Plasma Gasification of Spent Ion Exchange Resins and the Ash Conditioning in Geopolymer Matrix

FISA EURADWASTE 2025
SNETP Forum

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Introduction

Numerous technologies for thermal treatment of radioactive waste are currently available or under development worldwide. These technologies can be applied to various radioactive waste streams, including non-standard waste types with specific waste management challenges. The SIIEG NASU research group have worked with partners for several years to develop a hybrid gasification process of IER with incineration by plasma torch and gas cleaning technologies for different applications. The gasification process involves heating waste in a low-oxygen environment where it undergoes partial oxidation and combustion. The process converts the organics in the waste into a synthetic hydrocarbon gas (syngas) composed primarily of CO, H, and CH4. After gasification, the bottom ash was immobilised as the final waste form before final disposal. The THEREMIN project has previously developed an advanced immobilisation technology based on geopolymerization.

Description of the research problem

The plasma thermal treatment process is a fundamentally new technology of a multiloop circulating gasifier, which provides a complete thermal decomposition of RSOW at high temperatures in the reactor without oxygen. Ecological safety is the primary requirement imposed on modern RSOW processing technology. Adopting the multiloop circulation gasifier principle in waste processing allows for the significant fulfilment of this requirement, given the more profound destruction of waste. Furthermore, toxic volatiles in the pyrolysis gas are after-burned at a high temperature using a plasma torch and completely decompose. After gasification, ash is loaded into steel containers for further encapsulation. The first results of a bench scale arrangement combining both technologies are presented.

The thermal treatment unit consists of a hopper for loading waste, a gasification chamber, a gas afterburner, a heat exchanger, a smoke exhauster and a control unit (Fig 1).

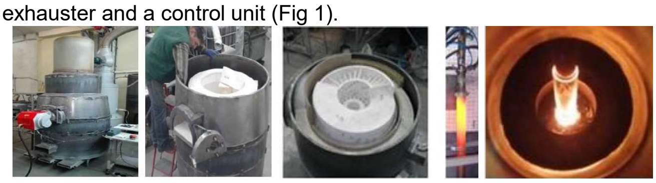


Figure 1. System for thermal treatment based on gasification technology

The lining is made of high-temperature ceramics, and the heat exchanger is made of stainless steel. Plasma technologies require unique refractory lining materials that are durable at extremely high temperatures and are aggressive in the influence of residue ash (slag). The construction of a high-temperature reactor has provided the most effective heating slag and prevented excessive heat losses (Fig. 2). The experiments were carried out using a plasma torch with a reactor with a spatially developed active zone.

Figure 2. The treatment process IER.

The main physical parameters of the process (e.g., temperature, pressure, time, and gas composition) are controlled. The automatic operating system (automatic cycle selection) for the entire cycle guarantees maximum safety. A surrogate waste cationic IER was used for loading during the experimental work. Processing occurs with the synthesis of gas, solid residue, and gaseous compounds, which are dependent on thermodynamic parameters and process speed.

Research Outlook

This study demonstrated that gasification of the IER would reduce the total volume requiring predisposal treatment. Thus, the thermal treatment process uses a plasma torch with a multi-loop circulating gasifier that completely decomposes RSOW without access to oxygen at high temperatures. An experimental test demonstrated the process's capability to treat spent IER through gasification and final ash solidification.

Characterisation of ashes after treated RSOW

Due to the strong dependence of the carbon content in the ash on the condition and temperature of IER waste gasification, one of the main goals was to characterise the ash phases and link this information to their behaviour under solidification. The thermal degradation samples of IER were studied, including the cracks and fragmentations from the original, and sintered into 5–10 mm size aggregates (Fig. 3).

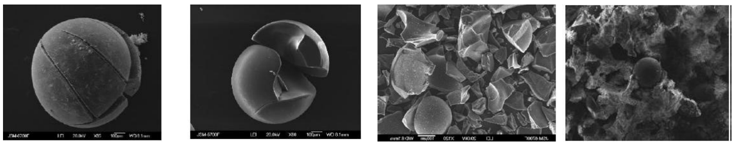


Figure 3. Destruction of IER under Gasification

The DTA analysis of ash samples (Fig 4) suggests that the degradation of IER can be separated into primary stages. For cationic IER, most weight loss results from decomposing the functional groups from 250 to 800°C. The last stage (temperatures from 800°C) is associated with degrading the particle's organic matrix and its subsequent mineralisation. The FTIR analysis shows that due to sulfur groups' symmetric and asymmetric stretching vibrations, bands between 1000 cm^{-1} and 1200 cm^{-1} are observed in the spectrum after the dehydration reaction. The thermal degradation study of acid ($–SO^3H^+$) cationic IER shows a mass loss up to 900°C.

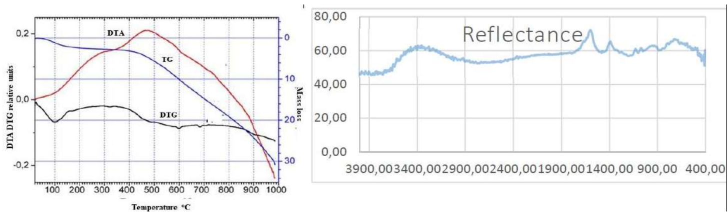
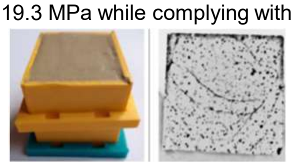


Figure 4. DTA and FTIR analysis of samples of ash

Interactions between the ash components and the geopolymer grout can affect the matrices' setting, hardening, and strength development, which are associated with the chemical characteristics of ash.

Preparation of geopolymer materials

Experiments were conducted with geopolymers on base blast-furnace slag (BFS) and metakaolin (MK). Modified slag-alkali grout with increased liquid glass was applied to create matrices into embedded waste. The pre-mixed alkaline activators and water were used as activators, using hydroxide potassium and solution silicate sodium. The obtained ash has been encapsulated in an alkali-activated geopolymer matrix with a loading factor of up to 24 wt.%. Metakaolin was added to the mortar binders to increase the porosity to 15% to prevent cracking, yet reduced the compressive strength to 19.3 MPa while complying with waste acceptance criteria (Fig 5)



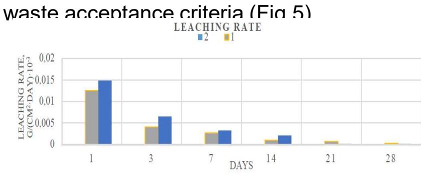


Figure 5. Geopolymer compound **Figure 6**. The leaching rate of caesium

Samples were taken for leaching after 28 days of hardening in an atmosphere of saturated water vapour. Analytical data obtained for the leaching of the surrogate have been based on ICP-MS results. According to these results, the values of the leaching rate were calculated and presented in (Fig.6).

Conclusions

The properties of binders' compositions of geopolymers intended to immobilise thermally treated organic wastes have been studied. The strength indicators of the compositions primarily depend on the ash's physical and mechanical properties. The leaching test showed that the MK/BPS geopolymer matrix has good leaching resistance and that the Cs leaching rate does not exceed the VAC for solidification waste.

Acknowledgement

This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945098