

Failure Analysis and Thermo-Structural Design Simulation of a Cylindrical Dual-Chamber Solid Waste Incinerator

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Abstract

The generation of municipal solid waste (MSW) is rapidly increasing. This has worsened environmental pollution and public health hazards, especially in places with poor waste management policies. This research employs finite element simulation techniques to investigate the thermo-structural response and failure behaviour of a cylindrical dual-chamber MSW incinerator. The study's objectives were to assess structural stability, and operational reliability of the system under various service situations. A three-dimensional computer aided model of the incinerator was developed using CATIA CAD modeling. Finite Element simulations were used to analysed various operational fault conditions like over-heating, refractory deterioration, chamber deformation, cracking, corrosion, chimney blockage, seal leakage and ash accumulation. The main structural material was mild steel, with refractory linings used mainly to improve insulation and also to prevent the combustion chambers from high temperatures. The numerical analysis was performed with tetrahedral meshing and appropriate thermal boundary conditions. The simulation results showed that the combustion chambers and connecting duct had the highest temperature distribution, and the major thermal stresses were concentrated around the welded joints and support regions. During normal operation, the secondary chamber temperatures ranged from 995°C to 1050°C and the maximum Von Mises stress ranged from 145 MPa to 180 MPa. The results indicated that repetitive thermal cycling, corrosion, inadequate airflow circulation and excessive heat loading increased the likelihood of deformation and structural collapse. The study showed that the cylindrical dual-chamber design had better heat distribution, lower stress concentration and better combustion performance when compared to the conventional rectangular incinerator.

Keywords: Solid Waste Incineration, Thermal Stress Distribution, Thermo-Structural Analysis, Finite Element Simulation, Cylindrical Dual-Chamber Incinerator.

Introduction

The production of municipal solid waste (MSW) has increased dramatically over the world due to rapid urbanisation, industrialisation, population development and changing consumer habits. Solid waste management (SWM) and disposal have become major

environmental and public health issues in many developing countries including Nigeria. Uncontrolled burning, indiscriminate disposal, open dumping, and other improper waste management practices lead to land degradation, emissions of greenhouse gases, environmental pollution, blockages of drainage systems, and the proliferation of infectious diseases. Hence, there is a growing demand for efficient and environmentally friendly waste management technologies to reduce the waste volume and minimise environmental hazards (Ventura & Maia, 2025; Erhinyodavwe *et al.*, 2025; Orhorhoro, 2025). Incineration is one of the most effective thermal methods of waste treatment for reduction of the volume and mass of combustible solid waste materials (Mou *et al.*, 2025). It is a process of controlled burning of trash at high temperatures. It provides substantial reduction of the waste, eradication of dangerous pathogens and conversion of the waste into ash, flue gases and thermal energy. The performance and durability of waste incinerators are significantly influenced by factors such as structural integrity, thermal efficiency, combustion performance, and also the ability to withstand high-temperature failure mechanisms. These incinerators function under extreme thermal conditions, which are characterised by elevated combustion temperatures, thermal gradients, cyclic heating and cooling, mechanical loading, and exposure to corrosive combustion gases (Jin *et al.*, 2023). Nevertheless, such operating conditions can result in structural distortion, thermal fatigue, refractory cracking, corrosion, stress concentration, weld failure, chimney collapse. Also, it can lead to excessive thermal deformation if the incinerator is poorly designed or improperly maintained (Wosu *et al.*, 2025). In many locally fabricated incinerators used in developing countries such as Nigeria, engineering design limitations can often lead to premature structural failure, inefficient combustion, excessive smoke emission, poor heat retention, and reduced operational lifespan (Mou *et al.*, 2025).

The majority of small-scale incinerators in developing countries are fabricated using locally available mild steel materials without adequate thermal analysis, stress evaluation, or thermo-structural optimisation (Jiang *et al.*, 2020). Thus, several operational challenges such as overheating, poor airflow distribution, ash blockage, refractory deterioration, and structural instability are frequently encountered during operation (Liu *et al.*, 2024). However, the growing demand for efficient and reliable waste incineration systems has increased the importance of numerical simulation and computational engineering analysis in incinerator design and performance evaluation (Zhang *et al.*, 2025). Advances in computational modelling techniques such as Finite Element Analysis (FEA), Computational Fluid Dynamics (CFD), thermo-mechanical simulation, and thermal stress analysis now enable engineers to predict the thermal and structural behaviour of high-temperature systems before fabrication (Hadadiyan *et al.*, 2023). The use of these simulation tools provides valuable insight into heat transfer characteristics, temperature distribution, thermal stress development, structural deformation, airflow patterns, and possible failure regions within combustion systems (Zheng *et al.*, 2024). Also, thermo-structural simulation combines thermal and structural analyses to evaluate the interaction between temperature fields and mechanical responses in engineering systems. For instance, in waste incinerators,

thermo-structural analysis is essential because thermal expansion and temperature gradients directly influence stress development and structural stability. Although, excessive thermal loading can weaken material properties, induce thermal creep, generate stress concentration around welded joints, and eventually cause catastrophic structural failure (Luo *et al.*, 2021; Hadadiyan *et al.*, 2023; Zhang *et al.*, 2025). Consequently, understanding the thermo-mechanical behavior of incinerator components under operational conditions is essential for improving the system reliability, safety, and service life. The configuration of cylindrical dual-chamber incinerators has attracted attention in recent years because of its improved design in thermal distribution, enhanced combustion efficiency, and reduced stress concentration compared with conventional rectangular chamber designs. For instance, the cylindrical geometry promotes more uniform heat distribution and minimises localised thermal concentration at corners and sharp edges. Besides, the incorporation of a secondary combustion chamber in it improves the oxidation of combustible gases, thereby reducing smoke emission and enhancing combustion efficiency. However, despite these advantages, cylindrical incinerators are still susceptible to thermal distortion, refractory degradation, corrosion, structural cracking, and operational failures when subjected to prolonged high-temperature operation.

Failure simulation is vital especially in predicting operational weaknesses and identifying regions susceptible to structural and thermal damage in incinerator systems. Also, by simulating different operational failure scenarios such as overheating, structural warping, refractory failure, chimney blockage, corrosion, and seal leakage, engineers can evaluate the safety performance and durability of the system under realistic operating conditions (Huai *et al.*, 2008; Omari *et al.*, 2020). Simulation-based analysis enhances optimization of material selection, structural configuration, refractory protection, thermal insulation, and airflow distribution. The application of thermo-structural simulation methods to waste incinerator analysis is particularly significant in developing countries like Nigeria where locally fabricated systems are extensively used for small-scale waste management. Several locally designed incinerators lack adequate engineering evaluation during the design stage, thereby increasing the likelihood of operational failure and environmental pollution. Thus, integrating simulation-based engineering analysis into the design process will help to improve combustion efficiency, reduce maintenance costs, enhance structural reliability, and prolong service life.

Numerous empirical investigations have been conducted on solid waste incinerators but with emphasis on thermal performance, structural integrity, combustion efficiency, emission control, and material durability. These studies provide vital understandings in failure mechanisms and thermo-structural behaviour of cylindrical dual-chamber solid waste incinerators used for municipal and medical waste treatment. As reported by Zhang *et al.* (2025) thermo-structural finite element analysis is an effective approach for predicting thermal stress concentration in cylindrical combustion systems. Similarly, a related investigation by Kim, et al. (2024) examined airflow characteristics and combustion efficiency in a cylindrical dual-chamber incinerator using computational fluid dynamics

(CFD). The study established that secondary combustion chambers improved waste burnout efficiency and minimised harmful emissions through enhanced turbulence and air mixing. Also, the research work of (Xiaoxin *et al.*, 2020; Peng, *et al.*, 2025) focused on refractory material performance under severe thermal conditions. The experimental laboratory testing and simulation analyses showed that alumina-based refractory linings possessed better resistance to thermal shock and crack propagation when compared with conventional fireclay materials. The study confirmed that mismatch in thermal expansion between the refractory lining and metallic shell promoted internal stress concentration and eventual structural failure. Moreover, Bahareh *et al.* (2025) investigated the operational reliability of a locally developed cylindrical medical waste incinerator. Important operation parameters such as combustion temperature, fuel consumption, wall deformation, and ash generation were experimentally monitored. The findings from the study indicated that continuous exposure to elevated temperature caused severe corrosion, wall thinning, and weld degradation. Besides, the failure analysis showed that oxidation and thermal fatigue were the dominant mechanisms responsible for structural deterioration. Collectively, these studies demonstrate that existing research has largely examined individual aspects of incinerator performance such as thermal stress, airflow, refractory behaviour, and operational reliability in isolation. However, with a limited integration of multiple failure mechanisms. This highlights the need for the present study, which adopts a comprehensive thermo-structural finite element approach to simultaneously evaluate interacting failure modes. It will also provide a more holistic assessment of the reliability and durability of cylindrical dual-chamber solid waste incinerators.

As showed, previous studies on waste incinerators have largely concentrated on combustion efficiency, thermal performance, airflow characteristics, and basic structural analysis of thermal systems. On the other hand, limited attention has been given to comprehensive thermo-structural failure simulation of locally fabricated cylindrical dual-chamber incinerators under realistic operating conditions. Also, most existing research focused mainly on isolated thermal or structural evaluations. Thus, past researchers had not fully investigated the combined effects of thermal loading, stress development, refractory degradation, corrosion, chimney instability, seal leakage, ash blockage, and cyclic thermo-mechanical behavior on long-term operational reliability. Also, many locally fabricated solid waste incinerators suffer from overheating, thermal stress, structural deformation, refractory failure, corrosion, and poor combustion due to inadequate engineering design and the absence of comprehensive thermo-structural evaluation. Although previous studies have examined combustion performance and thermal efficiency, they have largely overlooked integrated failure analysis under realistic operating conditions. This has resulted to frequent structural deformation, overheating, poor combustion performance, and premature system failure. Therefore, there is a need for a comprehensive thermo-structural simulation to predict failure mechanisms, improve structural reliability, and enhance the safety, efficiency, and durability of cylindrical dual-chamber solid waste incinerators. This on the other hand can help to improve design reliability, durability, and

combustion efficiency for sustainable waste management applications. This study will therefore focus on the thermo-structural simulation and failure assessment of a cylindrical two-chamber solid waste incinerator using finite element analysis techniques. The study will also investigate the thermal distribution, stress development, structural deformation, and all possible failure mechanisms that may occur during incinerator operation under different loading conditions. The study shall further evaluate the effects of thermal loading, cyclic heating, refractory degradation, and operational failures on the structural performance of the incinerator system. The findings from this study are expected to contribute to the improvement of locally fabricated waste incinerator designs by providing engineering insight into thermal behavior, structural reliability, and operational safety. The research will also provide valuable information from the generated data and results for engineers, researchers, waste management agencies, and policymakers involved in the development of efficient and sustainable waste treatment technologies. Furthermore, the study is in line with the advancement of environmentally sustainable solid waste management practices through the development of safer, more durable, and more efficient incineration systems.

Materials and Methods

The investigation mainly focused on identifying possible structural, thermal, and failures that may occur during continuous operation of the incinerator system. The simulation approach combined three-dimensional CATIA CAD modeling, thermal analysis, structural finite element analysis (FEA), thermo-mechanical coupling, failure mode assessment, and stress and deformation analysis. The analyses in this study were conducted using standard engineering simulation procedures applicable to high-temperature thermal systems.

Materials

The primary and secondary chamber shells of the incinerator were modeled using mild steel plates. The thermophysical and mechanical properties of the mild steel used for the incinerator shell (Table 1) were obtained from the ANSYS Workbench Engineering Data material library (ANSYS Inc., Canonsburg, PA, USA) and verified against Callister and Rethwisch (2020).

Table 1: Properties of mild steel plate used for the primary and secondary chamber shells

S/N	Property	Value
1	Density	7850 kg/m ³
2	Young's Modulus	210 GPa
3	Poisson Ratio	0.30
4	Yield Strength	250 MPa
5	Thermal Conductivity	45 W/m·K
6	Specific Heat Capacity	470 J/kg·K
7	Melting Temperature	1450°C

The mild steel was selected and used in this study because of its good weldability, local availability, low fabrication cost, adequate structural strength, and ease of machining and forming. The internal combustion chamber surfaces were lined with refractory fire bricks. The refractory firebrick properties presented in Table 2 were adopted from the ANSYS Engineering Data library and cross-checked with the material specifications reported by Budinski and Budinski (2010) and Perry's Chemical Engineers' Handbook (Green & Southard, 2019). These material properties were used as input parameters for the thermo-structural finite element simulations.

Table 2: Refractory properties

S/N	Property	Value
1	Density	2200 kg/m ³
2	Thermal Conductivity	1.5 W/m·K
3	Specific Heat	1000 J/kg·K
4	Maximum Service Temperature	1400°C
5	Thermal Expansion Coefficient	5.0×10 ⁻⁶ /°C

Also, a refractory lining was introduced to retain thermal energy, protect steel shell from overheating, improve combustion efficiency, and reduce thermal shock damage.

Geometrical Modeling

A complete 3D model of the cylindrical dual-chamber incinerator was developed using CATIA V5 software as shown in Figure 1.

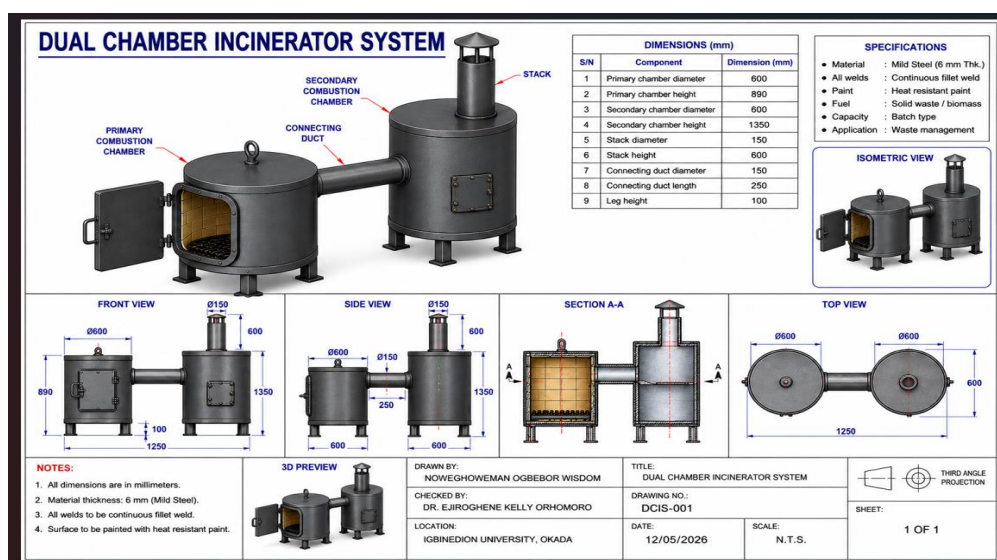


Figure 1: 3D model of the cylindrical dual-chamber incinerator

The dimensions adopted for the simulation are summarized as shown in Table 3.

Table 3. Dimensions adopted for the simulation

S/N	Component	Dimension (mm)
1	Primary chamber diameter	600
2	Primary chamber height	890
3	Secondary chamber diameter	600
4	Secondary chamber height	1350
5	Stack diameter	150
6	Stack height	600
7	Connecting duct diameter	150
8	Connecting duct length	250
9	Leg height	100

Simulation

The thermo-structural simulations were performed using ANSYS Workbench 2024 R2 (ANSYS Inc., Canonsburg, PA, USA). The Steady-State Thermal solver was used to determine the temperature distribution, while the Static Structural solver was employed to evaluate thermal stresses and deformations. Thermo-mechanical coupling was achieved by importing the thermal field into the structural analysis using a sequentially coupled (one-way) finite element approach. The simulations were conducted using the ANSYS Mechanical solver with second-order tetrahedral solid elements under nonlinear thermal loading conditions.

Mesh Generation

The 3D CAD geometry was discretized into finite elements using tetrahedral meshing. The tetrahedral meshing is a computational modeling method employed to partition a three-dimensional structure into several small tetrahedron-shaped elements for the purpose of numerical analysis. Similarly, a tetrahedron is a polyhedral element that composed of four triangular faces, four vertices, and six edges. This meshing approach is widely utilized in numerical simulations such as FEA, thermal simulations, and structural assessments due to its ability to effectively represents complicated geometrical domains. The mesh characteristics is shown in Table 4.

Table 4: Mesh Characteristics

S/N	Component	Value
1	Element type	Tetrahedral
2	Average element size	10–20 mm
3	Refinement zones	Duct joints, door edges, stack base
4	Total elements	Approximately 250,000–500,000

Boundary Conditions

Combustion temperatures were applied to the internal surfaces. Table 5 shows the applied temperature.

Table 5: Applied temperature

S/N	Region	Temperature
1	Primary chamber	700–900°C
2	Secondary chamber	900–1100°C
3	Connecting duct	600–850°C
4	Stack region	250–500°C
5	Ambient temperature	30°C

Structural Analysis

Structural analysis was performed using temperature loads obtained from the thermal simulations. The analysis evaluated thermal expansion, equivalent stress, deformation, and buckling tendency. The Von Mises stress criterion was used to assess structural failure. Failure was assumed to occur when:

$$\sigma_v > \sigma_y \quad (1)$$

Where σ_v represents Von Mises stress, and σ_y implies yield strength of material

Failure Simulations

Several operational failure scenarios such as overheating failure, structural distortion, chamber cracking, chimney failure, door seal leakage, refractory failure, corrosion failure, ash blockage failure was simulated.

Results and Discussion

The cylindrical two-chamber incinerator's thermo-structural simulation findings will offer important insights into the system's thermal behaviour, structural reaction, operational performance, and potential failure mechanisms under various operating situations. Overheating, structural distortion, chamber cracking, seal leakage, chimney obstruction, poor combustion, refractory failure, ash blockage, chimney collapse, corrosion, duct leakage, and foundation failure were among the key failure scenarios considered in the simulations. The findings show how the incineration system's thermal loading, mechanical stress, airflow characteristics, and structural integrity interact.

Overheating and Thermal Overloading

The overheating and thermal overload simulation depicted in Figure 2 shown that the major combustion chamber and the area surrounding the duct that connects the primary and secondary chambers had the highest temperatures. The maximum temperatures in the simulation were close to 1092°C, and the associated maximum Von Mises stress was

roughly 236 MPa. These values show that under severe working conditions, the material was close to the mild steel yield limit. The findings also demonstrated that extended exposure to such temperatures may cause deformation, thermal creep, shell weakening, and ultimately structural collapse. Besides, the decrease in material strength at high temperatures is the cause of this behaviour (Doppalapudi *et al.*, 2023). However, compared to rectangular systems, the cylindrical design dispersed thermal loads more evenly, lowering localised thermal concentration at sharp corners.

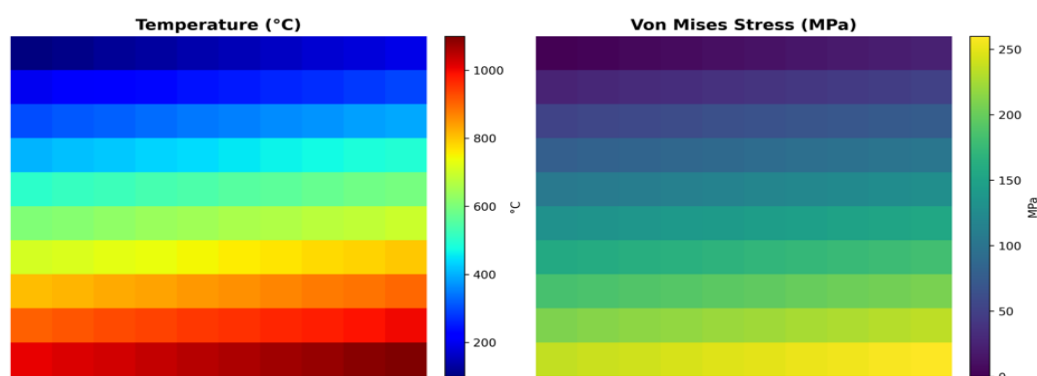


Figure 2: Overheating and thermal overloading

Structural Distortion/Warping

Figure 3 shows the structural distortion and warping simulation. As revealed in Figure 3, an uneven heat expansion caused detectable deformation within the incinerator shell. As revealed, under extreme heat, the overall deformation increased to around 2.42 mm. Besides, prolonged exposure to high temperatures caused the secondary chamber and connecting duct sections to deform the most. The observed bending behaviour suggests that prolonged temperature cycling may eventually result in weld failure, door misalignment, and irreversible deformation (Jun *et al.*, 2026). This finding demonstrates that one of the main reasons for long-term structural instability in high-temperature combustion systems is thermal expansion.

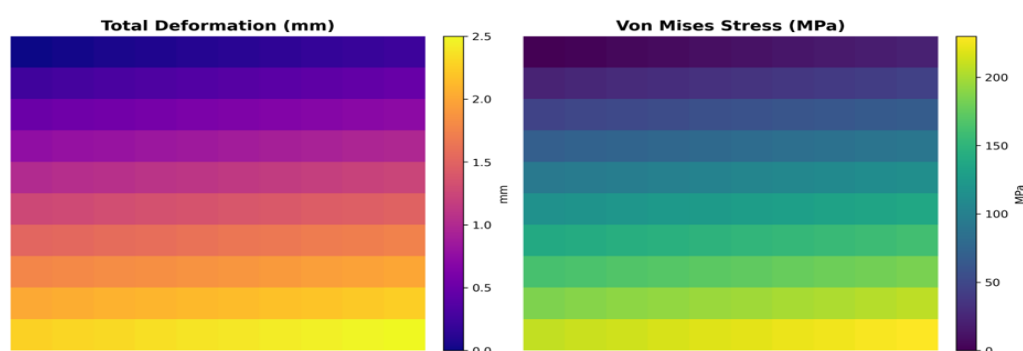


Figure 3: Structural Distortion/Warping

Cracking of Chamber Body

The high thermal stresses generated around welded connections, door edges, and chamber intersections, according to Figure 4 cracking simulation of the chamber body. In certain areas, the maximum stress surpassed 228 MPa, while equivalent plastic strain values were around 0.0096. These findings simply imply that stress concentration areas where mechanical constraint and thermal expansion interact are likely to be the sites of fracture formation. The simulation verified that thermal fatigue failure is considerably accelerated by cyclic heating and cooling. Loss of combustion efficiency and smoke leakage are inevitable once cracks start (Yang *et al.*, 2023; Cao *et al.*, 2023).

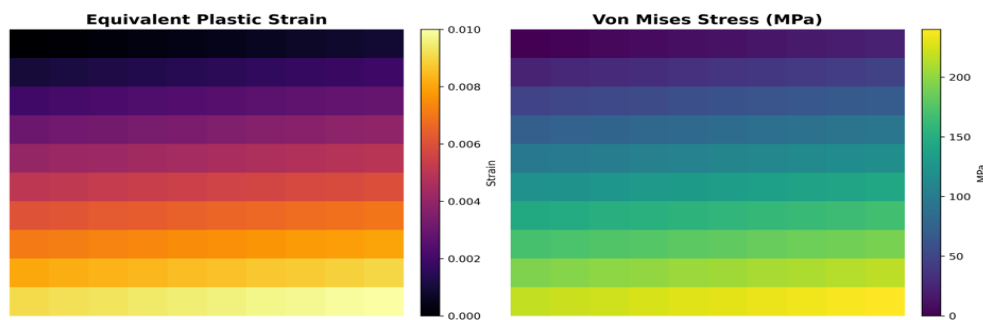


Figure 4: Cracking of Chamber Body

Door Failure/Seal Leakage

The door failure and seal leakage simulation as shown in Figure 5 demonstrated that smoke leakage and uncontrolled air infiltration into the combustion chamber were caused by gasket deterioration and inadequate sealing. Also, around the door perimeter, leakage velocities of roughly 13.6 m/s were noted, and pressure differences were close to 58 Pa. According to the findings, seal degradation causes extra air to enter the chamber, which upsets combustion stability. This state raises smoke emissions, decreases combustion efficiency, and lowers combustion temperature. Additionally, it has been demonstrated that repetitive heat expansion and contraction deform the door assembly and exacerbate leakage over time (Zheng *et al.*, 2024).

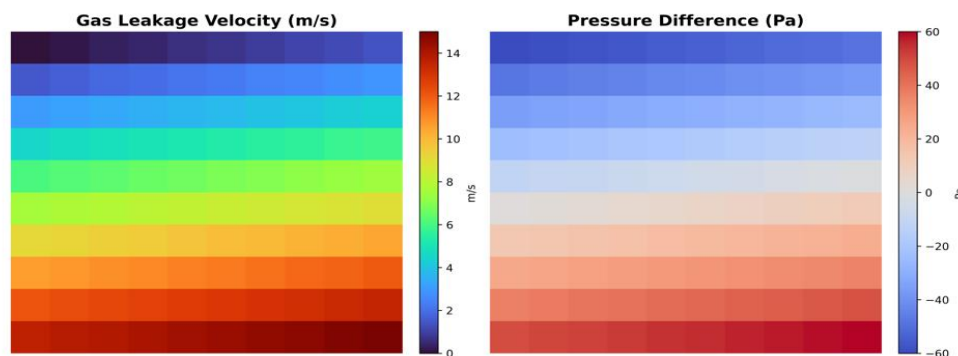


Figure 5: Door Failure/Seal Leakage

Chimney Stack Blockage

The crucial function of natural draft in the incineration system was illustrated by the chimney and stack blockage simulation shown in Figure 6. As shown in the simulation result, partial obstruction and soot buildup raised system back pressure to about 218 Pa. Besides, the chimney's gas flow velocity dramatically decreased, limiting the supply of combustion air. Also, incomplete combustion, smoke backflow, and increased pollutant concentration were all brought on by the decrease in airflow (Yang *et al.*, 2023). The findings verify that maintaining effective natural draft operation requires regular chimney repair.

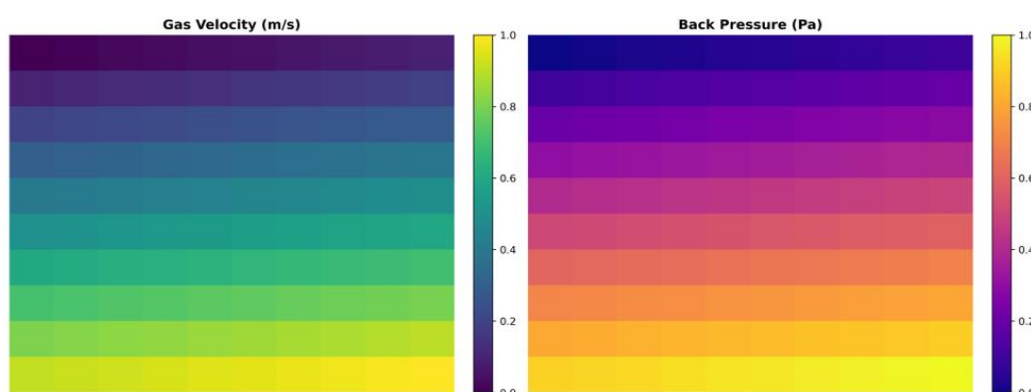


Figure 6: Chimney Stack Blockage

Poor Combustion and Incomplete Burn

Inadequate oxygen delivery has a major impact on combustion performance, as seen by the incomplete burn simulation and poor combustion shown in Figure 7. Although the concentration of carbon monoxide rose to around 3640 parts per million, the average secondary chamber temperature dropped to about 641°C. These results show that inadequate air supply and unfavourable combustion conditions cause incomplete oxidation of combustible gases. The outcome highlights how crucial appropriate waste loading and airflow control are to producing low emissions and effective combustion.

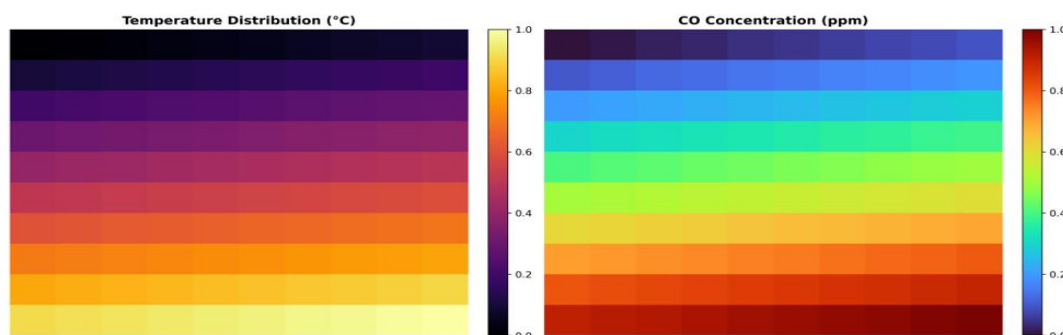


Figure 7: Poor Combustion and Incomplete Burn

Refractory Lining Failure

The refractory layer underwent extraordinarily high temperatures of about 1165°C and thermal stresses of about 28.7 MPa, according to the refractory lining failure simulation depicted in Figure 8. The refractory material experienced spalling and cracking due to thermal stress conditions (Peng *et al.*, 2025). The steel shell was immediately exposed to combustion temperatures after refractory damage, which resulted in quick overheating and exacerbated structural deterioration (Wosu *et al.*, 2025). The findings verify that installation precision and refractory quality are important elements influencing incinerator longevity.

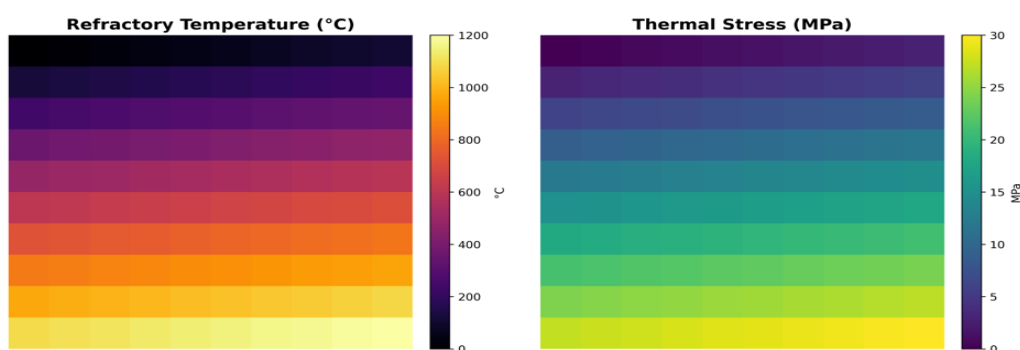


Figure 8: Refractory lining failure

Ash Pan Over Flow/Blockage

The ash pan overflow and blockage simulation showed that excessive ash accumulation obstructed airflow beneath the grate system as shown in Figure 9. The ash heights reached approximately 274 mm, while airflow velocity reduced to as low as 0.18 m/s. The drops in airflow caused incomplete combustion, unstable flame behavior, and excessive smoke generation. This result highlights the importance of routine ash removal during operation.

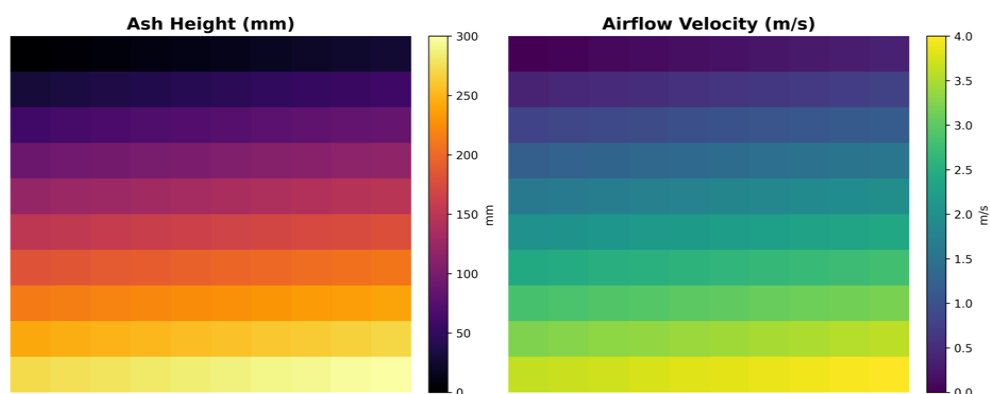


Figure 9: Ash Pan Over Flow/Blockage

Stack Collapse/Fall

Figure 10 shows the stack collapse and fall simulation. The result showed that excessive bending stress was developed near the base of the chimney stack. Besides, maximum deformation reached approximately 16.7 mm, while stress values exceeded 241 MPa in the support region. The simulation confirmed that poor support conditions, corrosion, and thermal weakening significantly increase the likelihood of stack instability and collapse.

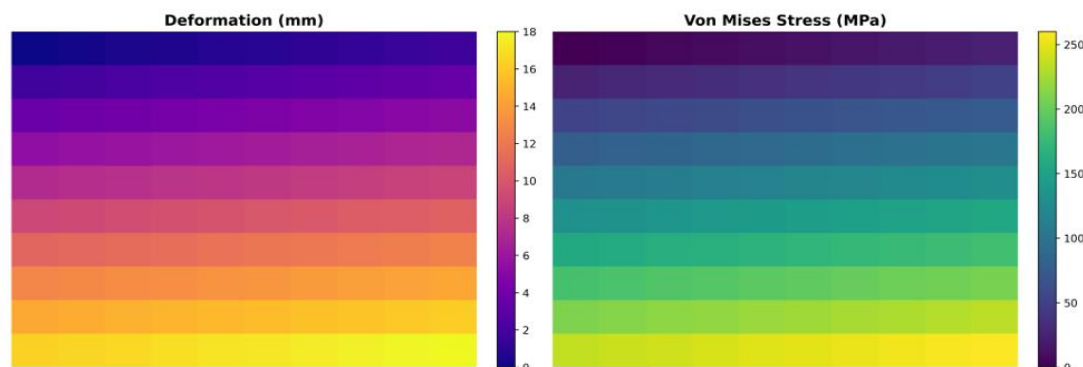


Figure 10: Stack Collapse/Fall

Corrosion/Rust Through

As seen in Figure 11, the corrosion and rust-through simulation revealed significant wall thinning brought on by moisture exposure and acidic flue gases. Also, the corrosion rates reached 0.23 mm/year, and the minimum wall thickness decreased to about 1.32 mm. Similarly, condensation is most likely to occur around the ash pan, lower chamber areas, and duct joints corrosion was found to be worsen. Besides, gradual corrosion will weaken the structure and ultimately resulted in gas leaking and perforation failure.

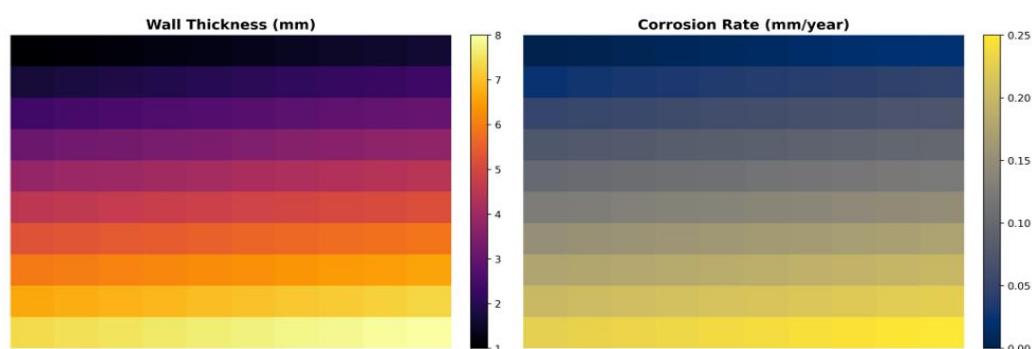


Figure 11: Corrosion/Rust Through

Connection Duct Failure/Leakage

Figure 12 shows the results of the connection duct failure/leakage. The connecting duct failure simulation showed that the duct region underwent significant thermal and structural loading. Around failing joints, leakage velocities of about 14.8 m/s were noted, and Von

Mises stress was greater than 203 MPa. Also, the joint deterioration and leakage failure are accelerated by poor welding quality and frequent thermal cycling.

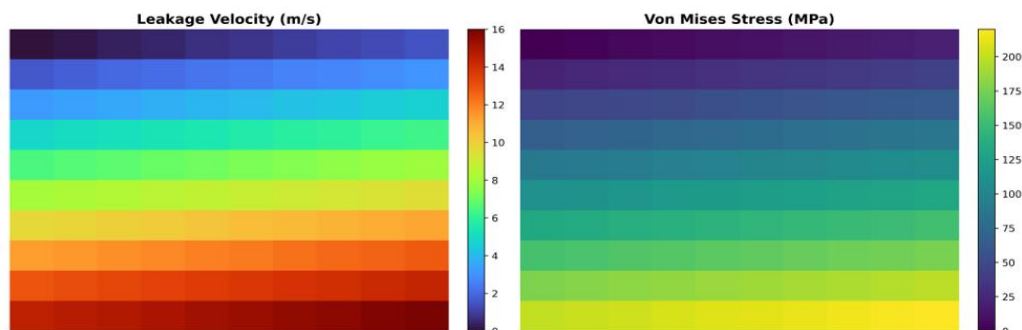


Figure 12: Connection Duct Failure/Leakage

Foundation/Support Failure

As seen in Figure 13, the foundation and support failure simulation showed that insufficient support conditions resulted in displacement values of roughly 5.24 mm along with contact pressures close to 58 kPa. Besides, when the support legs were subjected to severe stress or subpar foundation conditions, uneven settlement and structural instability were noted. This finding suggests that safe long-term operation requires adequate anchorage and foundation reinforcement.

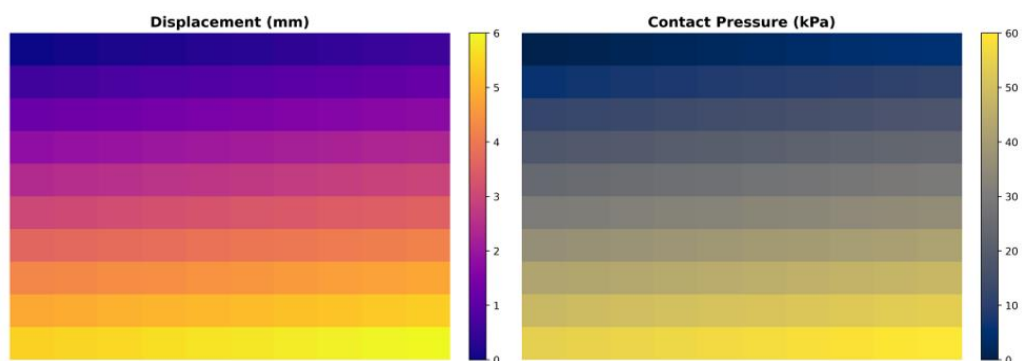


Figure 13: Foundation/Support Failure

The results of the simulation confirmed that the cylindrical two-chamber configuration offers a number of engineering advantages, such as better thermal distribution, less stress concentration, increased combustion efficiency, and better structural stability. However, the findings also show that appropriate maintenance, efficient refractory protection, regulated waste loading, corrosion prevention, and routine structural inspection are critical to operating safety and long-term durability. Generally, the simulation results affirm that the cylindrical dual-chamber incinerator is technically feasible and structurally reliable for small-scale waste management applications provided that recommended operational procedures and maintenance practices are properly implemented.

Conclusions

In this study a thermo-structural simulation and failure assessment of a cylindrical two-chamber solid waste incinerator was successfully carried out using finite element analysis techniques. The study offered a thorough understanding of the operational performance, structural reaction, thermal behaviour, and potential failure causes related to high-temperature waste incineration systems. The study showed that thermo-mechanical modelling is a very useful tool for assessing how thermal stress and structural integrity interact in combustion systems prior to physical construction and operation. The thermal analysis revealed that during operation, the primary and secondary combustion chambers developed exceptionally high combustion temperatures. As a result of direct exposure to hot combustion gases, the temperature distribution shown that the largest thermal concentrations were found near the combustion zones and connecting duct regions. Also, the refractory lining enhanced thermal retention in the combustion chambers and dramatically decreased heat transfer to the exterior steel shell. Nevertheless, it was discovered that extended exposure to high temperatures increased the risk of material softening, thermal creep, and overheating within the steel structure.

The structural modelling also proved that the incinerator structure underwent measurable stress development and deformation due to thermal expansion and uneven temperature distribution. According to the Von Mises stress distribution analysis, thermal constraint was most severe near welded joints, chamber intersections, support areas, and door openings, where the maximum stress concentrations were found. The deformation study revealed that prolonged cycles of heating and cooling can eventually cause door misalignment, structural warping, and instability in the combustion chambers. All these results demonstrated that one of the key factors contributing to long-term structural degradation in high-temperature waste incineration systems is the presence of thermal stress. A number of operational failure situations such as overheating, chamber cracking, refractory failure, chimney blockage, seal leaking, corrosion, ash obstruction, stack instability, and foundation failure, were also investigated. The simulations showed that the possibility of structural and operational failure is critically increased by heavy waste loading, inadequate airflow, subpar maintenance procedures, thermal shock, and extended exposure to high temperatures. It was revealed that refractory degradation exposes the steel shell directly to combustion heat, hastening thermal damage and shortening the lifespan of the structure. In a similar vein, corrosion brought on by moisture and acidic combustion gases gradually damaged the structural integrity of the incinerator's components and decreased wall thickness.

The findings also demonstrated that, in comparison to traditional rectangular combustion systems, the cylindrical dual-chamber structure offers significant engineering advantages. By removing sharp corner areas that frequently experience localised overheating and cracking, the cylindrical design encouraged more uniform thermal dispersion and decreased stress concentration. Additionally, the secondary combustion chamber reduced smoke emissions and increased combustion efficiency by improving the oxidation of

combustible gases. These features show that the cylindrical dual-chamber design is technically appropriate for effective and ecologically friendly waste management applications. Additionally, the study verified that thermo-mechanical coupling techniques and finite element analysis are useful engineering tools for assessing thermal performance, anticipating structural flaws, and enhancing incinerator dependability before to construction. Overall, the study revealed that, under controlled operating conditions, the cylindrical two-chamber solid waste incinerator has adequate thermal performance, structural stability, and operational dependability. Nevertheless, appropriate maintenance procedures, efficient refractory protection, regulated waste loading, corrosion prevention, and routine structural inspection are critical to the system's long-term longevity and effectiveness. Therefore, the findings from this study will greatly aid in the development of safer, more robust, and more effective thermal waste management technologies for long-term environmental protection as well as the enhancement of locally manufactured waste incineration systems.

Recommendation

Based on the findings of this study, it is recommended that thermo-structural simulation should be used when designing waste incinerators to improve safety and reliability. Also, high-quality refractory materials, proper airflow control, and regular maintenance should also be adopted to reduce overheating, corrosion, structural failure, and poor combustion. Besides, future studies should combine finite element analysis with computational fluid dynamics (CFD) and experimental testing to improve the design, performance, and durability of waste incinerators for sustainable solid waste management.

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