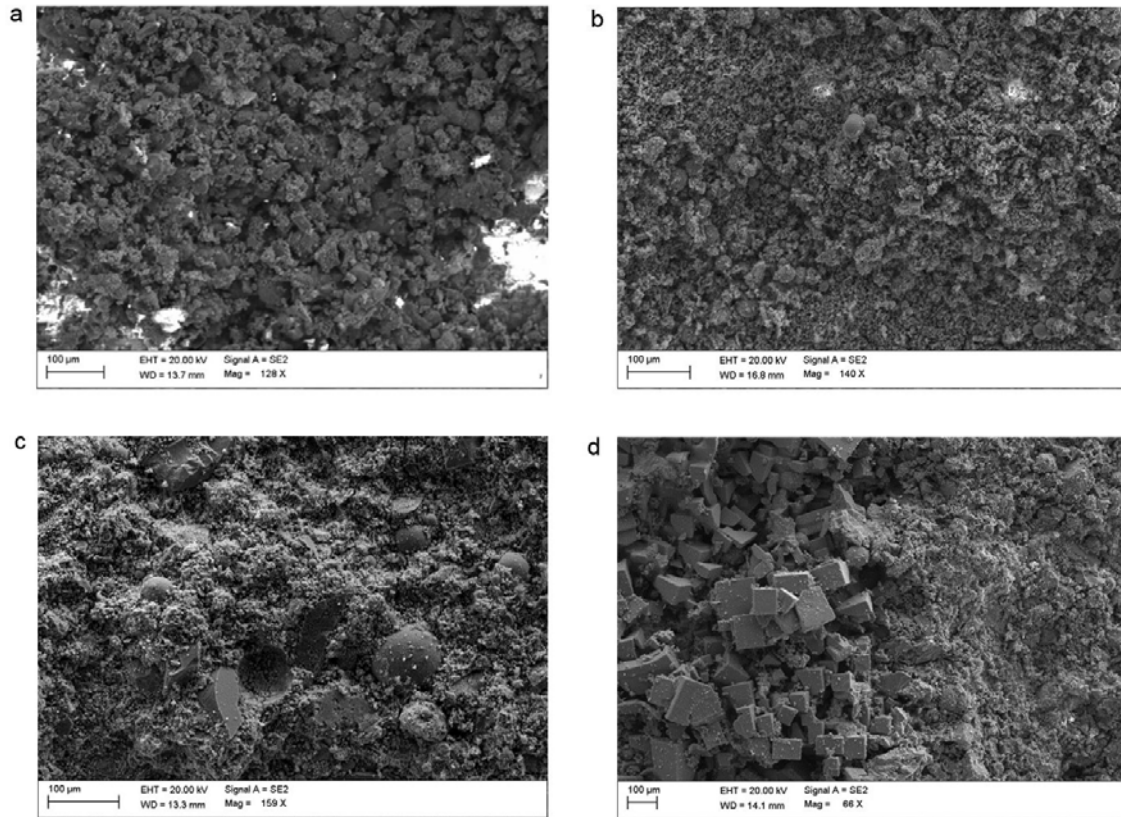


Fig. 4. SEM image of (a) ash deposit sample #3 inner layer; (b) ash deposit sample #3 outer layer; (c) ash deposit sample #4 inner layer; (d) ash deposit sample #4 outer layer.

Fig. 3 (b) shows a SEM image of the outer layer of sample #1. Compared to the inner layer of the deposit, the outer layer deposit is made up of a large number of agglomerated or sintered fine particles. Several grains with round shapes and smooth surfaces can be observed in the same picture. Fig. 3 (c) shows that the inner part of the ash deposit sample #1 is significantly different from that of sample #2 that was collected from the lower section of the combustion chamber. There is no clear melting visible in Fig. 3 (c). It is most probably related to lower temperatures in the top section of the combustion chamber, temperatures not high enough to cause intensive melting of the ash deposits. As shown in Fig. 3 (c), the inner layer of sample #2 is built up by agglomeration of cubic-like, elongated, plate-like, polygon and spherical particles with different sizes. The various shapes of the deposited ash particles are mainly attributed to intensive ash entrainment but also the variable composition of MSW [6]. According to EDX analysis, the dominant elements in the large spherical particles are Ca, Si, Al, K and Na, indicating formation and melting of silicates. Fig. 3(d) shows that the outer layer of ash deposit sample #2 is built up with clusters of cubic-like and irregular shape particles. The size of these particles are rather similar, in the range of 15-30  $\mu\text{m}$ . EDX analysis results indicate that they are containing mainly alkali chloride and calcium sulfates. Fig. 4 displays that the ash deposit sample #3 and #4 have similar morphology and microstructures as found for the ash deposit sample #1 and #2. The similarities of morphology, microstructures and chemistry of samples from the two plants indicate that general formation mechanisms in term of deposit formation can be concluded. To the author's best knowledge, the present work is the first study about SEM-EDX analysis on ash deposits samples collected from different WtE and comparison of analysis results. Complementary mineralogical investigations on the samples with XRD will be conducted.

#### 4. Conclusions

In this work, ash deposits from two WtE plants were collected and characterized in terms of bulk chemical composition, morphology and microstructure. The results showed that the chemical compositions of the samples collected from the lower and top section of the combustion chamber are significantly different. The ash deposit samples collected from lower section of the combustion chamber contains more non- and less volatile Ca, Si, Al and Fe. Their formation is mainly originating from the entrainment and agglomeration of coarse fuel/ash particles from the grate. On the other hand, the ash deposit samples from the top section are rich in S, Cl, K and Na that are readily devolatilize from the MSW during the combustion process. Formation of the ash deposits sample in the top section of the combustion chamber is due to condensation, agglomeration and sintering of calcium sulfates, alkali sulfates and chlorides.

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#### References

- [1] Becidan M, Wang L, Fossum M, Midtbust HO, Stuen J, Bakken JI Evensen E, Norwegian Waste-to-Energy (WtE) in 2030: Challenges and Opportunities. *Chemical Engineering Transactions*, 2015; 43: 2401-2406.
- [2] Wang L, Øye B, Becidan M, Stuen J, Skreiberg Ø. Ash deposits characterization in a large-scale municipal waste-to-energy incineration plant. *Chemical Engineering Transactions*, 2016; 50: 25-30.
- [3] Wang L, Øye B, Becidan M, Fossum M, Skreiberg Ø. Composition and morphology of ash produced in a Waste-to-Energy (WtE) plant. *Chemical Engineering Transactions*, 2016; 50:157-62.
- [4] Eichelet J, Pfrang-Stotz G, Bergfeldt B, Seifert H, Knapp P. Formation of deposits on the surfaces of superheaters and economisers of MSW incinerator plants. *Waste Management*, 2013; 33: 43-51.
- [5] Becidan M, Houshfar E, Wang L, Lundstrøm P, Grimshaw A. S-Cl-Na-K chemistry during MSW gasification: A thermodynamic study. *Chemical Engineering Transactions*, 2015; 43:2011-2016.
- [6] Phonegphiphat A, Rcu C, Finney KN, Sharifi VN, Swithenbank J. Ash deposit characterisation in a large-scale municipal waste-to-energy incineration plant. *Journal of Hazardous Materials*, 2011; 186: 218-226.



#### Biography

Liang Wang is a research scientist at SINTEF Energy Research in Trondheim Norway. His research focus on characterization of biomass and wastes using combined analytical instruments and techniques, advanced biomass carbonization technology, experimental and kinetic study of torrefaction, pyrolysis, gasification and combustion, of biomass and charcoal, ash chemistry during biomass and waste thermal conversion.