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Development and Experimental Assessment of an Induction-Heated Sanitary Waste Incineration System

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Abstract

The recent developments in energy and environmental engineering show the significance of decentralized and energy-efficient systems to the safe handling of sanitary waste. Inappropriate disposal of the used sanitary napkins causes contamination of the environment, toxic gases, and health hazards to the people. The paper is a design, fabrication, and experimental analysis of a portable sanitary napkin incinerator that was designed under the purview of energy-efficient systems. The proposed incinerator of 61 cm x 10 cm x 8 cm size, uses electric-heating technology. The system works under a 2000 W nichrome heating coil operating at 230 V with a sanitary napkin capacity of 5-10 in a cycle. Trials conducted in the laboratory showed full combustion in 170 to 200 s per batch. The evaluation of performance revealed that there was a mean waste mass decrease of about 91 % with the residual inert ash mass of between 3.4 g to 5.1 g per cycle which proves that the performance of volume reduction was achieved. Operating temperatures of 800-1050°C were maintained during combustion. The filtration unit containing activated carbon and gravel was intended to reduce different pollutants. Approximate fabrication cost of the prototype was INR 8,000-12,000, while the operating electricity cost was about INR 2–4 per cycle depending on operating time and local electricity tariff. The results show that energy- efficient systems can be successfully incorporated in small scale incineration system to provide a sustainable resolution to the use of decentralized sanitary waste in the field of environmental engineering.

Keywords

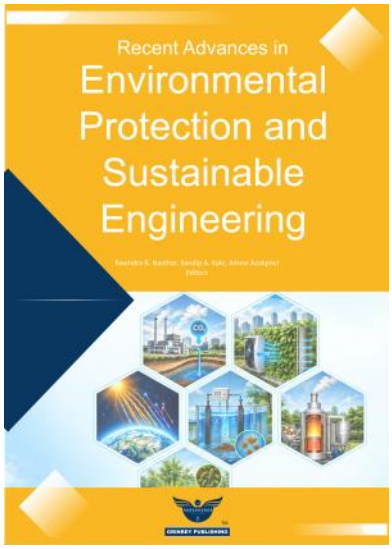
Carbonation Incinerator; Nichrome heating; Energy; Environmental; Combustion

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1. Introduction

The control of menstrual hygiene has become the international concern, especially in low-income regions where it is still a significant obstacle to the health and career development of women [1]. The practical evidence in India has shown that unhygienic menstrual habits tend to initiate the occurrence of urogenital infection, therefore need to underline the fact that clean practices and good sanitation systems are not only luxuries but necessities [2].

The growing preference for disposable wipes reflects a significant cultural evolution in menstrual management. Nevertheless, as these products become the standard in low-income areas, the resulting sanitary debris creates a pressing environmental challenge that demands immediate mitigation [3]. This trend is further accelerated by the increasing rate of urbanization, in particular, in professional and educational fields of activity, where the accumulation of sanitary debris is surging to record heights, creating an environmental crisis that can no longer be ignored [4]. Disposable pads are the products of plastics, saturated chemicals, and synthetic fibers, are highly resistant to biodegradation. Several sanitary napkin disposal systems have also been developed to address the growing challenge of menstrual waste management in institutions and public places. Consequently, conventional waste management infrastructures remain ill-equipped to process these synthetic fibers, leading to long-term environmental accumulation [5, 6]. When disposed recklessly, buried shallow, drained in the drainage system, or burnt indiscriminately, such products cause long-term effect on the surrounding communities.

The use of disposable menstrual pads significantly increases the comfort of the user and helps him to comprehend more about personal physiological processes. Accordingly, the hygienic behaviors will become more uniform among different demographics [7]. However, the cities and schools also see a significant increase in the amount of waste that can be explained by this tendency [8]. Disposable products are a mixture of plastic, specialized paper and chemically intensive gels all resistant to standard landfill degradation protocols and none of which is dissolved [9, 10]. They are deposited by some users in open pits, others used to avoid trenches or towards latrine systems. Burning is used in exceptional cases and in this technique a partial combustion is achie

ved. Disposal of waste is associated with a distinct environmental cost. Combining these risks in a vicious circle contributes to the destruction of civilization that endangers both the health of the populace and the safety of ecosystems in general [10, 11].Improper management of sanitary waste also contributes to broader environmental sustainability issues associated with municipal solid waste management, particularly in developing countries [12].Improper management of sanitary waste also contributes to broader environmental sustainability issues associated with municipal solid waste management [13, 14]

Research has also shown how infrastructure limitations, especially the lack of disposal bins that belong to the privately owned individuals, have a direct impact on the choice of behavior that women make in dealing with menstrual management. In educational institutions that lack safe and healthy dumping systems and receptacles, adolescents are inclined to conceal the discarded items in the general rubbish and garbage, therefore, building a feeling of embarrassment and unwillingness to visit or participate in lessons [15]. These inclinations are evident in other cultural environments whereby women are not free to discuss menstruation at will, which is a setback in the use of waste containers [16, 17]. Besides, there are soil arrangements, mixed with municipal wastes, offering greater risks to workers in the sanitation sector, downstream sorting and processing a complicated task.

One of the weaknesses of handling menstrual supplies is the disposal. In the schools where good receptacles are not available, the wastes are normally buried by students under the desk or under the sleeves of their clothes. In places where infrastructure is down, it is replaced by secrecy [18, 19]. Lack of avenues of

disposal subjects many students into an academic withdrawal several studies have also reported that inadequate menstrual hygiene management negatively affects girls' school attendance and participation in education [19, 20].since they are more interested in hiding rather than studying to avoid embarrassment that may follow. Secondly any blood-stained objects that enter sewage accidentally put the sanitation workers at a risk and the fact that a certain number of them remains hidden in mixed waste make the separation process dangerous Improper handling of infectious waste also increases occupational health risks for waste handlers and sanitation workers [20].

Despite the changes in the modern society, where disposable pads have gained wider exposure, the long-term environmental impact of non-biodegradable menstrual waste and its safe disposal remains largely unaddressed and requires immediate intervention.

2. Experimental methodolgy

The present study focuses on the development of a small-scale sanitary napkin incinerator. The aim of the study is providing a safe and environmentally responsible disposal method. Methodology includes the entire process involving conceptual design to the unit's construction and performance evaluation. The system was designed to accommodate a heating chamber, temperature control system and a simple filtration system to provide controlled emissions and efficient burning. A careful selection of materials was made while fabricating the different components of prototype. Then, functioning of the incinerator, the effectiveness of control, residue management and maintenance requirements was discussed.

2.1. Design of incinerator

The incinerator’s designed was a compact, portable unit for safe disposal of sanitary waste. The major components of the design are a heating chamber, nichrome coil and an outlet linked to a filtration unit. The goal of this design is to obtain complete combustion, while limiting the emissions as much as possible.Waste-to-energy incineration systems with high energy efficiency have been intensively studied for a sustainable reduction in waste volume and recovery of thermal energy [21]. Proper airflow, sufficient temperature, and safe handling were taken in consideration during the design stage. The structure of the system is simple so that it can be easily used in institutions or households. The actual and well labelled model of incinerator is shown in Fig. 1.

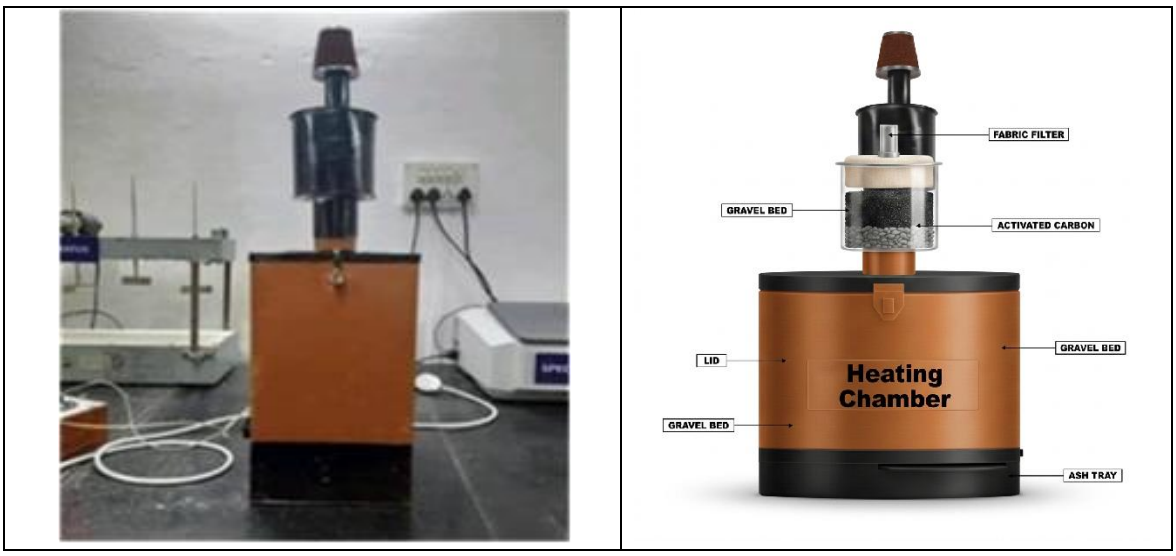


Fig.1. Actual and well labelled model of incinerator

2.2. Fabrication of incinerator

The fabrication process involved selection of suitable materials and then assembly of different components. The outer body was made using galvanized steel sheets to ensure durability and resistance to corrosion. The overall dimensions of the incinerator were approximately 61 cm in height, 10 cm in length, and 8 cm in breadth, making it compact and easy to handle and easy to use. It should be noted that the reported operating temperature of 800–1050°C corresponds only to the combustion chamber. The outer galvanized steel body was separated from the combustion chamber by an air gap, which minimized heat transfer and maintained the external casing at a substantially lower temperature during operation. Therefore, the galvanized outer body was not directly exposed to the combustion temperature.

The fabrication of the prototype was done step by step which includes cutting the sheets to a required dimensions, shaping, and welding them to form the main structure of the incinerator. After assembling the body, surface finishing and painting were done. The nichrome heating coil was installed inside the combustion chamber to provide the required heat.

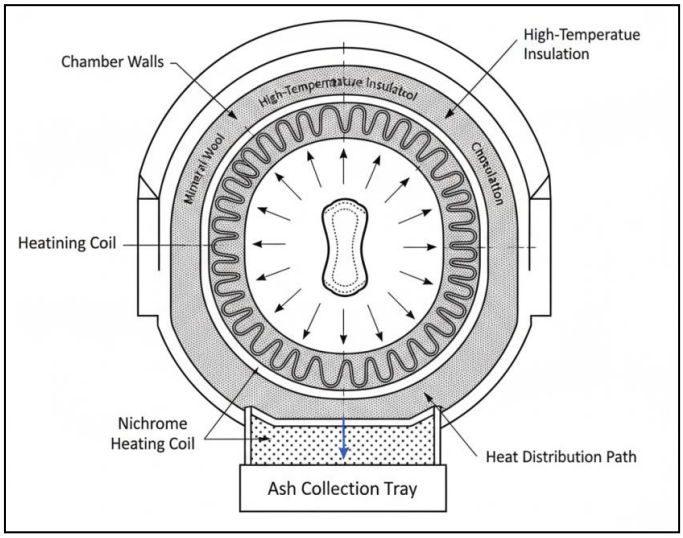


Fig.2. Combustion chamber cross-sectional view.

The cross sectional view of combustion chamber is shown in Fig. 2. A filtration unit was attached at the outlet in cylindrical form. It was filled in layers consisting of gravel at the bottom, activated carbon in the middle, and again the gravel on top.

2.3. Working of incinerator

The developed prototype, referred to as the "induction-heated" sanitary waste incineration system, employs a nichrome resistance heating coil as the heat source. Heat is generated by electrical resistance in the nichrome coil and transferred directly to the combustion chamber to achieve the required operating temperature. The incinerator works on the principle of electrical heating using a nichrome coil. When power is supplied, the coil generates high temperature inside the combustion chamber, which is sufficient to burn sanitary waste completely. The working incinerator is shown in Fig. 3. The combustion chamber was designed to accommodate up to 10 sanitary pads per cycle. However, the experimental trials reported in this study were conducted using 4–5 sanitary pads per cycle. Temperature is controlled using a simmer stat, which regulates the input voltage and maintains the desired heating conditions. In this process, the temperature ranges between 800 to 1050°C, depending on the material of the waste. It takes around 2 minutes to 15 minutes for

complete combustion. During this operation, the waste is placed inside the chamber, on the mesh plate above the nichrome heating coil for effective heat transfer and inductive combustion purpose and then, heat is applied until it is converted into ash, which is collected in the ash tray [22, 23]. The gases produced during combustion pass through the filtration unit, where harmful pollutants are reduced before being released into the atmosphere.



Fig.3. Working Incinerator

2.4. Operation and process control

Proper control of temperature and airflow is essential for efficient combustion of the incinerator. The simmer stat is used to adjust the temperature according to the amount and type of waste. Maintaining an optimum temperature ensures complete combustion and reduces the formation of toxic gases.

The filtration system plays a very important role in the process control by minimizing emissions. Adsorption-based materials such as activated carbon remain among the most effective media for capturing volatile organic compounds and other gaseous pollutants, and recent developments in advanced adsorbents further highlight the importance of adsorption technologies in environmental treatment systems [23] .Achieving proper emission control is very important, since the results of the tests conducted on the environmental performance of incineration systems are related to the combustion efficiency and the technologies used to remove pollutants [24, 25]. Regular monitoring of temperature and filter condition is required to maintain efficiency.The filtration system consists of gravel and activated carbon and was designed to reduce particulate matter and adsorb gaseous pollutants based on the adsorption characteristics of activated carbon. However, direct measurements of VOCs, dioxins, furans, or other gaseous emissions before and after filtration were not performed in the present study. Therefore, the emission reduction capability of the filtration unit was not experimentally verified and will be investigated in future work.

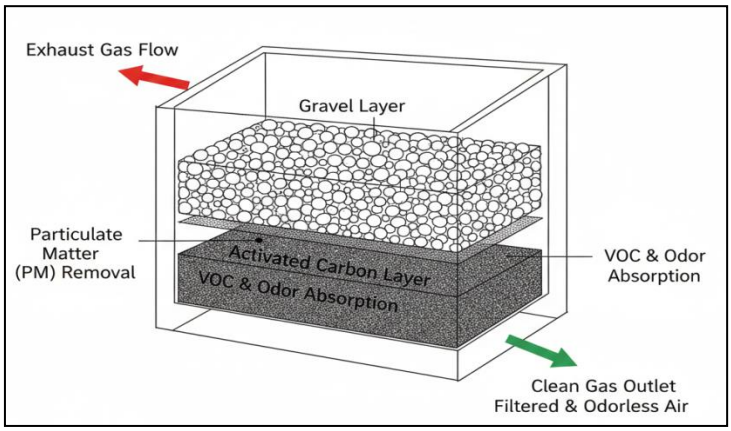


Fig.4. Emission control and filtration mechanism

2.5. Residue handling

After the combustion process, the remaining residue is collected in an ash tray placed at the bottom of the chamber. The residue is mainly in the form of ash, indicating effective burning of waste. It was observed that there is a significant reduction in weight it is around 90% or more, which confirms the efficient incineration.

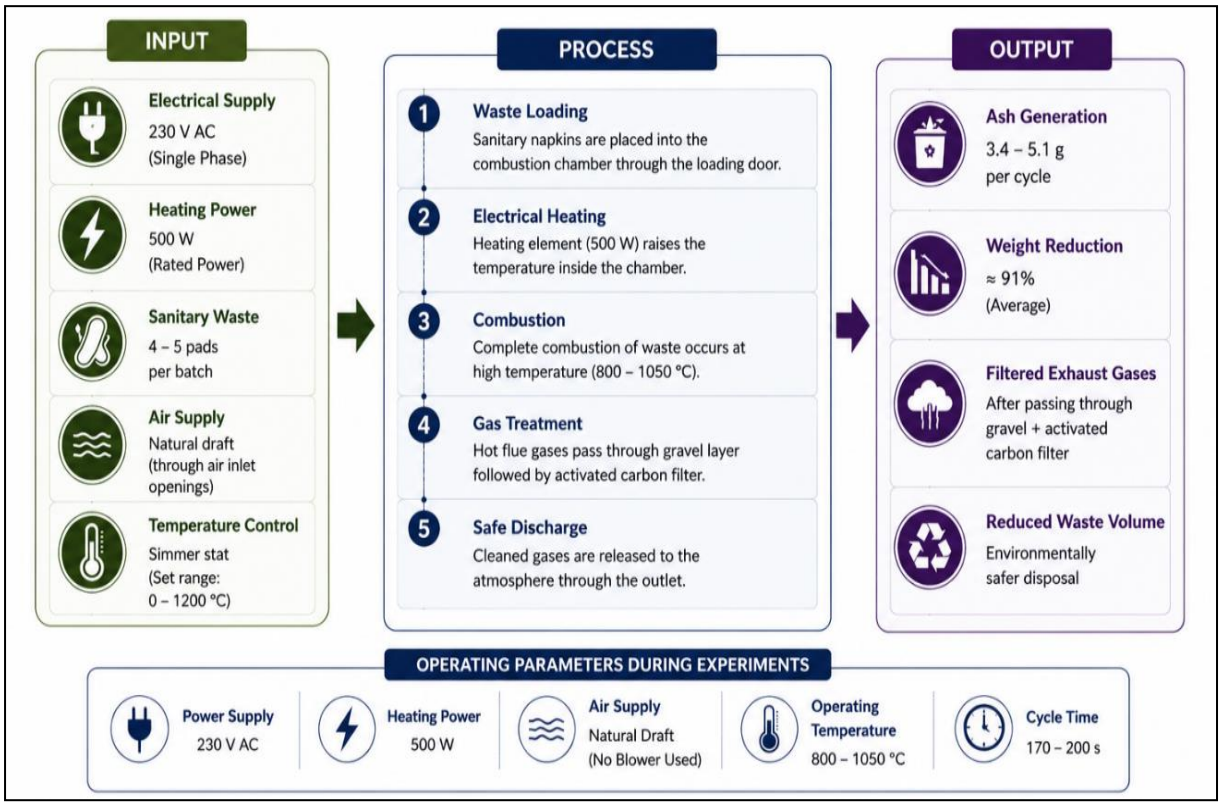


Fig.5. Input–process–output relationship of the developed sanitary napkin incinerator showing the operating conditions and performance obtained during the experimental study.

For the experiments, the operating parameters are a 230V AC power supply and 500W heating unit. It is represented in Fig. 5. The combustion air was introduced into the chamber through the inlets of the incinerator and the flue gases passed through the filtration unit before they are discharged. There was no blower or forced-air system used and the prototype was designed to run under natural draft. Thus, the air flow rate was not measured in the experimental study. These operating conditions were followed for all the conducted experimental trials. Fig. 5 presents a conceptual representation of the system inputs, processes, and outputs. Quantitative operating parameters such as electrical power input (W) and airflow rate (L/min or m^3/h) were not directly measured during the present investigation and are therefore not included in the diagram. Future studies will incorporate these measurements to enable a more comprehensive evaluation of the incinerator performance

2.6. Operation and maintenance

The incinerator is simple to operate and requires minimal training. Waste is inserted into the chamber, temperature is set using the control unit, and the process is allowed to complete. Regular maintenance includes cleaning of the ash tray, checking electrical connections, and replacing or cleaning the filter media when required.

2.7. zSafety features

The incinerator has been designed with simple safety features to ensure safe and secure operation when handling waste and burning it. The outer metal body stays insulated from the heating chamber, which minimizes the possibility of burns when using this product. The loading door has a heat-resistant handle to make it easier to open and close the chamber. The chamber should be left closed while the combustion cycle is taking place during operation. The ash is gathered in a removable ash collection tray at the bottom of the unit. The incinerator should be turned off and left to cool down before removing the ash. Then gloves may be used to remove the ash, and the ash can be disposed of following local waste management practices. No manual contact with the contaminated surface should be made when placing pads in the chamber. Waste should be regarded as being potentially infectious until it is properly burnt. Hence, the operator should use disposable gloves when handling the waste and wash his/her hands after operation. These are straightforward precautions to take to minimize the danger of burns, unintended exposures and exposure to pathogens when using these items. Based on published literature, temperatures in the range of 300–340°C are generally considered sufficient for thermal inactivation of many pathogenic microorganisms. However, no microbiological tests were conducted in the present study to experimentally verify pathogen destruction. Therefore, this statement is based on literature evidence rather than direct experimental validation. During laboratory testing, no visible damage to the galvanized outer body was observed. For long-term use, stainless steel is recommended for the combustion chamber.

During the laboratory-scale experiments, no visible degradation of the galvanized steel outer casing was observed. However, stainless steel is recommended for the combustion chamber in long-term or commercial applications because of its superior high-temperature resistance.

3. RESULTS AND DISCUSSION

The experimental results show the incinerator works effectively under controlled conditions. By adjusting the temperature, time, and waste quantity, proper burning of sanitary waste was achieved. It was observed that higher temperature and sufficient heating time led to faster and more complete decomposition, while the different pad materials showed slightly different burning behavior. A significant reduction in waste volume was seen in the form of ash, and the filtration system helped in reducing harmful emissions. Overall, the study confirms that proper operation improves efficiency and makes the system suitable for safe waste disposal. Careful record was taken of the use of electricity as efficient use of electrical energy is also an important performance parameter in thermal waste treatment systems [25]. Low ash residue means efficient combustion while incomplete combustion usually results in higher input of energy for complete oxidation [26].The observations supported the potential of the apparatus to process waste environmental soundly in an environment that does not have centralized disposal facilities.

3.1. Performance evaluation based on operating temperature and time

The test materials that were used to test the incinerator were offered a series of stringent test exercises wherein four or five extra pads were placed on each test to satisfactorily test the exact patterns of restroom usage [27]. The operating temperatures ranged between 800°C and 1050°C, which are consistent with the temperature range recommended for the safe thermal treatment of healthcare waste. Table 1 reflects a brief overview of the duration of combustion with respect to temperature. An increase in temperature makes the combustion rate faster, hence causing faster fibrils, gels, and polymer degradation. Even heat distribution reduces the amount of residual waste whereas systematic observation eliminates flare-up or partial burning, as observed in Fig. 6 indicating operating temperature vs combustion time.

Table.1 Performance Evaluation of Sanitary Napkin Incinerator

Trial No.	Number of Pads	Operating Temperature (°C)	Combustion Time (s)
1	4	800	210
2	5	850	195
3	5	900	180
4	4	950	165
5	5	1050	150

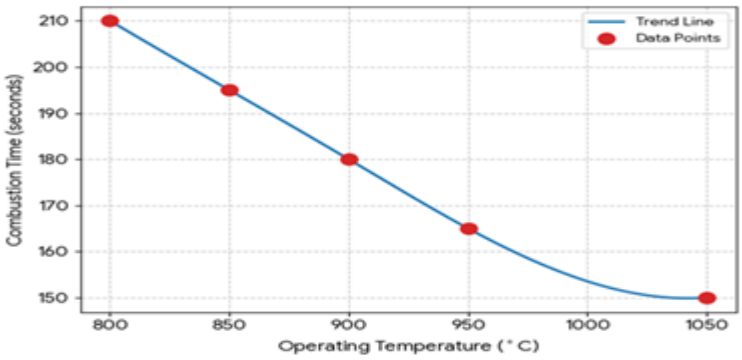


Fig.6. Operating Temperature vs Combustion Time

From Table 1 and Fig. 6 it is observed that, as the operating temperature increases, the combustion time decreases. At lower temperatures (800°C), the burning process takes longer, while at higher temperatures (up to 1050°C), the pads burn much faster. This happens because higher heat speeds up the breakdown of fibers and polymers present in the pads. The trend confirms that maintaining a higher and stable temperature improves the overall performance and efficiency of the incinerator.

3.2. Weight reduction and combustion efficiency

Weight loss was calculated by comparing pad mass before and after combustion. Table 2 shows the results of weight reduction for each trial combining different pad combinations, initial weight, final weight and ash weight.

Table.2 Weight Reduction and Percentage Reduction

Trial No.	No. of Pads	Initial Weight (g)	Ash Weight (g)	Weight Reduced (g)	% Weight Reduction
1	4	46.0	4.1	41.9	91.09
2	5	55.5	4.6	50.9	91.71
3	5	51.0	5.0	46.0	90.20
4	4	42.0	3.6	38.4	91.43
5	5	54.0	4.7	49.3	91.30

The empirical data show that there was about 91% weight reduction, which highlights how effective is the system when it is installed in limited architectural designs [28]. Comparative combustion experiment Lignocellulosic fibers and biodegradable polymer matrices were subjected to rapid pyrolysis, but their synthetic counterparts required high burning temperatures in the Puerto bottles. The fuller combustion which maximized the reduction of the particulate and gaseous emissions was also helped by the maximum

upwards-facing convective airflow . This 91% value represents only the reduction in waste weight. It should not be considered as energy saving. The energy performance is discussed separately in Table 6.

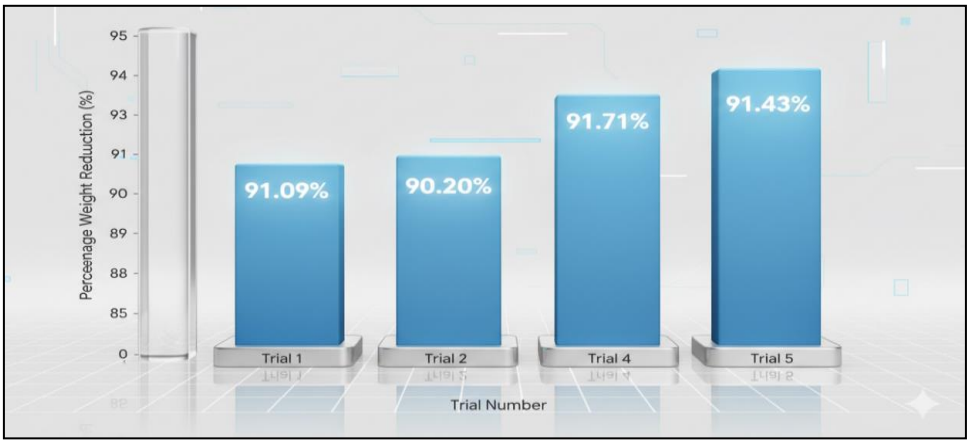


Fig.7. Percentage weight reduction across trials

The trials done on incineration gave consistent results of percentage weight reduction in Fig. 7, the highest value of weight reduction is 91.43%, with the weight of the waste being always reduced to greater than 90% limit. This consistency in non-sequential trials confirms the effectiveness of the sustained oxidation method, which demonstrates that it is a feasible and scalable solution to the rapid degradation of the sanitary debris in resource-limited settings [26, 28].

3.3. Rate of combustion and specific mass reduction

The combustion rate was derived from weight loss over time. It is represented in Table 3, while specific weight reduction per pad evaluated scale-up potential is indicated in Table 4.

Table.3 Rate of Combustion

Trial No.	Weight Reduced (g)	Time (s)	Combustion Rate (g/s)
1	41.9	210	0.20
2	50.9	195	0.26
3	46.0	180	0.26
4	38.4	165	0.23
5	49.3	150	0.33

The fact that the rate of combustion increased with temperature in the range of 0.20-0.33 g/s testifies to the fact the process was accelerated as the amount of heat input increased. Mean loss of specific weight of 9.86g/pad is a desirable metric of waste-handling capacity and an indicator of the scale-up of the system in future.

The results of the comparative combustion rates during different experimental runs (Fig. 8) support the effectiveness of the incineration unit in maintaining elevated speeds of the combustion. In the five experiments, the burn rate was between 0.20g/s and 0.33g/s. These findings indicate that through the optimization of the operating environment, the system can enhance the degradation of organic materials significantly, hence, improving the amount of material that the treatment unit can process in a day [27, 28].

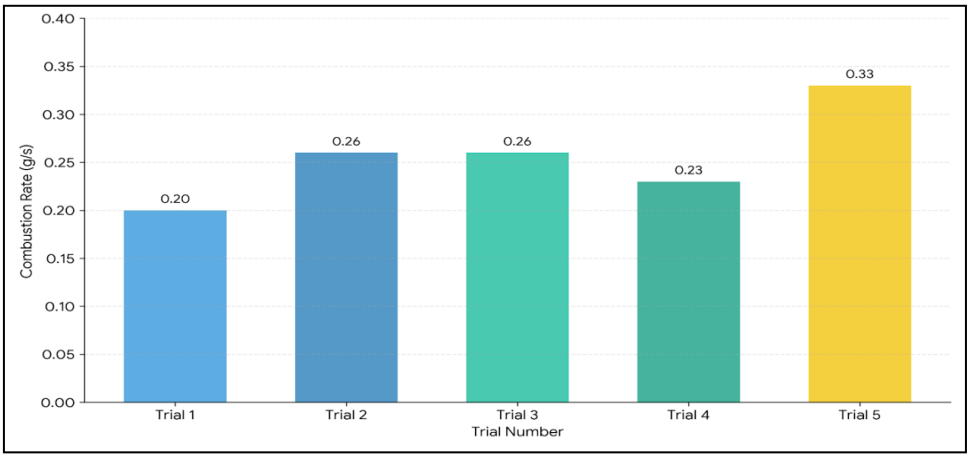


Fig.8. Comparative combustion rates recorded during experimental runs.

Table.4 Specific Weight Reduction per Pad

Trial No.	No. of Pads	Weight Reduced (g)	Reduction per Pad (g/pad)
1	4	41.9	10.48
2	5	50.9	10.18
3	5	46.0	9.20
4	4	38.4	9.60
5	5	49.3	9.86

The values shown in Table 4 are the mean for each experimental batch in this study, for weight loss per pad. This parameter was added for the purpose of offering a simple indication of the treatment capacity of the developed incinerator with the tested conditions. The amount of reduction will vary depending on the composition, thickness, absorbent capacity and original weight of sanitary napkins, and should not be fixed for any commercial product. The combustion characteristics of different brands were different as shown in Table 5, due to the different material composition of various brands. The data given in Table 4 are thus only representative for the pads investigated in the present study.

Higher combustion rates were observed at elevated temperatures, confirming the direct relationship between thermal input and oxidation speed.

3.4. Brand-wise combustion characteristics

The various commercially brands of the sanitary napkins were experimented to determine the influence of the material composition on the combustion behavior. The comparative results are presented in Table 5. The trials were carried out in a lab-fabricated sanitary napkin incinerator to observe how different brands burn under controlled conditions. It was observed that pads made from natural fibers burned faster and required lower temperature, while pads with more plastic and chemicals took longer and needed higher heat. The incinerator worked properly for all types, but more time and energy were required for plastic-based pads. These trials clearly showed that material composition plays an important role in combustion behavior. The observed differences in combustion behavior among the tested sanitary napkin brands may be attributed to variations in material composition and product design. However, as only one experimental trial was conducted for each brand, this observation is preliminary and requires further validation through replicated experiments and detailed material characterization.

Table.5 Brand-wise Combustion Characteristics of Sanitary Napkins

Brand Name	Material Composition	Effective Temperature (°C)	Combustion Time (s)
Nua	Organic cotton fibers	800	90
Saathi	Banana fiber + biodegradable polymers	820	110
Sirona (Reusable Cloth)	Multi-layer cotton fabric	850	140
Whisper Ultra Clean	Wood pulp + SAP + PP sheet	900	170
Stayfree Dry Max	Gel-based SAP + polymers	950	210
Sofy Antibacterial	Chemically treated polymers	1000	240
Plastic-based Pad	Polyethylene & polypropylene	1050	300

3.5. Energy-specific mass reduction

Table 6 shows the amount of waste treated per unit of energy, where efficiency is calculated as the ratio of weight reduced to energy consumed.

Table.6 Energy-Specific Mass Reduction

Trial No.	Time (s)	Energy Used (kWh)	Weight Reduced (kg)	Reduction (kg/kWh)
1	210	0.12	0.0419	0.35
2	195	0.11	0.0509	0.46
3	180	0.10	0.0460	0.46
4	165	0.09	0.0384	0.43
5	150	0.08	0.0493	0.62

The overall efficiency showed some improvement from Trial 1 to Trial 3, but a decrease was noted in Trial 4 and a maximum in Trial 5. This difference may be attributable to the slight difference in composition of the sanitary pad used and its original weight and slight differences in the arrangement of the sanitary pad in the combustion chamber. These can affect the distribution of heat and the combustion characteristics, leading to slight variations in the efficiency of weight reduction. The slight reduction in efficiency observed during Trial 4 was not associated with any intentional change in the operating conditions. This variation is likely due to minor experimental factors, such as differences in sanitary pad composition, moisture content, loading arrangement, or normal combustion variability encountered during laboratory-scale testing. As the decrease was observed in only one trial and the efficiency increased again in Trial 5, it is considered an isolated variation rather than a systematic performance trend. Further replicated experiments are required to establish the statistical significance of such variations.

The results indicate that an explosive burning process can instantly cut cotton into ash. With a small amount of heat and a short amount of time, the cotton is turned into ash [26, 27, 28]. Synthetic padding, in comparison, has significantly greater thermal resistance, which is due to the high-density polymer matrix and cannot withstand pyrolysis as long in the flame.

In order to obtain sufficient breakdowns of such materials, increasingly high temperatures should be used continuously. Combustion byproducts escape mostly as a dense smoke when the temperature fails to turn to

the required level instead of evaporating in a clean manner. Hence, close management of the flame is critical; failure of which results in emission of poisonous aerosols to the immediate environment.

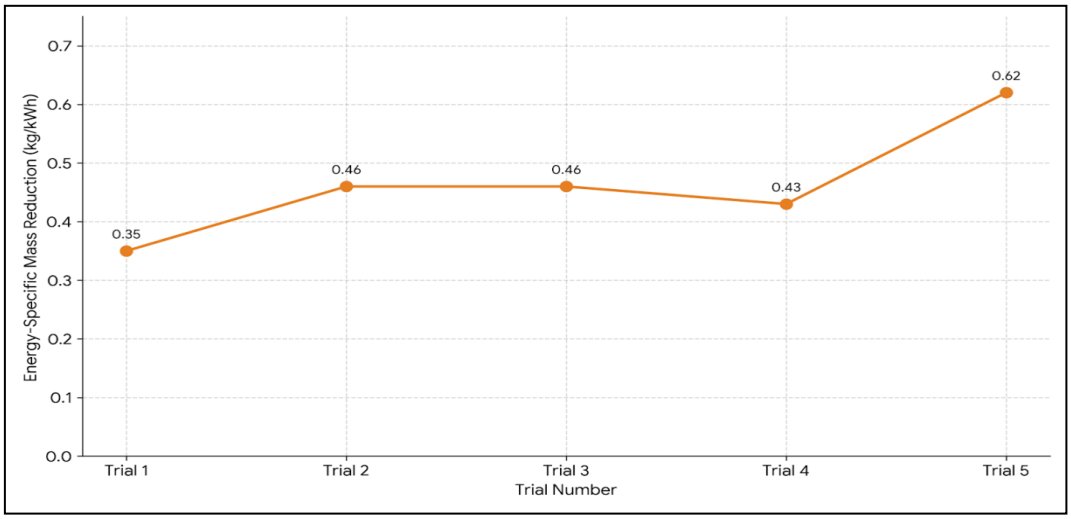


Fig.9. Energy-Specific Mass Reduction Efficiency

From every-specific mass reduction (kg/KWh) varying between 0.35 and 0.62 Kg (as illustrated in Fig. 9), the visible depletion of waste material serves as clear proof of the incinerator's performance and power usage. The efficiency is evident in the situation whereby destruction occurs without consuming an excessive amount of electricity and most especially in compact units that are powered by current alone.

The results obtained from Table 6, indicates that better efficiency is achieved at lower energy input with proper control of burning time. During trials in the lab-fabricated incinerator, cotton-based materials burned quickly and converted to ash in a short time, while synthetic pads showed higher resistance and needed more heat. Inappropriate temperature maintenance led to dense smoke if it occurred during the burning. So, it's essential to have the proper and adequate operating temperature. The efficiency of the lab fabricated sanitary napkin incinerator (kg/kWh) obtained clearly indicates the change in efficiency with the different trials of the incinerator (Fig. 9). One can see that the efficiency improves as the trials go on, then decreases slightly in trial 4, and peaks at Trial 5. This demonstrates that the more tightly the operating conditions (e.g., burning time, temperature) are controlled, the better the performance. Trial 5 gives the best results and is the most efficient use of energy and minimum waste. Overall, the trend demonstrates that adjustments to the incinerator to create a proper setting result in a more effective and cleaner combustion.

3.6. Comparison with previous studies

The sanitary napkin incinerator developed was evaluated and compared with the similar small scale incinerators reported in literature. The developed system resulted in a weight reduction of around 91% (Table 7), which is similar to that reported in the previous studies. The combustion time was similar to that reported for small capacity sanitary waste incinerators. In addition, the fuel consumed was relatively low with the 500 W heating unit and about the same combustion efficiency was achieved. The results show that the prototype developed is as performance as any of the prototypes existing and simple and economical too in use in decentralized applications. Table 7 is used to make the comparison. The data presented in Tables 1-6 are from five tests conducted under the same operating conditions. Standard deviation could not be computed because repeated experiments were not carried out. Repeated trials and statistical analysis will be conducted in the future. The approximate cost of fabrication of the prototype was INR 8,000 – 12,000 and

the cost of electricity used in the operation of the prototype was INR 2-4 per cycle depending on the operating time and the local electricity tariff. This enables the system to be used in low-resource and decentralized contexts.

Table.7 Comparison with previous studies

Study	Combustion Time	Weight Reduction	Energy/Power	Remarks
[25]	3–5 min	85–90%	1000 W	Electrically heated unit
[26]	4–6 min	88–92%	750 W	Small-scale sanitary waste incinerator
[27]	5 min	80%	800 W	Combustion unit
[28]	4 min	85%	700 W	Small disposal unit
Present Study	170–200 s	≈91%	500 W	Low-cost prototype

Although the experimental results demonstrated consistent trends across the five trials, further replicated experiments are required to statistically validate the repeatability and reliability of the reported performance

3.7. Practical limitations

The main goal of this study was to test the combustion performance of the developed sanitary napkin incinerator. The present study was limited to the assessment of the combustion performance developed prototype only. This work did not include a detailed emission analysis, such as the measurement of VOCs, dioxins, furans, particulate matter and other combustion gases before and after the filtration unit, which will be taken into account in future investigations. In the present work, ash characterization was not considered. Hence, chemical composition of the ash and presence of unburned materials and other contaminants were not investigated in the ash residue. Thus, in this study the safety of ash for disposal was not tested. Further studies will include a detailed ash characterization to determine the composition of the ash and to determine its suitability for disposal as per applicable environmental guidelines. Furthermore, all the trials were performed with only one type of sanitary napkin of each brand. So, the comparison with the brands is preliminary and further study will involve repeated experiments. The performance data reported in Tables 1-6 are from five separate experimental trials with the same operating parameters. No repeatability analysis, no standard deviation and no confidence interval could be obtained because repeated measurements were not made for each operating condition. The combustion time, weight loss, and energy used were found to be fairly consistent for all of the trials, indicating a fairly consistent operation of the prototype; however, these results should be viewed as preliminary. Replicate experiments and statistical analysis of the results will be conducted in the future to ensure the repeatability and reliability of the incineration system developed in this study. Microbiological analyses to verify pathogen destruction were not performed. Future studies will include microbiological testing to experimentally confirm pathogen inactivation during the incineration process.

4. Conclusion

The current paper demonstrates that small sized incinerators of sanitary napkins can be an appropriate, low-resource decentralized method of menstrual waste management. The effect of the device in processing sanitary pads, as shown through experimental analysis, was the ability to process between 5-10 Sanitary pads in one cycle at a burning time of 170-200 The process yielded a 91% mass reduction with only 3.4–5.1 g of ash remaining per test, effectively proving the system's ability to achieve full oxidation.

The equipment was continuously maintained at temperatures of 800°C to 1050°C, the heating of the apparatus was also by nichrome heating coil, and as a result, allowed the transmission of thermal energy in the most precise manner, thus enhancing the decomposition processes and minimizing the use of electricity. Moreover, filtration unit was successfully introduced to reduce the visible emissions and, as a result, the prototype was found to be potentially useful to reduce environmental and occupational risks with regard to small-scale garbage burns.

Approximate fabrication cost of the prototype was INR 8,000–12,000, while the operating electricity cost was about INR 2–4 per cycle depending on operating time and local electricity tariff. This makes the system suitable for decentralized and low-resource settings.

The high level of portability, low level of infrastructural reliance, and certain easy-to-use features make the prototype viable in educational setups, health facilities, dormitory, and community cozy area centers, especially in areas where municipal infrastructure facilities to handle garbage are either limited or absent. The data during operation confirmed the stability of the system, and it helped to control the changes in load during the process, which was also a demonstration of the applicability of the system in the scaled implementation process without overloading the local power system. The results indicate that the use of energy-efficient heating systems, precise control of air flow, and efficient and effective filtration, offer a safe, effective and environmentally friendly approach to waste treatment.

The research provides evidence-based solutions to decentralized incineration systems thus helping to achieve progress in the area of the health, clean management of waste and ecologically friendly environmental practices.

Abbreviations

- **SAP** – Super Absorbent Polymer
- **PP** – Polypropylene
- **PE** – Polyethylene
- **MSW** – Municipal Solid Waste
- **kg/kWh** – Kilogram per Kilowatt-hour
- **g/s** – Gram per second
- **°C** – Degree Celsius
- **V** – Volt
- **A** – Ampere
- **s** – Second
- **g** – Gram
- **cm** – Centimeter

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