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Emissions Control Strategies for Waste Incineration Plants: A Review

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Abstract

Waste incineration, a process of burning waste materials at high temperatures, offers a viable solution for waste volume reduction and energy recovery. However, the combustion process generates various air pollutants, including particulate matter (PM), nitrogen oxides (NOx), sulfur dioxide (SO2), acid gases (HCl, HF), dioxins and furans (PCDD/Fs), and heavy metals. These emissions pose significant threats to human health and the environment. This review paper provides a comprehensive overview of the common air pollution control technologies (APCTs) employed in waste incineration plants to mitigate these emissions. It examines the principles of operation, removal efficiencies, advantages, disadvantages, and recent advancements in each technology category. The review covers pre-combustion control measures, primary control strategies within the combustion chamber, and secondary control strategies or end-of-pipe treatment systems. Emerging technologies and future research directions for enhancing the performance and sustainability of emissions control in waste incineration are also discussed.

Keywords: Waste management, Incineration, Hazardous gases, Emission control, waste to energy.

1. Introduction

The escalating global population and increasing urbanization have led to a surge in solid waste generation. Traditional waste management methods such as land filling and incineration are proving to be unsustainable and environmentally problematic. Landfills contribute to greenhouse gas emissions, leachate contamination of soil and groundwater, and take up valuable land space. Incineration, while reducing waste volume, can release harmful air pollutants and leave behind ash that still requires disposal. These methods often fail to recover valuable resources embedded within the waste stream, contributing to the depletion of natural resources and perpetuating a linear & quot;take-make-dispose" economic model. Therefore, there is an urgent need for innovative and integrated waste management strategies that prioritize waste reduction, reuse, recycling, and resource recovery to mitigate environmental impacts and transition towards a circular economy. Waste incineration, also known as waste-to-energy (WtE), presents a viable waste management alternative by significantly reducing waste volume, often by up to 90%. This

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process not only minimizes landfill space requirements but also recovers valuable energy in the form of heat or electricity, which can then be used for heating purposes or distributed through power grids (Akpan VE et al. 2020). However, the combustion process inherent in waste incineration is not without its environmental challenges (Ahirwar R et al. 2020, Awasthi AK et al. 2018). It inevitably leads to the release of harmful air pollutants, including particulate matter, nitrogen oxides (NOx), sulfur dioxide (SO2), dioxins, and furans, which can negatively impact air quality and human health. Therefore, the successful and sustainable implementation of waste incineration relies heavily on the implementation of effective and stringent emissions control strategies, such as advanced filtration systems, scrubbers, and other technologies designed to minimize the release of these pollutants into the atmosphere (Azam M et al. 2019, Bimir MN 2020). These control measures are crucial for mitigating the environmental impact and ensuring the long-term viability of waste-to-energy as a responsible waste management solution (Ahmed R et al. 2022, Akpan VE et al. 2020).

This paper aims to provide a comprehensive review of the various emissions control strategies employed in waste incineration plants. Specifically, it will explore the different technologies and processes used to minimize the release of harmful pollutants from these facilities. The aim is to provide decision-makers with the comprehensive information needed to select and implement the most sustainable and effective WtE solutions for their specific contexts.

2. Pollutants Generated During Waste Incineration

Pollutants Generated During Waste Incineration: Waste incineration, a thermal treatment process used to reduce the volume of waste, inevitably generates a variety of pollutants that can pose significant environmental and health risks (Bing X et al. 2016). These pollutants arise from the combustion process itself and from the composition of the waste being burned (Zhao H et al. 2022, Block C et al. 2014). Key pollutants include:

2.1 Particulate Matter (PM): Fine and ultrafine particulate matter (PM), commonly referred to as PM2.5 and PM0.1 respectively, are inhalable particles with diameters of 2.5 micrometers or less and 0.1 micrometers or less. Their small size allows them to bypass the body's natural defenses and penetrate deep into the lungs, reaching the alveoli and even entering the bloodstream. This deep penetration can trigger or exacerbate a range of respiratory problems, including asthma, bronchitis, and reduced lung function. Furthermore, PM exposure is linked to cardiovascular issues, such as heart attacks, strokes, and irregular heartbeats. Beyond their direct impact, PM particles can also act as vectors, adsorbing (collecting on their surface) heavy metals like lead, mercury, and cadmium, as well as harmful organic compounds, including polycyclic aromatic hydrocarbons (PAHs) and dioxins. This adsorption significantly increases the toxicity of PM, further contributing to adverse health effects upon inhalation and deposition within the body. The adsorbed pollutants can detach and be absorbed into lung tissue and the bloodstream.

2.2 Heavy Metals: Metals like mercury, lead, cadmium, arsenic, and chromium, commonly found in waste streams from discarded items such as batteries and electronic devices, pose a significant environmental threat when released during incineration processes. These metals are highly toxic to humans and wildlife, exhibiting persistence in the environment for extended periods. Their stability allows them to accumulate in soil and water systems, leading to contamination. Moreover, these heavy metals bioaccumulate and biomagnify as they move up the food chain, potentially reaching dangerous concentrations in organisms at higher trophic levels, including humans, who consume contaminated food sources. This accumulation can result in a range of adverse health effects, depending on the specific metal and the level of exposure (Zheng J et al. 2022).

2.3 Acid Gases: Sulfur dioxide (SO2), nitrogen oxides (NOx), and hydrogen chloride (HCl) are produced from the combustion of sulfur, nitrogen, and chlorine-containing materials in waste during incineration or other waste treatment processes. These gases, released into the atmosphere, have significant detrimental effects. They are major contributors to acid rain, which damages ecosystems, corrodes buildings and monuments, and leaches harmful metals into water sources. Furthermore, these gases are respiratory irritants, exacerbating conditions like asthma and bronchitis, and causing discomfort for even healthy individuals. Finally, they are highly corrosive, leading to the degradation of infrastructure, machinery, and electronic equipment, resulting in costly repairs and replacements.

2.4 Dioxins and Furans (PCDD/PCDF): These are highly toxic and persistent organic pollutants (POPs) known as dioxins and furans. They are formed unintentionally as byproducts of incomplete combustion processes, especially when chlorine is present. This includes activities such as waste incineration, industrial manufacturing (particularly involving chlorine-based chemicals), pulp and paper bleaching, and certain metal production processes. Due to their chemical stability, dioxins and furans resist environmental degradation, persisting in soil, sediment, and water for extended periods. A significant concern is their ability to bioaccumulate. This means they accumulate in the tissues of living organisms, and their concentration increases as they move up the food chain, posing a greater risk to top predators, including humans. Dioxins and furans are classified as known human carcinogens (cancer-causing agents) and are also potent endocrine disruptors. Even at very low levels of exposure, they can interfere with hormone signaling, potentially leading to developmental problems, reproductive issues, immune system dysfunction, and other adverse health effects.

2.5 Carbon Monoxide (CO): A poisonous gas produced by incomplete combustion is carbon monoxide (CO). It is a colorless, odorless, and tasteless gas, making it difficult to detect. Incomplete combustion occurs when there isn't enough oxygen available for a fuel to burn completely. Common sources of carbon monoxide include malfunctioning furnaces, gas stoves, generators, and vehicle exhaust. When inhaled, carbon monoxide prevents the blood from carrying sufficient oxygen to the body's vital organs, leading to symptoms ranging from headache and dizziness to loss of consciousness and even death.

2.6 Volatile Organic Compounds (VOCs): Various organic compounds broadly emitted from sources like vehicle exhaust, industrial processes, and natural vegetation, can contribute to smog formation through photochemical reactions in the atmosphere. These compounds, often referred to as volatile organic compounds (VOCs), react with nitrogen oxides (NOx) in the presence of sunlight to produce ground-level ozone and particulate matter, the primary components of smog. This smog not only reduces visibility but also poses significant health risks, including respiratory irritation, asthma exacerbation, cardiovascular problems, and even increased susceptibility to certain cancers. The specific health impacts and the extent of smog formation depend on the type and concentration of the organic compounds, as well as meteorological conditions.

2.7 Greenhouse Gases: Carbon dioxide (CO_2) is a major greenhouse gas released during incineration processes, primarily from the burning of organic materials. Due to its ability to trap heat in the atmosphere, CO_2 emissions significantly contribute to global warming and climate change. While CO_2 constitutes the largest portion of greenhouse gas emissions from incinerators, other potent gases like methane (CH_4) and nitrous oxide (N_2O) may also be released, albeit in smaller quantities. Although the quantities of CH_4 and N_2O are less than CO_2, their significantly higher global warming potentials (GWP) mean they can still have a considerable impact on the overall greenhouse gas footprint of incineration.

2.8 Nitrogen Oxides (NOx): NOx, a collective term for nitrogen oxides like nitrogen monoxide (NO) and nitrogen dioxide (NO_2), is a harmful byproduct of combustion processes. It primarily forms through two distinct mechanisms: thermal NOx and fuel NOx. Thermal NOx arises when nitrogen present in the air, which is a substantial component of combustion mixtures, is oxidized at high temperatures during the combustion process. Fuel NOx, on the other hand, is generated by the oxidation of nitrogen that is chemically bound within the fuel or waste being burned. It is a key contributor to the formation of smog, a visible air pollution that reduces visibility and harms human health. Furthermore, NOx reacts with other atmospheric compounds to form acid rain, which damages ecosystems, corrodes buildings, and pollutes water bodies. Finally, exposure to NOx can exacerbate respiratory problems such as asthma and bronchitis, and long-term exposure can even contribute to the development of respiratory illnesses. Therefore, controlling and reducing NOx emissions is crucial for protecting both the environment and public health.

2.9 Sulfur Dioxide (SO_2): SO_2, or sulfur dioxide, is primarily formed from the oxidation of sulfur compounds present in waste materials, often during combustion processes in industrial facilities and power plants. This colorless gas is a major environmental pollutant, notably contributing significantly to acid rain. When SO_2 is released into the atmosphere, it reacts with water vapor and other compounds to form sulfuric acid, which then falls back to Earth as acid rain, damaging ecosystems, buildings, and infrastructure. Furthermore, SO_2 poses a serious threat to human health, acting as a respiratory irritant. Exposure to elevated levels of SO_2 can trigger or exacerbate respiratory illnesses such as asthma, bronchitis, and other pulmonary conditions, particularly affecting vulnerable populations like children and the elderly (Cheng Z et al. 2021, Chew KW et al 2021).

3. Emissions Control Strategies

Emissions control strategies in waste incineration plants can be categorized into three main approaches: pre-combustion control, combustion control, and post-combustion control.

PREVENTION

PREPARING FOR REUSE

RECYCLING-WASTE TO ENRGY

RECOVERY

DISPOSAL

3.1 Pre-Combustion Control: Pre-combustion control strategies focus on reducing the formation of pollutants before the combustion process begins. These strategies aim to minimize the introduction of problematic elements and compounds into the combustion chamber, ultimately leading to cleaner emissions. Effective pre-combustion control not only reduces air pollution but also improves the overall efficiency and longevity of waste-to-energy (WTE) facilities. These strategies include:

3.1.1 Waste Sorting and Segregation: Removing potentially hazardous materials, such as batteries (containing heavy metals like mercury, cadmium, and lead), electronic waste (containing brominated flame retardants and other toxins), and bulky items (like tires, which release harmful hydrocarbons when burned), from the waste stream can significantly reduce the emission of heavy metals, dioxins, furans, and other toxic substances (Wang Y et al. 2022, Valdés CF et al. 2020). This can be achieved through public education campaigns, incentivized recycling programs, and dedicated collection streams for specific waste types. Moreover, source separation by residents and businesses is crucial for the effectiveness of this strategy.

3.1.2 Waste Pre-Treatment: Pre-treatment processes, such as shredding and homogenizing the waste, can improve combustion efficiency and reduce the formation of incomplete combustion products (Chanthakett A et al. 2021). Shredding increases the surface area of the waste, facilitating more complete and uniform burning. Homogenization blends different types of waste, creating a more consistent fuel source and reducing fluctuations in combustion temperature and air flow. This leads to more stable and efficient combustion, minimizing the production of carbon monoxide (CO), unburned hydrocarbons, and particulate matter (Alawa B et al. 2022, Al-Rumaihi A et al. 2020, Peretz JH et al. 1997).

3.2 Primary Control Strategies (In-Combustion Control: Primary control strategies are proactive measures implemented directly within the combustion chamber of a waste incinerator or similar combustion-based system (Suriapparao DV et al. 2022). Their fundamental goal is to minimize the formation of harmful pollutants – such as carbon monoxide (CO), nitrogen oxides (NOx), and polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) – during the combustion process itself, rather than relying solely on downstream, "end-of-pipe" treatment. These techniques focus on manipulating the combustion environment to favor complete oxidation of waste and prevent the creation of undesirable byproducts. Common primary control techniques include:

3.2.1 Optimized Combustion Conditions: Maintaining optimal combustion conditions is paramount for achieving complete waste destruction and minimizing pollutant formation. This involves a delicate balance of several key factors:

3.2.2 High Temperatures (850-1100°C): Elevated temperatures are essential for driving the oxidation reactions required to break down complex organic molecules in the waste stream. The specific temperature range required can vary depending on the waste composition and incinerator design, but generally falls between 850 and 1100 degrees Celsius (Choudhary R et al. 2023, Christensen TH et al. 2001, and Fu J et al. 2018, Havukainen J et al. 2017, Ilankoon IMSK et al. 2018).

3.2.3 Sufficient Oxygen Supply (Excess Air): Ensuring an adequate supply of oxygen is critical for complete combustion. This often involves providing " excess air, " meaning more air than theoretically required for stoichiometric combustion (Koushki PA et al. 2002). The excess air percentage must be carefully controlled to avoid excessive cooling of the combustion chamber, which could hinder complete oxidation (Shahabuddin M et al 2020).

3.2.4 Adequate Residence Time: Residence time refers to the amount of time the waste materials spend within the high-temperature zone of the combustion chamber (Roy H et al. 2022a). Sufficient residence time allows for complete oxidation reactions to occur, ensuring that pollutants have enough time to be broken down. Insufficient residence time can lead to incomplete combustion and increased emissions (Yu Z et al. 2023).

3.2.5 Turbulence and Mixing: Promoting thorough mixing of air and fuel is critical for ensuring that all waste particles come into contact with oxygen. Turbulence enhances this mixing process, facilitating more complete and uniform combustion. Well-designed combustion chambers incorporate features that promote turbulence, such as strategically placed baffles or injection nozzles.

3.2.6 Low NOx Burners (LNBs): LNBs are advanced burner designs specifically engineered to reduce NOx formation. NOx compounds are primarily formed through two mechanisms: thermal NOx (formed at high temperatures) and fuel NOx (formed from nitrogen-containing compounds in the fuel). LNBs primarily target thermal NOx through a process called staged combustion.

3.2.7 Staged Combustion: LNBs employ staged combustion, which involves dividing the combustion process into multiple zones. Typically, the initial stage operates under fuel-rich conditions (i.e., less air than required for stoichiometric combustion). This creates a reducing environment that minimizes NOx formation in this zone. A limited amount of air is introduced in this stage, which can help convert fuel-bound nitrogen to N2.

3.2.8 Air Injection: In the subsequent combustion stage(s), additional air is injected to complete the combustion process and burn off any remaining fuel. This staged approach reduces the peak flame temperature, consequently lowering thermal NOx formation without sacrificing overall combustion efficiency.

3.2.9 Air Staging/Fuel Staging: Similar to LNBs, air staging and fuel staging are techniques that involve introducing air or fuel at different points in the combustion chamber to control the temperature profile and oxygen concentration. Air staging involves strategically injecting air at different locations within the combustion chamber (Manggali AA et al. 2019). This can be used to create localized zones of lower temperature or lower oxygen concentration, inhibiting NOx formation in those regions (Anufriev IS 2021). For example, injecting air downstream of the primary combustion zone can lower the overall temperature and reduce thermal NOx formation. Fuel staging involves injecting fuel at multiple locations within the combustion chamber. This can be used to control the flame temperature and oxygen availability in different zones. For example, injecting a portion of the fuel downstream can create a fuel-rich zone that inhibits NOx formation. Both air and fuel staging offer flexibility in optimizing the combustion process to minimize NOx emissions while maintaining efficient waste destruction.

While effective at reducing NOx, water/steam injection can also have some drawbacks, such as potentially reducing overall combustion efficiency and increasing the volume of flue gas, which may impact downstream treatment processes. The amount of water or steam injected must be carefully controlled to optimize NOx reduction without negatively impacting the overall system performance.

By implementing these primary control strategies, incinerator operators can proactively minimize the formation of pollutants at the source, reducing the burden on downstream air pollution control devices and contributing to a cleaner and more sustainable waste management process.

3.3 Secondary Control Strategies (End-of-Pipe Treatment): Secondary control strategies, also known as end-of-pipe treatments, are applied to the flue gas after the combustion process to remove pollutants before they are released into the atmosphere. Common APCTs include:

3.3.1 Particulate Matter Removal:

• Electrostatic Precipitators (ESPs): ESPs use an electric field to charge and collect particulate matter on charged plates. They are highly efficient in removing PM but are less effective for very

fine particles (Wajda A et al. 2022).

• Fabric Filters (Baghouses): Baghouses use fabric filters to trap particulate matter. They are highly efficient for removing both coarse and fine particles and are widely used in waste incineration plants. Pulsed-jet, reverse-air, and shaker-cleaning methods are used to remove accumulated dust from the filter bags (Lobo-Recio MÁ et al. 2021).

• Wet Scrubbers: Wet scrubbers use liquid sprays to remove particulate matter from the flue gas. They can also remove acid gases and other pollutants. Venturi scrubbers and spray towers are common types.

3.3.2 Acid Gas Removal:

• Wet Scrubbing: Wet scrubbing uses alkaline solutions, such as lime (Ca (OH)2) or sodium hydroxide (NaOH), to neutralize acid gases (Cheng Z et al. 2021). The acidic gases react with the alkaline solution to form salts that are subsequently removed (Kumar A et al. 2020).

• Dry Scrubbing: Dry scrubbing involves injecting dry alkaline sorbents, such as hydrated lime or sodium bicarbonate, into the flue gas stream. The sorbents react with the acid gases to form solid salts that are collected by particulate control devices.

• Semi-Dry Scrubbing: Semi-dry scrubbers involve spraying lime slurry into the flue gas stream. The water evaporates, leaving a dry powder that reacts with the acid gases (Pouranian MR et al. 2020).

3.3.3 NOx Reduction:

• Selective Catalytic Reduction (SCR): SCR uses a catalyst, such as vanadium pentoxide or titanium dioxide, to reduce NOx to nitrogen and water in the presence of ammonia (NH3). SCR is highly effective but requires careful control of temperature and ammonia injection rates (Kumar A et al. 2019, 2020, 2021, 2022).

• Selective Non-Catalytic Reduction (SNCR): SNCR involves injecting ammonia or urea into the flue gas stream without a catalyst. The ammonia or urea reacts with NOx at high temperatures to form nitrogen and water. SNCR is less effective than SCR but is also less expensive.

3.3.4 Dioxin and Furan Removal:

• Activated Carbon Injection (ACI): ACI involves injecting powdered activated carbon (PAC) into the flue gas stream. Dioxins and furans adsorb onto the surface of the activated carbon, which is then collected by particulate control devices (Ahirwar R et al. 2021). ACI is a cost-effective method for removing PCDD/Fs.

• Catalytic Oxidation: Catalytic oxidation uses a catalyst to promote the oxidation of dioxins and furans to carbon dioxide and water. Catalytic oxidation can be integrated into the SCR system or used as a separate unit.

3.3.5 Heavy Metal Removal:

• Activated Carbon Injection (ACI): ACI can also remove heavy metals by adsorption onto the activated carbon (Saeidi-Mobarakeh Z et al. 2020, Wei Y et al. 2020, Thakur AK et al. 2021).

• Wet Scrubbing: Wet scrubbers can remove some heavy metals by dissolving them in the scrubbing liquid.

4. Conclusion

Waste incineration has become a cornerstone of contemporary waste management, offering a solution for reducing landfill volume and recovering energy from non-recyclable materials. However, the process is not without its drawbacks, notably the release of various air pollutants that can negatively impact air quality and human health. Therefore, the implementation of robust and effective Air Pollution Control Technologies (APCTs) is paramount to mitigating the environmental footprint of waste incineration facilities. This review delves into the diverse landscape of APCTs currently utilized in these plants, encompassing a comprehensive range of approaches. These include pre-combustion controls aimed at optimizing waste feedstock, primary control strategies focused on manipulating the combustion process itself, and secondary control systems designed to treat flue gases after combustion.

Successfully minimizing emissions from waste incineration plants requires a nuanced and informed selection of APCTs. This selection process is heavily influenced by a multitude of interconnected factors. These include the specific composition of the waste being incinerated (e.g., plastic content, moisture levels), the operational parameters of the combustion process (e.g., temperature, residence time), the stringency of local and national regulatory requirements for air emissions, and the overall economic feasibility and cost-effectiveness of implementing different technologies.

Looking forward, continuous innovation and refinement are essential for the long-term sustainability of waste incineration. This involves not only optimizing the performance of existing APCTs to achieve higher removal efficiencies and lower operational costs but also investing in research and development to create entirely new and more effective pollution control technologies. By prioritizing these advancements, we can ensure that waste incineration plays a responsible and environmentally sound role in waste management, safeguarding both human health and the integrity of our environment.

References

Ahirwar R, Tripathi AK (2021) E-waste management: a review of recycling process, environmental and occupational health hazards, and potential solutions. Environ Nanotechnol, Monit Manag 15:100409. https://doi.org/10.1016/J.ENMM.2020.100409.

Ahmed R, Deka H (2022) Vermicomposting of patchouli bagasse—a byproduct of essential oil industries employing Eisenia fetida. Environ Technol Innov 25:102232. https://doi.org/10.1016/J.ETI.2021.102232.

Akpan VE, Olukanni DO (2020) Hazardous waste management: an African overview. Recycl 5:15. https://doi.org/10.3390/RECYCLING5030015.

Alawa B, Galodiya MN, Chakma S (2022) Source reduction, recycling, disposal, and treatment. Hazard Waste Manag 67–88. https://doi.org/10.1016/B978-0-12-824344-2.00005-7.

Al-Rumaihi A, McKay G, Mackey HR, Al-Ansari T (2020) Environmental impact assessment of food waste management using two composting techniques. Sustain 12:1595. https://doi.org/10.3390/SU12041595.

Anufriev IS (2021) Review of water/steam addition in liquid-fuel combustion systems for NOx reduction: waste-to-energy trends. Renew Sustain Energy Rev 138:110665. https://doi.org/10.1016/J.RSER.2020.110665.

Awasthi AK, Wang M, Wang Z, Awasthi MK, Li J (2018) E-waste management in India: a mini-review. Waste Manag Res 36:408–414. https://doi.org/10.1177/0734242X18767038.

Azam M, Jahromy SS, Raza W, Wesenauer F, Schwendtner K, Winter F (2019) Comparison of the characteristics of fly ash generated from bio and municipal waste: fluidized bed incinerators. Mater 12(2664):2664. https://doi.org/10.3390/MA12172664.

Bimir MN (2020) Revisiting e-waste management practices in selected African countries. https://doi.org/10.1080/10962247.2020.1769769.

Bing X, Bloemhof JM, Ramos TRP, Barbosa-Povoa AP, Wong CY, Vorst JG (2016) Research challenges in municipal solid waste logistics management. Waste Manag 48:584–592. https://doi.org/10.1016/j.wasman.2015.11.025.

Block C, Van Caneghem J, Van Brecht A, Wauters G (2014) Vandecasteele C (2014) Incineration of hazardous waste: a sustainable process? Waste Biomass Valorization 62(6):137–145. https://doi.org/10.1007/S12649-014-9334-3.

Chanthakett A, Arif MT, Khan MMK, Oo AMT (2021) Performance assessment of gasification reactors for sustainable management of municipal solid waste. J Environ Manage 291:112661. https://doi.org/10.1016/j.jenvman.2021.112661.

Cheng Z, Li M, Li J, Lin F, Ma W, Yan B, Chen G (2021) Transformation of nitrogen, sulfur and chlorine during waste tire pyrolysis. J Anal Appl Pyrolysis 153:104987. https://doi.org/10.1016/J.JAAP.2020.104987.

Chew KW, Chia SR, Chia WY, Cheah WY, Munawaroh HSH, Ong WJ (2021) Abatement of hazardous materials and biomass waste via pyrolysis and co-pyrolysis for environmental sustainability and circular economy. Environ Pollut 278:116836. https://doi.org/10.1016/J.ENVPOL.2021.116836.

Choudhary R, Mukhija A, Sharma S, Choudhary R, Chand A, Dewangan AK, Gaurav GK, Klemeš JJ (2023) Energy-saving COVID–19 biomedical plastic waste treatment using the thermal - Catalytic pyrolysis. Energy 264:126096. https://doi.org/10.1016/j.energy.2022.126096.

Christensen TH, Kjeldsen P, Bjerg PL, Jensen DL, Christensen JB, Baun A, Albrechtsen HJ, Heron G (2001) Biogeochemistry of landfill leachate plumes. Appl Geochem 16:659–718. https://doi.org/10.1016/S0883-2927(00)00082-2.

Fu J, Zhang H, Zhang A, Jiang G (2018) E-waste recycling in China: a challenging field. Environ Sci Technol 52:6727–6728. https://doi.org/10.1021/acs.est.8b02329.

Havukainen J, Zhan M, Dong J, Liikanen M, Deviatkin I, Li X, Horttanainen M (2017) Environmental impact assessment of municipal solid waste management incorporating mechanical treatment of waste and incineration in Hangzhou, China. J Clean Prod 141:453–461. https://doi.org/10.1016/J.JCLEPRO.2016.09.146.

Ilankoon IMSK, Ghorbani Y, Chong MN, Herath G, Moyo T, Petersen J (2018) E-waste in the international context – a review of trade flows, regulations, hazards, waste management strategies and technologies for value recovery. Waste Manag 82:258–275. https://doi.org/10.1016/j.wasman.2018.10.018.

Koushki PA, Al-Humoud JM (2002) Analysis of household hazardous substances in Kuwait. Pract Period Hazardous, Toxic, Radioact Waste Manag 6:250–255. https://doi.org/10.1061/(ASCE)1090-025X(2002)6:4(250).

Kumar A, Lingfa P (2019) Base-Activated Sodium Bentonite Clay: Mutated Characteristics and Industrial Slant Springer NatureSingapore (EnergyRecoveryProcesses fromWastes) https://doi.org/10.1007/978-981-32-9228-4_18.

Kumar A, Lingfa P (2020) Acid-activated sodiumbentonite and kaolinclay: Comparativestudy byphysicochemical Properties. CCHTS 23:433-445 DOI: 10.2174/1386207323666200311114349.

Kumar A, Lingfa P (2020) Physico-chemicalCharacterization ofhydrochloric acid-treatedkaolinclay:Anindustry approach as apotentialcatalyst. CCHTS 23:205-213. https://doi.org/10.2174/1386207323666200219123459.

Kumar A, Lingfa P (2021) Thermal cracking ofHigh-DensityPolyethylene Wastesand Production ofLiquidHydrocarbon Awinash Kumar, V.Prasad Singh, andPradip Lingfa Advances inThermofluids andRenewableEnergy, Springer 2021 https://doi.org/10.1007/978-981-16-3497-0_24.

Kumar, A. and *Lingfa*, *P*. (*2022*), Base-Activated Sodium Bentonite Clay: Mutated Characteristics and Industrial Slant, *ECS* Transactions, *107*(1), pp.*2303*-2314.

Kumar A, Reddy SN (2020) Subcritical and supercritical water in-situ gasification of metal (Ni/Ru/Fe) impregnated banana pseudo-stem for hydrogen rich fuel gas mixture. Int J Hydrogen Energy 45:18348–18362. https://doi.org/10.1016/j.ijhydene.2019.08.009.

Lobo-Recio MÁ, Rodrigues C, Custódio Jeremias T, Lapolli FR, Padilla I, López-Delgado A (2021) Highly efficient removal of aluminum, iron, and manganese ions using Linde type-A zeolite obtained from hazardous waste. Chemosphere 267:128919. https://doi.org/10.1016/J.CHEMOSPHERE.2020.128919.

Manggali AA, Susanna D (2019) Current management of household hazardous waste (HHW) in the Asian region. Rev Environ Health 34:415–426. https://doi.org/10.1515/REVEH-2019-0049/MACHINEREADABLECITATION/RIS.

Peretz JH, Bohm RA, Jasienczyk PD (1997) Environmental policy and the reduction of hazardous waste. J Policy Anal Manag. https://doi.org/10.1002/(SICI)1520-6688(199723)16:4<556::AID-PAM3>3.0.CO;2-F.

Pouranian MR, Notani MA, Tabesh MT, Nazeri B, Shishehbor M (2020) Rheological and environmental characteristics of crumb rubber asphalt binders containing non-foaming warm mix asphalt additives. Constr Build Mater 238:117707. https://doi.org/10.1016/J.CONBUILDMAT.2019.117707.

Roy H, Alam SR, Bin-Masud R, Prantika TR, Pervez MN, Islam MS, Naddeo V (2022a) A review on characteristics, techniques, and waste-to-energy aspects of municipal solid waste management: Bangladesh perspective. Sustainability

14:10265. https://doi.org/10.3390/su141610265.

Saeidi-Mobarakeh Z, Tavakkoli-Moghaddam R, Navabakhsh M, Amoozad-Khalili H (2020) A bi-level and robust optimization-based framework for a hazardous waste management problem: a real-world application. J Clean Prod. https://doi.org/10.1016/j.jclepro.2019.119830.

Shahabuddin M, Alam MT, Krishna BB, Bhaskar T, Perkins G (2020) A review on the production of renewable aviation fuels from the gasification of biomass and residual wastes. Bioresour Technol 312:123596. https://doi.org/10.1016/J.BIORTECH.2020.123596.

Suriapparao DV, Gupta AA, Nagababu G, Kumar TH, Sasikumar JS, Choksi HH (2022) Production of aromatic hydrocarbons from microwave-assisted pyrolysis of municipal solid waste (MSW). Process Saf Environ Prot 159:382–392. https://doi.org/10.1016/J.PSEP.2022.01.014.

Thakur AK, Kumar R, Chaudhari P, Shankar R (2021) Removal of heavy metals using bentonite clay and inorganic coagulants. In: Shah MP (ed) Removal of emerging contaminants through microbial processes. Springer, Singapore, pp 47–69. https://doi.org/10.1007/978-981-15-5901-3_3.

Valdés CF, Marrugo GP, Chejne F, Marin-Jaramillo A, Franco-Ocampo J, Norena-Marin L (2020) Co-gasification and co-combustion of industrial solid waste mixtures and their implications on environmental emissions, as an alternative management. Waste Manag 101:54–65. https://doi.org/10.1016/J.WASMAN.2019.09.037.

Wajda A, Brociek R, Pleszczyński M (2022) Optimization of energy recovery from hazardous waste in a waste incineration plant with the use of an application. Processes 10:462. https://doi.org/10.3390/PR10030462.

Wang J, Shih Y, Wang PY, Yu YH, Su JF, Huang CP (2019) Hazardous waste treatment technologies. Water Environ Res 91:1177–1198. https://doi.org/10.1002/wer.1213.

Wang Y, Li D, Li J, Li J, Fan M, Han M, Liu Z, Li Z, Kong F (2022) Metal organic framework UiO-66 incorporated ultrafiltration membranes for simultaneous natural organic matter and heavy metal ions removal. Environ Res 208:112651. https://doi.org/10.1016/J.ENVRES.2021.112651.

Wei Y, Zhao Y, Zhao X, Gao X, Zheng Y, Zuo H, Wei Z (2020) Roles of different humin and heavy-metal resistant bacteria from composting on heavy metal removal. Bioresour Technol 296:122375. https://doi.org/10.1016/j.biortech.2019.122375.

Yu Z, Gao C, Yang C, Zhang L (2023) Insight into quantities, flows, and recycling technology of e-waste in China for resource sustainable society. J Clean Prod

393:136222. https://doi.org/10.1016/j.jclepro.2023.136222.

Zhao H, Liu H, Wei G, Zhang N, Qiao H, Gong Y, Yu X, Jianhua Zhou J, Wu Y (2022) A review on emergency disposal and management of medical waste during the COVID-19 pandemic in China. Sci Total Environ 810:152302. https://doi.org/10.1016/J.SCITOTENV.2021.152302.

Zheng J, Zhang X, Li G, Fei G, Jin P, Liu Y, Wouters C, Meir G, Li Y, der Bruggen BV (2022) Selective removal of heavy metals from saline water by nanofiltration. Desalination 525:115380. https://doi.org/10.1016/J.DESAL.2021.115380.