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Review

Comparative Study on the Applicability of Solid Waste Treatment by Fixed Grate and Fluidized Bed Incinerators: A Bibliometric Review

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Abstract

Using thermal treatment in the waste management process has advantages such as reducing volume and the possibility of energy recovery. There are several incineration technologies with different characteristics and potential. Incineration, however, requires efficient environmental control to reduce associated risks, such as the emission of harmful compounds. The paper aims to compare solid waste treatment processes in grate and fluidized bed incinerators based on technical and environmental characteristics. For this purpose, a bibliometric review was conducted, and consulting works available in the scientific literature describe the waste treatment process with these two technologies. The searches were carried out in the Web of Science and Web of Knowledge databases using the following search engines: "fixed grade incinerator," "grate incinerator" and "fluidized bed incinerator". Grate incinerators present a range of elective waste for treatment compared to fluidized bed incinerators, as they do not require homogeneous waste. The study compared solid waste incineration in fixed grate and fluidized bed furnaces. While promising for sludge treatment, the fluidized bed technology may require pre-treatment, increasing costs and limiting its use to larger facilities. Fixed grate furnaces can handle a wider variety of waste without this additional step but generate more halogenated compounds when plastic waste is present. These technologies were primarily studied in Asia and Europe, where landfill space is limited and more significant potential for energy recovery exists. Adopting these technologies in other regions depends on waste characteristics, economic conditions, and environmental impacts.

Keywords

Waste treatment; waste incineration; grate incinerator; fluidized bed incinerator; incineration technologies; waste treatment technologies

1. Introduction

Solid waste incineration is a treatment process to reduce the volume and risks associated with dangerous waste. To this end, the waste is oxidized at high temperatures [1]. This treatment also offers the potential for energy recovery [2] and the extraction of mineral resources [3]. However, incineration poses significant environmental risks, mainly due to generating and releasing gaseous effluents that may contain hazardous substances. These include dioxins [4], highly toxic compounds with potential long-term health impacts, and heavy metals [5], which can accumulate in ecosystems and pose severe environmental and human health threats. Releasing these harmful substances into the atmosphere raises concerns about air quality and the health of humans and ecosystems. Soil and water contamination are also environmental issues related to this waste treatment [4]. Thus, incineration impacts multiple aspects of the environment.

Incineration plants can treat various types of waste, including urban solid waste, sludge from effluent treatment plants, industrial waste, and healthcare waste (HCW) [1]. This diversity in the composition of treated waste results in variations in the incineration technologies used and the emission of greenhouse gases (GHGs) [6].

Compared to the levels recorded in Latin America and the Caribbean, the largest share of incineration among solid waste treatment methods is found in Europe and the USA [7]. In Brazil, incineration treated 7.9% of agricultural pesticide packaging in 2021 [8], and 43.4% of HCW in the same year [9]. However, regarding municipal waste treatment, a study indicated that generating energy through incineration is economically unfeasible due to Brazil’s energy tariffs, requiring government intervention to increase the competitiveness of this waste treatment technique in the country [10]. It is also worth noting that the diversion of recyclable materials to incineration reduces the availability of recycling materials, which increases the demand for raw materials and energy. Recycling is a process with lower energy consumption than thermal treatment [11].

Incineration is one of the most widely used methods globally for treating pathological waste [4]. It is also commonly adopted for municipal solid waste (MSW) in countries like South Korea and Japan [12]. Consequently, the waste sent to incineration plants varies in composition, origin, and quantity, and the social and geographic specificities of the generation sites also influence it.

Waste incineration systems employ various technologies, with fixed grate and fluidized bed incinerators being among the most prominent. Grate incinerators are the most commonly used type in Europe, with estimates indicating that 90% of European plants rely on this technology, including fixed and mobile grate incinerators [1]. Fluidized bed incinerators are typically applied to treat homogeneous waste and sewage sludge. Some authors emphasize the need for pre-treatment to ensure uniform temperature and oxygenation in fluidized bed incinerators, which is not required for grate incinerators [1]. Another study demonstrated that both fluidized bed and grate firing systems enhanced environmental performance and energy efficiency, yielding similar results in municipal solid waste combustion of municipal solid waste [13].

Bottom ash is the primary solid residue from municipal solid waste incineration and contains valuable materials such as metals, glass, and minerals. The authors discussed metal recovery in grate incinerators, suggesting the future opportunity for metals recovered per kilogram of MSW [3].

Understanding the current usage profile of the two incineration technologies, along with a summary of their key operational characteristics and environmental implications, can offer valuable insights for more informed technology selection based on local demands and guide future research direction. Therefore, this study aims to compare the scientific bibliometric data on the applicability of solid waste treatment through incineration using fixed grate and fluidized bed furnaces. It compares their main technical and environmental characteristics as identified through the literature review.

The expectation is to understand the current use profile of two incineration technologies and summarize their vital operational characteristics and environmental implications. This will provide valuable information to assist in selecting the most appropriate waste treatment technology based on local needs. Additionally, the study seeks to identify potential areas for future research.

2. Materials and Methods

A bibliometric review was conducted, including publications on waste incineration using the two focus technologies: fixed grate and fluidized bed. To this end, a search was carried out using the following keywords: "fluidized bed incinerator", "grate incinerator," and "fixed grate incinerator" in the scientific databases Web of Science and Web of Knowledge. The term "grate incinerator" was included to ensure the inclusion of papers focused on fixed grate incinerators, as they are occasionally referenced under this designation. The focus was on documents that described waste incineration processes, regardless of the type of waste treated, specifically involving incineration in either a grate or fluidized bed system.

A systematic review was conducted as a complementary approach to provide a summary of evidence related to a specific intervention strategy. This is achieved through applying explicit and structured search methods, critically assessing, and synthesizing the selected information. The systematic review followed the PRISMA guidelines [14], which provide updated reporting guidance for systematic reviews and reflect advances in identifying, selecting, appraising, and synthesizing studies. These guidelines have been widely used in papers within the same area [15, 16]. From this perspective, critical studies on incineration were selected, focusing on aspects such as incinerator type, waste type, operation conditions, and other relevant details.

The papers were identified based on the country where they were carried out, type of waste, and the quantity of waste treated. Results were also analyzed, including the year of publication, research area, topics addressed, language, principal authors, and associated sustainable goals. The techniques were compared according to the technological, economic, and environmental specificities described in the works consulted. Aiming to interpret the study findings better, the units for quantifying the amounts treated were standardized in tons per day (ton/d). To this end, it was considered that the operation took place 30 days a month and operated 15 hours a day.

3. Results and Discussion

This research identified and analyzed 2474 papers published between 1964 and 2023 using bibliometric methods. In a second phase, with more specific inclusion criteria, 535 papers were found about fluidized bed incinerators, and 249 discussed grate incinerators. From these, 13 case studies were selected for detailed discussion based on the inclusion criteria, describing the operation of incineration plants using studied technologies regardless of the type of waste treated.

Despite the large volume of papers initially identified, the volume was reduced by more than 200% after inserting specific inclusion criteria. Thus, there is a noticeable gap in the scientific literature regarding studies on waste incineration that provide detailed methodologies for different types of incinerators. This gap presents a research opportunity to explore and better understand the specific characteristics of waste treatment processes for each kind of incinerator.

3.1 Bibliometric Analysis

The main results of the bibliometric review are presented below, through Figure 1, Figure 2, and Figure 3, as well as Table 1 and Table 2, consolidating the main findings of this research. Figure 1 indicates the increasing tendency of publications about the studied topic, particularly after 2010.

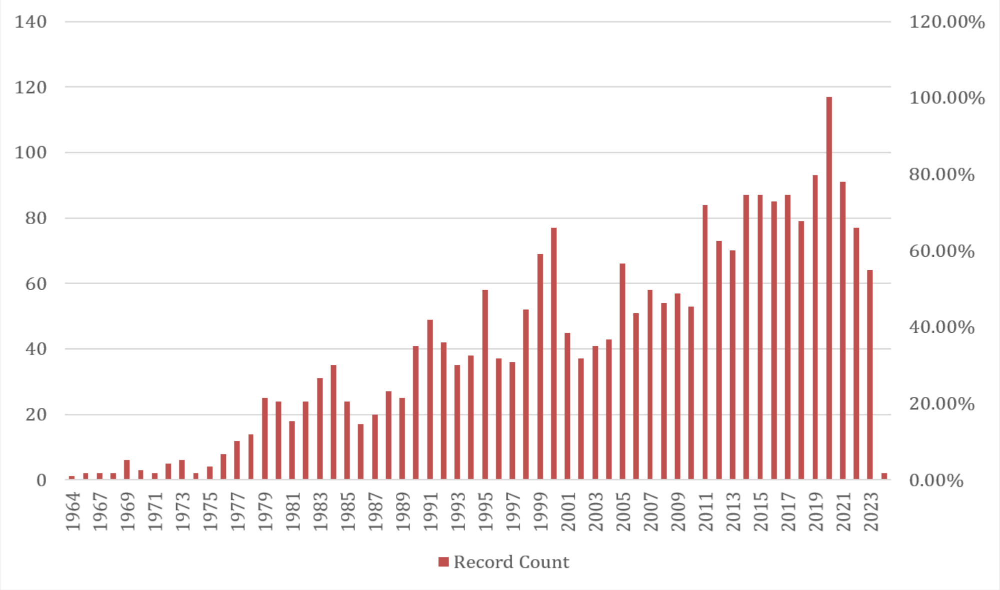

Figure 1 Publication about grate and fluidized bed incinerators over the years.

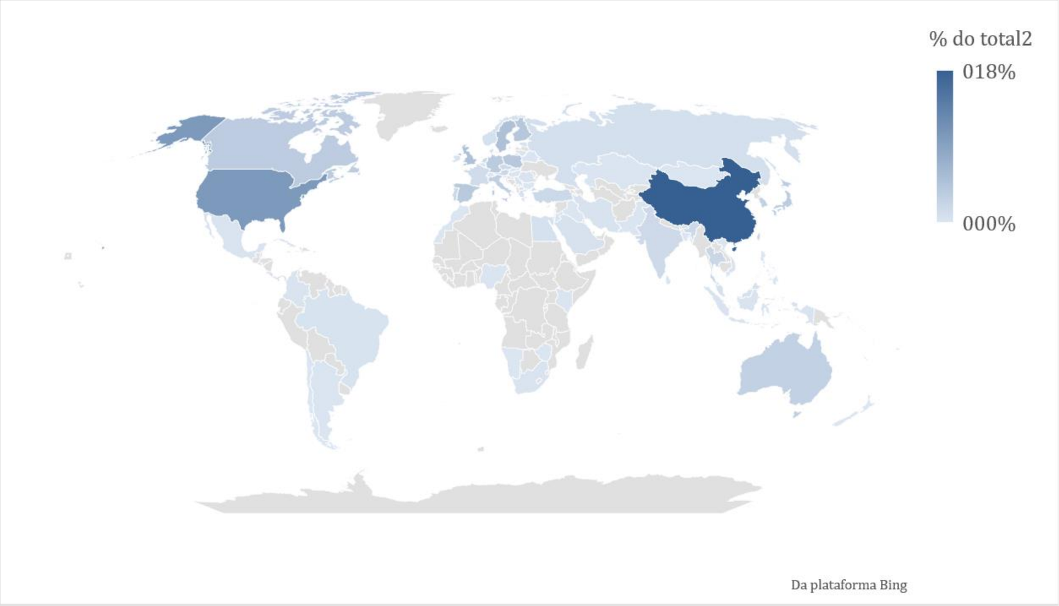

Figure 2 Publication about grate and fluidized bed incinerators according to countries where the studies were made.

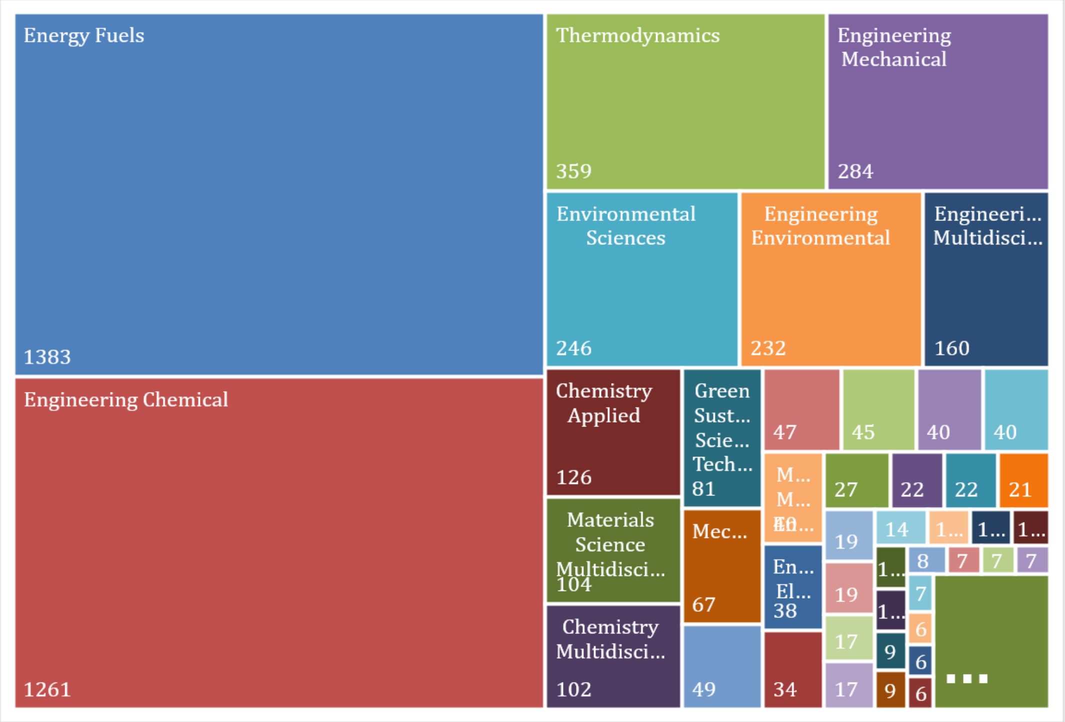

Figure 3 Number of publications about grate and fluidized bed incinerators by related scientific topic.

Table 1 Publication about grate and fluidized bed incinerators by scientific journals.

Journal	Record Count	%
Fuel	269	10.09
Energy Fuels	203	7.61
Fuel Processing Technology	96	3.60
Energy	54	2.02
Combustion and Flame	53	1.99
Chemical Engineering Science	52	1.95
Vdi Berichte	47	1.76
Powder Technology	41	1.54
Applied Energy	40	1.50
Abstracts of Papers of the American Chemical Society	36	1.35
Industrial Engineering Chemistry Research	36	1.35
Chemical Engineering Journal	34	1.27
Combustion Science and Technology	33	1.24
Applied Thermal Engineering	31	1.16
Waste Management	30	1.12

Table 2 Publication about grate and fluidized bed incinerators by scientific journals.

Sustainable Development Goals	Record Count	%
07 Affordable and Clean Energy	1170	64.61%
13 Climate Action	275	15.18%
11 Sustainable Cities and Communities	158	8.72%
12 Responsible Consumption and Production	129	7.12%
06 Clean Water and Sanitation	26	1.44%
03 Good Health and Well Being	25	1.38%
02 Zero Hunger	24	1.33%
15 Life on Land	4	0.22%

Figure 2 highlights the most relevant countries in terms of scientific paper production, with China leading at 18.3%, followed by EUA (10.5%), Sweden (5.1%) and United Kingdom (5.0%). Brazil, with only 0.44%, showed limited output, suggesting that this topic has received low priority in the country. Publications according to the journal and topics addressed were presented in Table 1 and Figure 3, suggesting that most research focuses on energy and fuel-related demands.

The main research areas of the scientific paper found were Engineering (36.8%), Energy Fuels (29.1%), Thermodynamics (7.6%), Chemistry (5.7%) and Environmental Sciences Ecology (5.3%). About language, English represented 93.1% of all papers found, followed by German (3.6%) and Japanese (1.1%). When discussing Funding Agencies, it was reported that 205 results were associated with the National Natural Science Foundation of China (11.1%), followed by the European Union (1.8%). This information confirms China as the largest investor in the studied topic and, consequently, with greater publications, as indicated in Figure 2. Analyzing the Sustainable

Development Goals discussed in the selected papers, Table 2 shows the predominance of clean energy and climate topics addressed.

3.2 Technologies Applications by Type of Waste and Its Technical Considerations

Grate incinerators are commonly used to treat MSW and other types of waste, such as commercial, industrial, and healthcare waste [1]. In contrast, it is noted that fluidized bed incineration requires waste with greater homogeneity [1], which increases the cost associated with this technique due to the need for pre-treatment of heterogeneous waste, such as crushing and removal of ferrous materials. The incineration of raw and untreated MSW in grate incinerators was described in [2, 17, 18]. Hazardous waste treatment using grate incinerators was listed in [6, 18, 19].

A fluidized bed incinerator to treat commercial solid waste was verified in a privately operated plant with an incineration capacity of 48 tons/d of waste [20]. Additionally, fluidized bed incineration has been applied to treat sewage sludge from a domestic effluent treatment plant, with one pilot plant having a treatment capacity of 3.75 tons/d [21]. Another study also describes sewage sludge treatment using a fluidized bed incinerator with treatment of 45.00 ton/d of semi-dry sludge [22]. Furthermore, a different aspect of fluidized bed sewage sludge treatment was explored, highlighting the structural benefits of using ash from the incineration process in brick production for civil construction [23].

The treatment of MSW by the fluidized bed after pre-treatment to homogenize the waste is enabled using this technology [24, 25]. Another study showed that pre-treatment in a shredder machine aims to remove ferrous materials and add small amounts of sewage sludge (5-10%) [17]. A limitation of the use of fluidized beds is associated with the characteristics of the treated waste, which restricts the technology to plants with greater treatment capacity [1]. On the other hand, when a fluidized bed incinerator is integrated with an effective control system, it can significantly enhance the efficiency of waste incineration. This combination not only improves emissions control, reducing the release of harmful pollutants, but also simplifying the gas cleaning process. The streamlined gas treatment lowers operational costs and makes the overall waste management process more cost-effective while maintaining stringent environmental standards [1].

The integration of the studies technologies is also feasible. One study suggested that the portion rejected in the pre-treatment of MSW for treatment in a fluidized bed could be treated in a grate incinerator [17]. In this case, the amount treated in a grate incinerator corresponds to 30% of the total received by the plant [17]. The strategy of combining the use of both treatment technologies may represent a way of combining the potential and resolving the limitations that exist in each of the technologies studied.

3.3 Environmental Aspects

A study listed the emission of poly-aromatic hydrocarbons (PAHs) and halogenated poly-aromatic hydrocarbons (Cl/Br-PAHs) in the treatment of solid waste by incineration [18]. Among the technologies analyzed (fixed grate, rotary kiln, and stoker), fixed grate incinerators showed the highest average emissions of PAHs and Cl/Br-PAHs. No relationship was found between the emission of PAHs and Cl/Br-PAHs and incinerator capacity or operating temperature [18]. Another study, which examined the emission factor of PAHs during the incineration of HCW in a fixed grate and mobile grate incinerator, found the highest emission in the one with a fixed grate, 85,600 μg/kg.

waste compared to 24,900 µg/kg.waste [19]. Both values exceeded the emissions observed during the incineration of MSW in a fluidized bed, which was 871 µg/kg of waste [24]. The observed differences in emission values for organic pollutants may be attributed to the qualitative aspects of the treated waste. In fluidized bed incinerators, enhanced control over the incineration process can lead to reduced generation of by-products, thereby improving emission performance.

The generation and emission of PAHs is due to the composition of the treated waste, mainly regarding the percentage share of plastic waste and the need to add auxiliary fuels [19]. Although the fraction of PAHs with the highest carcinogenic potential was reduced by 83% due to the action of control equipment for fixed and mobile grate incinerators (742 µg/kg.waste and 112 µg/kg.waste), these still present an emission rate significantly higher than that found in emissions from MSW treatment in a fluidized bed (12.6 µg/kg.waste) [19]. In this way, the need to search for improvements in the control of emissions in the treatment of HCW and the search for techniques that aim to reduce the volume generated by this waste is reinforced.

Regarding pollution related to volatile compounds containing heavy metals in waste treatment using fluidized beds, [21] points to the occurrence of vaporization of volatile compounds containing Cd and Pb formed during the incineration of sewage sludge. A more significant enrichment of compounds containing Zn and Pb was noticed in fly ashes from the incineration of MSW in a fluidizing bed when operated with lower temperatures [25]. The presence of compounds containing zinc at values above the regulatory limits (>1000 mg/kg) in fly ashes is found to be waste from incinerators of this type [26].

Several studies have also focused on the emissions of greenhouse gases (GHGs) and nitrogen oxides (NO_x). One study on a fluidized bed plant reported emissions of 1,403 tons CO_2eq/year. However, the study could not determine whether the variations in equivalent carbon emissions come from the type of incinerator used or due to variations in waste and operating conditions [20]. Another study demonstrates the importance of maintaining high temperatures at the freeboard of fluidized bed incinerators to reduce emissions of NO_2, CO, NH_3 and Organic Carbon, recommending the addition of auxiliary fuels when it is not possible to achieve these. temperatures and guaranteeing gas homogeneity [22]. A separate modeling study on the efficiency of grate incineration showed that increasing the initial temperature improves the efficiency of thermal treatment. Still, it emphasized the need to maintain an optimal temperature of 473 K to prevent increased NO_x emissions and potential equipment damage [27].

3.4 Geographic Aspects

A summary of the operational characteristics of the works consulted can be seen below in Table 3, which also indicates the countries where incinerators were located, considering the 13 papers selected for a more specific discussion.

Table 3 Operational characteristics of the grate and fluidized bed incinerators consulted.

Reference	Country	Incinerator Type	Waste Type	Capacity
[19]*	Taiwan	Fixed grate	Health Service Waste	0.14 ton/batch
[19]*	Taiwan	Moving grate	Health Service Waste	1.05 ton/batch
[18]**	Korea Republic	Fixed grate	MSW + Industrial waste	188.93 ton/d
[6]	Korea Republic	Moving Grate	Specified Waste	44.00 ton/d
[2]	Italy	Moving grate	MSW	1169.40 ton/d
[17]	Austria	Grate incinerator	MSW	694.40 ton/d
[24]	Taiwan	Fluidized bed	MSW	700.00 ton/d
[22]	Germany	Fluidized bed	Sewage sludge	45.00 ton/d
[21]	Italy	Fluidized bed	Sewage sludge	3.75 ton/d
[20]	Korea Republic	Fluidized bed	CSW	48.00 ton/d
[26]	China	Fluidized bed	MSW	800.00 ton/d
[25]	China	Fluidized bed	MSW	300.00 ton/d
[17]	Austria	Fluidized bed	MSW + sewage sludge	277.78 ton/d

*[19] does not specify the amount of waste treated per batch. ** [18] presents average data from a plant that contains a grid incinerator among its three incinerators.

Figure 4 and Figure 5 below present the geographical distribution of the studies used in this study, emphasizing regions. It is possible to notice a concentration of studies in Asia and Europe that use grid and fluidized bed incinerators.

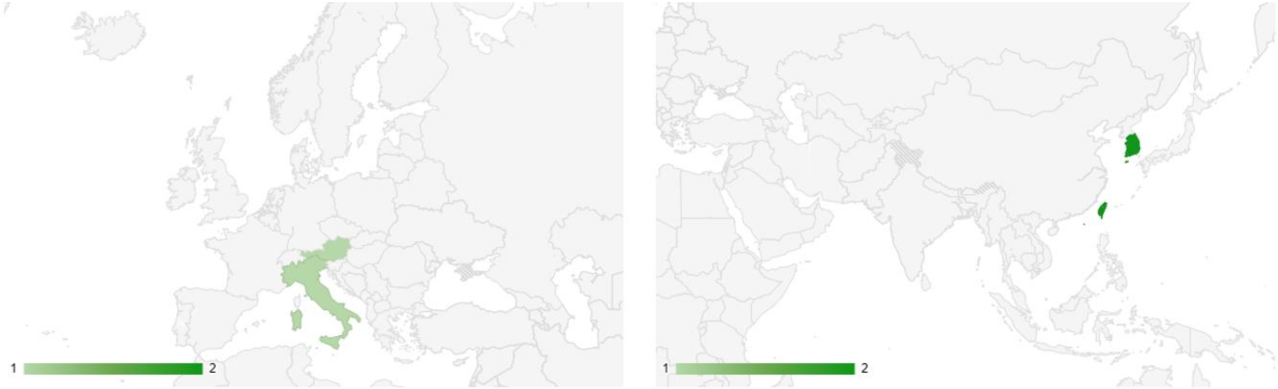

Figure 4 Geographic distribution of studies describing the use of grate incinerators around the world.

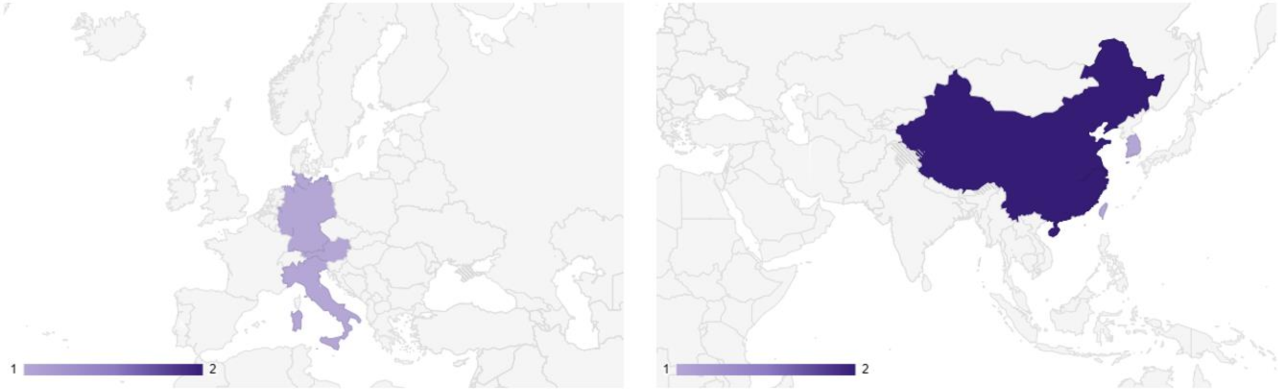

Figure 5 Geographic distribution of studies describing the use of fluidized bed incinerators around the world.

Regarding geographical distribution, it is essential to emphasize that the scientific studies discussed here focus on specific cases involving incineration processes rather than representing the actual global distribution of incinerators. The studies mentioned reflect the locations where scientific research has been carried out. The countries involved in these studies exhibit significant differences in economic development and socioeconomic aspects, which can influence the availability of resources for research and the priorities and practices in waste management. The following paragraphs will detail the economic characteristics of the countries studied, providing insight into how these variables can impact the results and distribution of research in waste incineration.

In countries where land costs are high and there is limited landfill space availability, incineration can be an economically viable solution for waste management. By significantly reducing the volume of waste, incineration lessens the need for large landfills [13]. In countries that generally have access to advanced technologies that make incineration more efficient and environmentally safe, facilities can be modern and equipped with emission control systems that capture pollutants, making the practice more acceptable from both an environmental and regulatory perspective [6]. However, incinerators require substantial investment for construction and maintenance, which can be prohibitive for developing countries where resources are scarce and investment priorities include health, education, and basic infrastructure.

In developed countries, waste incinerators are designed to recover energy through electricity or heat, which can be sold or used locally. This process transforms waste into an alternative energy source, contributing to the circular economy and reducing dependence on fossil fuels [12]. In contrast, underdeveloped countries often lack the infrastructure for efficient waste collection and segregation, making sustainable incineration more challenging. The absence of proper waste sorting at the source can result in the incineration of recyclable or organic materials, leading to economic losses and negative environmental impacts [10].

Environmental regulation can encourage waste incineration technologies that meet stringent environmental standards while minimizing negative impacts such as dioxin and furan emissions [15]. However, landfills are often more commonly used for waste management in developing countries, where the cost of implementing and maintaining such technologies is high. This reliance on landfills can cause long-term environmental issues, including groundwater contamination and greenhouse gas emissions. Incineration, when not equipped with proper emissions controls, can worsen air pollution and pose public health risks [16]. Incinerators may operate to lower standards in countries with weaker environmental regulations, resulting in hazardous emissions.

Adopting thermal treatment as a solution for waste management in a European context is notable. Incineration is described as the way to treat more than 20% of waste generated on the continent in 2017 [7]. It is estimated that between 120 and 720 tons/day of waste in Europe are treated using mobile grate incinerators and between 36 and 200 tons per fluidized bed [1]. When observing the Asian countries that are the source of studies on technology, it is noted that they have undergone a recent and dizzying industrialization process with an increase in production and, consequently, challenges related to solid waste management.

In the second half of the 20th century, China implemented economic reforms that encouraged business investments, transformed the latter into market reserves, and created frameworks capable of maintaining the rapid economic growth resulting from the process [28]. Two studies [25, 26] highlighted that searching for waste treatment and disposal solutions is a frequent issue in the Chinese context. The fluidized bed, the second most commonly used technology for waste treatment in China, was presented in 38% of plants and represented 33% of incinerators in the country [29]. One study mentions that using fluidized beds in China is associated with the co-processing of MSW with coal due to the low average calorific potential of Chinese MSW for energy recovery [26]. Fluidized bed plants are more prevalent in small and medium-sized cities and the country's central and eastern portions [26].

Industrialization in Taiwan and the Republic of Korea followed similar development plans in the post-war period, relying on state incentives for sector development that increased competitiveness in capital-intensive and high-technology sectors [30]. Waste incineration has increasingly been used in these countries to reduce waste volume and generate electricity [16]. Globally and in Australia, waste management is a growing concern, with alternatives to traditional landfills being more widely adopted. Waste incinerators offer a viable option to alleviate landfill pressure, and modern incinerators designed to generate electricity have gained increased appeal among policymakers [31, 32]. It is also adequate to highlight our identified opportunity to discuss police and regulation, exposure risk, and implications for public health [16].

When comparing the recyclable materials in bottom ash from a fluidized bed combustion plant and a grate incinerator, a study in Austria focused on grain-size distribution, recyclable content (metals, glass, and minerals), and leaching behavior [17]. Results showed that the fluidized bed combustion produced higher-quality recyclables with less corrosion and fewer impurities in metals and glass. However, it also generated significantly more fly ash, which is currently landfilled. Based on these findings and the scarcity of information in the scientific literature, there is a clear need to conduct further studies to compare these methods comprehensively.

Finally, when evaluating the method adopted in this article, the bibliometric review has proven to be effective, offering a comprehensive overview of the topic addressed and incorporating numerous references. This method allowed us to narrow the focus when elements of the systematic review were applied. Similar scientific studies have also demonstrated strong results using bibliometric reviews [33, 34].

4. Conclusions

The study achieved its objective by comparing the applicability of solid waste treatment via incineration in fixed grate and fluidized bed furnaces, focusing on their critical technical and environmental characteristics. It was found that using finely separated waste in fluidized bed incinerators may require an additional pre-treatment step, which could increase costs and limit this technology to facilities with larger budgets and more robust infrastructures. While fluidized bed incinerators showed potential for treating sludge from sewage treatment plants, the volatilization of heavy metal compounds was observed during the process. In contrast, grate incinerators offer the advantage of handling a wider variety of waste types without pre-treatment. Otherwise, this diversity leads to a complex composition of gaseous effluent, especially related to halogenated compound emissions.

For both technologies, most studies were concentrated in Asia and Europe, where industrialization is well-established, land for landfills is limited, and waste generated has high calorific value, enabling energy recovery. This highlights the connection between production chains, spatial organization, and adopting these technologies. In this way, proposing these technologies in other locations must consider the region's potential in terms of waste treatment and the physical-chemical characteristics of the waste generated. The economic situation in the area must be considered when applying the method or technology to dispose of the trash. In addition, the risk, safety, and environmental impact are drivers for the company and government decisions.

Author Contributions

ATRS, MFSG and MPGM: Conceptualization, writing – original draft; ATRS, GCW, MFSG and MPGM: Formal analysis, writing – review and editing; MFSG and MPGM: Methodology and conceptualization. All authors have read and approved the published version of the manuscript.

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Competing Interests

The authors have declared that no competing interests exist.

References

1. Neuwahl F, Cusano G, Benavides JG, Holbrook S, Roudier S. Best available techniques (BAT) reference document for waste incineration: Industrial emissions directive 2010/75/EU (integrated pollution prevention and control). Luxembourg: Publications Office of the European Union; 2019.
2. Panepinto D, Zanetti MC. Municipal solid waste incineration plant: A multi-step approach to the evaluation of an energy-recovery configuration. Waste Manage. 2018; 73: 332-341.
3. Meylan G, Spoerri A. Eco-efficiency assessment of options for metal recovery from incineration residues: A conceptual framework. Waste Manage. 2014; 34: 93-100.

4. Khan BA, Cheng L, Khan AA, Ahmed H. Healthcare waste management in Asian developing countries: A mini review. Waste Manage Res. 2019; 37: 863-875.
5. Manzoor J, Sharma M. Impact of biomedical waste on environment and human health. Environ Claims J. 2019; 31: 311-334.
6. Hwang KL, Choi SM, Kim MK, Heo JB, Zoh KD. Emission of greenhouse gases from waste incineration in Korea. J Environ Manage. 2017; 196: 710-718.
7. Margallo M, Ziegler-Rodriguez K, Vázquez-Rowe I, Aldaco R, Irabien Á, Kahhat R. Enhancing waste management strategies in Latin America under a holistic environmental assessment perspective: A review for policy support. Sci Total Environ. 2019; 689: 1255-1275.
8. ABRELPE. Panorama 2021 [Internet]. Lausanne, Switzerland: ABREMA; 2024. Available from: https://www.abrema.org.br/panorama/.
9. ABRELPE. Panorama 2022 [Internet]. Lausanne, Switzerland: ABREMA; 2024. Available from: https://www.abrema.org.br/panorama/.
10. dos Santos IF, Mensah JH, Gonçalves AT, Barros RM. Incineration of municipal solid waste in Brazil: An analysis of the economically viable energy potential. Renew Energy. 2020; 149: 1386-1394.
11. Tyskeng S, Finnveden G. Comparing energy use and environmental impacts of recycling and waste incineration. J Environ Eng. 2010; 136: 744-748.
12. Tabata T, Tsai P. Heat supply from municipal solid waste incineration plants in Japan: Current situation and future challenges. Waste Manage Res. 2016; 34: 148-155.
13. Leckner B, Lind F. Combustion of municipal solid waste in fluidized bed or on grate-A comparison. Waste Manage. 2020; 109: 94-108.
14. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. Int J Surg. 2021; 88: 105906.
15. Ajay SV, Prathish KP. Dioxins emissions from bio-medical waste incineration: A systematic review on emission factors, inventories, trends and health risk studies. J Hazard Mater. 2024; 465: 133384.
16. Tait PW, Brew J, Che A, Costanzo A, Danyluk A, Davis M, et al. The health impacts of waste incineration: A systematic review. Aust N Z J Public Health. 2020; 44: 40-48.
17. Blasenbauer D, Huber F, Mühl J, Fellner J, Lederer J. Comparing the quantity and quality of glass, metals, and minerals present in waste incineration bottom ashes from a fluidized bed and a grate incinerator. Waste Manage. 2023; 161: 142-155.
18. Horii Y, Ok G, Ohura T, Kannan K. Occurrence and profiles of chlorinated and brominated polycyclic aromatic hydrocarbons in waste incinerators. Environ Sci Technol. 2008; 42: 1904-1909.
19. Lee WJ, Liow MC, Tsai PJ, Hsieh LT. Emission of polycyclic aromatic hydrocarbons from medical waste incinerators. Atmos Environ. 2002; 36: 781-790.
20. Choi SM, Im JK, Hong JH, Lee SB, Zoh KD. The estimation of emission factor of N_2O and CH_4 by measurement from stacks in the waste incinerators and cement production plants. J Environ Health Sci. 2007; 33: 217-226.
21. Marani D, Braguglia CM, Mininni G, Maccioni F. Behaviour of Cd, Cr, Mn, Ni, Pb, and Zn in sewage sludge incineration by fluidised bed furnace. Waste Manage. 2003; 23: 117-124.
22. Sänger M, Werther J, Ogada T. NO_x and N_2O emission characteristics from fluidised bed combustion of semi-dried municipal sewage sludge. Fuel. 2001; 80: 167-177.

23. Anderson M, Skerratt RG, Thomas JP, Clay SD. Case study involving using fluidised bed incinerator sludge ash as a partial clay substitute in brick manufacture. Water Sci Technol. 1996; 34: 507-515.
24. Mi HH, Chiang CF, Lai CC, Wang LC, Yang HH. Comparsion of PAH emission from a municipal waste incinerator and mobile sources. Aerosol Air Qual Res. 2001; 1: 83-90.
25. Zhang L, Su X, Zhang Z, Liu S, Xiao Y, Sun M, et al. Characterization of fly ash from a circulating fluidized bed incinerator of municipal solid waste. Environ Sci Pollut Res. 2014; 21: 12767-12779.
26. Zhang M, Buekens A, Li X. Characterising boiler ash from a circulating fluidised bed municipal solid waste incinerator and distribution of PCDD/F and PCB. Environ Sci Pollut Res. 2018; 25: 22775-22789.
27. Yan M, Wang J, Hantoko D, Kanchanatip E. Numerical investigation of MSW combustion influenced by air preheating in a full-scale moving grate incinerator. Fuel. 2021; 285: 119193.
28. Jabbour E. China: Desenvolvimento e socialismo de mercado. 1st ed. Florianópolis: Cadernos Geográficos; 2020.
29. Nie Y. Development and prospects of municipal solid waste (MSW) incineration in China. Front Environ Sci Eng China. 2008; 2: 1-7.
30. Helal DH, Rocha DF. Comparando políticas de desenvolvimento e atuação do estado: América Latina e Leste Asiático. Desenvolv. Quest. 2013; 11: 4-39. doi: 10.21527/2237-6453.2013.23.4-39.
31. Passarini F, Nicoletti M, Ciacci L, Vassura I, Morselli L. Environmental impact assessment of a WtE plant after structural upgrade measures. Waste Manage. 2014; 34: 753-762.
32. Hu H, Li X, Nguyen AD, Kavan P. A critical evaluation of waste incineration plants in Wuhan (China) based on site selection, environmental influence, public health and public participation. Int J Environ Res Public Health. 2015; 12: 7593-7614.
33. Moshari A, Aslani A, Zolfaghari Z, Malekli M, Zahedi R. Forecasting and gap analysis of renewable energy integration in zero energy-carbon buildings: A comprehensive bibliometric and machine learning approach. Environ Sci Pollut Res. 2023; 30: 91729-91745.
34. Tayefeh A, Abdous M, Zahedi R, Aslani A, Zolfagharzadeh MM. Advanced bibliometric analysis on water, energy, food, and environmental nexus (WEFEN). Environ Sci Pollut Res. 2023; 30: 103556-103575.