Whitepaper

Endress+Hauser
People for Process Automation

High temperatures, high stakes

The applications, challenges, solutions and future outlook for high-temperature thermocouples in energy recovery plants.

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Executive summary
This white paper explores the essential role of high-temperature thermocouples in energy-from-waste (EfW) plants. Accurate temperature monitoring is critical for operational efficiency, safety and regulatory compliance in energy recovery. Thermocouples provide real-time data vital for combustion control, emissions reduction and equipment protection in harsh, high-temperature environments. However, these conditions pose significant durability challenges unless high-performance thermowell materials are used. Endress+Hauser addresses these challenges through advanced material selection, customised design and collaboration with plant operators, achieving extended device lifespans and improved cost-efficiency. Looking ahead, the role of temperature measurement will only grow as EfW plants evolve with carbon capture technologies and potential transitions to waste-to-chemicals production. With a leading presence in UK EfW sites, Endress+Hauser remains at the forefront of thermocouple innovation, supporting the industry's current needs and future ambitions.

Introduction
Energy-from-waste (EfW) plants are facilities designed to generate electricity and sometimes heat by incinerating non-recyclable waste materials. These plants serve a dual purpose: they help manage waste that would otherwise go to landfill, and they contribute to the country's energy supply by converting waste into usable energy. EfW plants operate under strict environmental regulations to control emissions and ensure safe operation. By reducing the volume of waste and recovering energy, these facilities support the UK's broader goals of sustainable waste management and a low-carbon energy transition.

Left: Photo taken at an EfW site demonstrating a typical failure mode of high-temperature thermometers. Shown is the cracking and failure of an alumina ceramic thermowell.

Left: Endress+Hauser's iTHERM FlameLine TAF16 high-temperature thermometer can be manufactured in a range of materials to maximise protection from temperature, corrosion and oxidation.

High-temperature thermocouples offer several key benefits when used in EfW plants, which operate at very high temperatures to ensure complete combustion and reduce harmful emissions. High-temperature thermocouples provide precise and reliable measurements critical for maintaining optimal combustion conditions. The devices are required to withstand extreme heat, corrosive gases and abrasive particles common in waste incineration environments, with their durability affecting the frequency of replacements and maintenance.

As well as providing improved efficiency and control, accurate temperature measurement is essential to meet strict environmental regulations regarding emissions and waste treatment, making thermocouples a vital component in EfW plant instrumentation. Most importantly for owners and operators of these plants, reliable temperature measurement is vital to prevent damage to plant infrastructure and ensure overall operational safety for both their staff and the public.

The role of thermocouples in EfW plants

Thermocouples are temperature sensors that function based on the Seebeck effect. When two dissimilar metals are joined in an electrical circuit two junctions are created and, if a temperature gradient is present between those two junctions, a voltage is generated. The magnitude of this voltage is proportional to the size of the temperature difference between the 'hot' junction and the 'cold' or reference junction.

In EfW plants, thermocouples are vital for providing accurate, real-time temperature measurements in both combustion chambers and the boiler flue gas path. In the combustion chambers, reliable and precise data from high-temperature thermocouples enables operators to maintain optimal combustion conditions, improve energy efficiency and ensure compliance with environmental regulations. There is often a requirement to maintain temperatures within a particular range for a defined period to reduce the emissions of nitrogen oxides (NOx) and sulphur oxides (SOx). Temperature monitoring in the flue gas path of the boiler is carried out for two reasons, the first being to determine how much water is needed to be fed to the boiler drum from the deaerator on a closed loop boiler system. The aim is to prevent corrosion, ensure efficient heat transfer and maintain boiler reliability. The second reason is for equipment protection, to ensure the correct mixture of water and steam is present in the boiler drum. Failing to monitor boiler and flue gas temperatures effectively can increase the difficulty in controlling boiler drum level and low-level incidents in the boiler drum can lead to potentially catastrophic steam explosions, particularly if the pressure is not released using an over-pressure protection system.

These temperature measurements are so critical that they are performed using a two out of three (2oo3) voting system. In this setup, three identical thermocouples monitor the same parameter, and a control decision is made based on the agreement of at least two out of the three. The main purpose of this system is to increase reliability and safety. If one sensor fails or provides an inaccurate reading due to a fault or drift, the system can still operate safely by

relying on the other two. This approach minimises false alarms or unnecessary shutdowns, while still ensuring that real issues trigger the correct response. It's even common for six instruments to be used at once, to provide stand-alone layers of protection for the safety instrumented system (SIS) independent of the control system.

Regulatory and compliance considerations

In the UK, temperature measurement in EfW plants is governed by a combination of national legislation and environmental regulations, primarily enforced by the Environment Agency (EA). These regulations collectively ensure that EfW plants operate safely, efficiently and with minimal environmental impact, with temperature measurement playing a crucial role in compliance and performance.

Key regulations include the Environmental Permitting (England and Wales) Regulations 2016, which require EfW plants to obtain environmental permits that stipulate strict conditions, including continuous temperature monitoring in the combustion chamber to ensure complete waste incineration and control of emissions such as NOx and SOx. In addition, the Waste Incineration Directive (WID), an EU directive retained in UK law post-Brexit, mandates that the temperature in the combustion chamber must be maintained at a minimum of 850°C for at least two seconds (or 1,100°C for hazardous waste), ensuring complete destruction of organic pollutants.

There are also requirements for continuous emissions monitoring systems (CEMS), often working in tandem with temperature controls and essential for validating emissions data and demonstrating compliance with legal limits.

Challenges in high-temperature environments

EfW facilities operate at temperatures in excess of 800°C. These high temperatures are needed to avoid harmful and odorous gases which can be a byproduct of incomplete combustion. However, these temperatures are still not hot enough to burn or even melt some inorganic contents such as glass. To avoid this, some modern operations utilise higher heat, achieving temperatures of up to 1650°C through the addition of auxiliary fuel.

The thermocouples used for temperature monitoring therefore need to be able to withstand these extreme environments. Endress+Hauser's thermocouples can be manufactured in a wide range of materials from basic stainless steels to advanced, high-temperature, high-corrosion and oxidation-resistant alloys and ceramics. These thermowell materials include Kanthal, Incoloy, silicon nitride (Si_3N_4) or carbide ceramics and other specially sourced materials, offering extended life cycles within the harsh conditions found in EfW plants.

Around 63 EfW plants are operational in the UK.

When considering which material is most appropriate, the type of waste being incinerated needs to be considered. Feedstocks to EfW plants can vary significantly depending on location, the waste supplier and origin of the waste. Propane gas cannisters or batteries in the waste, for example, can cause localised explosions, leading to temperature spikes and mechanical shock damaging fragile alumina ceramic thermowells. In this case hard ceramics such as Si3N4 and silicon carbide (SiC) may be used for the thermowells.

Cost-benefit analysis

Due to the high temperatures, corrosive gases and abrasive ash found within the furnace, the operational lifespan of these temperature instruments can be as little as four weeks. However, the correct application of appropriate thermowell materials can help elongate their lifespan – sometimes significantly. This not only controls costs by reducing consumption of the instruments but limits the need to regularly exchange the probes in operation, which is a hot, dusty and demanding task due to their elevated position on top of the boiler.

Endress+Hauser's objective is to work with customers to iron out problems and increase the lifespan of these devices. With a collaborative approach to thermowell construction and design, Endress+Hauser has been able to assist several customers in operating their high-temperature thermocouples for a year or more without failure, compared with just weeks achieved by inferior devices. With instrumentation in around 60% of EfW plants in the UK and favoured by leading EfW constructors such as Hitachi Zosen Inova (HZI), Endress+Hauser has the knowledge, expertise and exposure to these applications to advise customers on the best solutions and address any challenges that arise. For example, one customer changed their waste supply to include medical waste and was having to burn at higher temperatures, which resulted in a reduced lifespan for the temperature devices. Following discussions with their technical team we revisited the material selection and trialled some alternatives, resulting in the customer achieving the same thermocouple lifespan despite the higher

temperatures. With access to a wide range of ceramic and metallic materials, and our own manufacturing facility in the UK, we are able to select the right combination of materials, no matter the application.

Future outlook

Although collectively EfW plants may only provide less than 4% of our peak power demand, their primary function is the treatment of residual waste. This residual waste is in part a renewable energy source and so the power generation and heat recovery that results is low-carbon energy. Around 63 EfW plants are operational in the UK with a further 18 in various stages of development. This number is likely to continue to grow as we continue to divert waste from landfill to reduce carbon emissions. The UK government is committed to both achieving net-zero emissions and increasing the number of heat networks, making EfW plants attractive, providing they continue to meet stringent emissions limits. Several UK energy recovery facilities are currently trialling or have plans for carbon capture and storage (CCS) technology. Among the companies and operators leading the chase are Viridor, Encyclis, Suez, Veolia and Enfinium.

For some there is a concern that as we decarbonise the grid it will be less desirable to generate power from EfW plants unless CCS technology is used. It is also likely that future EfW plants will have to provide an increasing portion of their energy output as recovered heat to neighbouring consumers or district heat networks. For a number of years there has been extensive research into adapting EfW plants to become waste-to-chemicals (W2C) plants, allowing the generation of simple hydrocarbon chemicals from waste. In addition to providing a continued method of diverting waste from landfill, the synthesised hydrocarbon feedstocks generated by W2C sites provide an alternative feedstock for plastics and chemicals manufacture, reducing the demand for virgin crude oil.

However these sites and the industry progress, temperature measurement is expected to remain a vital part of EfW operation. As such, investigations are ongoing to improve thermocouple drift behaviour, a common issue experienced at high temperatures. The technology is being developed to predict how much the devices have drifted based on time in service and the temperature profile that they've been exposed to. Endress+Hauser is also looking at technologies to provide early indication of thermowell failure, allowing operators of EfW sites to plan maintenance activities for a convenient time before temperature measurement is lost.

In conclusion, high-temperature thermocouples are critical to the safe, efficient and environmentally compliant operation of EfW plants. With evolving regulations and increasing pressure to optimise performance, robust temperature monitoring is more important than ever. Endress+Hauser's commitment is to provide operators with solutions that not only meet today's standards but are ready for the challenges of tomorrow.

The Endress+Hauser Group

Endress+Hauser is a global leader in measurement and automation technology for process and laboratory applications. The family company, headquartered in Reinach, Switzerland, achieved net sales of more than 3.7 billion euros in 2024 with a total workforce of over 17,000.

As well as supplying best-in-class products for flow, level, pressure, temperature and analytical measurement, Endress+Hauser offers consultancy and maintenance services to help customers optimise their processes. The valuable knowledge gained from accurate and reliable measurement of different parameters not only improves economic efficiency and safety but also reduces the environmental impact of industrial processes.