International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 08 Issue: 05 | May - 2024 SJIF Rating: 8.448 ISSN: 2582-3930

Hydrogen as Potential Primary Energy Fuel for Municipal Solid Waste Incineration for a Sustainable Waste Management

Dr. Saranya S N[1], Kiran S[2]

[1]Assistant Professor, Department of Electronics and Communication, Dayananda Sagar Academy of Technology and Management, 560082, Bangalore, Karnataka, India

[2]Student of Department of Electronics and Communication, Dayananda Sagar Academy of Technology and Management, 560082, Bangalore, Karnataka

E-mail: kiranvarun38@gmail.com

Abstract

The control of municipal stable waste (MSW) has lengthy offered difficulties for the community. Affecting the sustainability of the environment. The expected reasons are rising earnings and population. The maximum superior and practicable technique for coping with municipal strong waste is incineration generation. The foundation of incinerator generation is the combustion of trash with the use of fossil fuels. Not handiest are these fuels strolling out day by day, however burning them poses a chance to the environment. The modern study appears into the viability of using hydrogen as the main gas for combustion within the incineration of municipal strong waste (MSW). It is now viable to run an incinerator of the vertical shaft type on natural hydrogen. Through specially made burners, a gasoline aggregate of hydrogen and oxygen in a stoichiometric ratio has been fed. The burners are made in this kind of manner as to offer uniform heat dispersion. In order to envision how the incinerator operates at the very best accredited moisture degree, more than a few Tests were carried out on both homogeneous and heterogeneous MSWs with excessive moisture possibilities ranging from 60 to 90%. It has been mentioned that the incineration reached a most temperature of 850C. There has been a important drop in weight percentage, 86–94%, and loss on ignition (1.74%–6.41%). For homogeneous paper and meals waste (1 kg), the hydrogenbased totally incinerator executed fine, accomplishing 60% and 87% of moisture content, in that order. The weight reduction become 97.14% and 88.88%, respectively, with energy expenditure of 108 Wh and 321 Wh. The efficiency of the hydrogen-based incinerator gadget decreases as the moisture content of the rubbish will increase.

Keywords: Municipal waste management (MSW), hydrogen, incineration, fuel.

I. Introduction

Managing stable waste is one of the maximum vital tasks for municipalities and the businesses they work with.

It includes the professionals for series, transportation, and disposal tactics. Municipal solid waste era is presently anticipated to be 2.01 billion tonnes in step with 12 months, and by 2050, that variety is anticipated to upward push to a few Four billion tonnes.

The primary causes are growing income and populace. Contributions from East Asia and the Pacific vicinity account for 23%, with Europe and South Asia following at 20% and 17%, respectively. MSW includes the majority of rubbish generated in houses. This trash consists of a large part of meals waste, wood, paper, and every so often items like polymers, rubber, and textiles that come from fossil fuels. Compared to excessive-income countries, low-profits nations have a higher waste share of organic or food waste.

One of the useful outcomes of treating this MSW may be power. The waste-to-electricity quarter is now a thriving enterprise with around valued at USD 37.6 million in 2020, with a projected USD 44 million in revenue with the aid of 2024 [3]. By 2015, 1179 incinerators with a capacity of 700000 MT/d were constructed international; of these, 80 WtE incinerators flowers have been running in the USA alone, producing 2769 MWh of electricity for the grid every day by processing 96000 tonnes of MSW [3]. With more than 240000 MT/d of MSW burning capacity, China currently holds the file. WtE incineration vegetation in China alone have extended quickly, from 3.70 to 133.08 million metric tonnes of designed ability in 2003 and 2018, respectively. As a result, China's incineration price grew from 14.66% in 2010 to 44.77% in 2018.

Plasma era faces demanding situations because of the costly excessive-energy DC deliver required, making it a big contributor to energy-in depth industries liable for 30% of greenhouse gas emissions.

While microwave generation is considered green, it has obstacles along with incapacity to work at large scale, non-co-generation manner, and suitability best for positive styles of waste because of versions in dielectric homes.

Incineration emerges because the most widely used thermal conversion generation for municipal solid waste because of its operational ease, lower price, and capability to manner diverse feed types. The international marketplace for incinerators is growing, with extensive ability for waste treatment and electricity technology.

Incineration plants have the capability to deal with waste remedy and energy era issues, with the ability to produce strength and decrease carbon emissions. Incineration is in comparison favorably to landfills, with lower greenhouse gas emissions and the capability to get better energy. European international locations which includes Sweden, Denmark, Finland, and Estonia are leaders in incineration, decreasing landfill dependency and accomplishing sizeable waste discount with managed emissions.

The choice of waste management technology is stimulated by using regional factors which includes hydrological situations, waste composition, and environmental policies.

Overall, incineration emerges as a preferred waste control option because of its effectiveness in waste treatment, strength generation, and environmental benefits in comparison to different technologies mentioned.

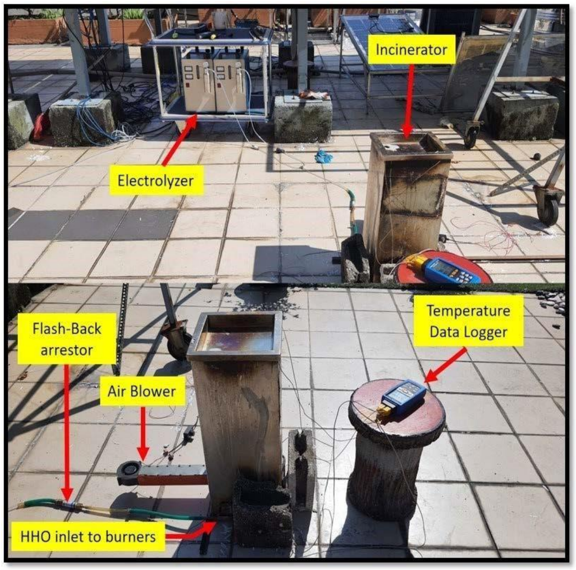

figure 1. Setup to test incineration by using hydrogen as a fuel

Incinerators are furnaces that burn municipal strong waste (MSW) with the aid of fuel and oxygen to reap clean combustion. Various design changes had been explored to beautify performance, consisting of recent studies on rocket-engine-based totally incinerators. Two not unusual kinds are the grated fire incinerator (GFI) and fluidized mattress incinerator (FBI), each regularly utilizing coal as auxiliary fuel.

Low moisture content in waste is vital for powerful incineration, as high moisture levels can reduce the process yield and performance. Moisture content material above 50% necessitates auxiliary gasoline, typically fossil fuels like oil and gasoline.

The growing international era of MSW poses challenges for incineration, mainly in phrases of fossil gasoline intake and greenhouse gas emissions. By 2025, round 129.30MJ of power can be required for incineration, in most cases sourced from fossil fuels.

To deal with these challenges, hydrogen is proposed as a green opportunity to fossil fuels for incineration. Hydrogen offers easyburning houses and potential for zeroemission waste control. Studies advise electrolysis techniques the usage of renewable strength resources for hydrogen manufacturing are environmentally pleasant.

Recent studies have examined hydrogen as a fuel for incinerating MSW, demonstrating its effectiveness in waste management. Hydrogen's capability as an opportunity gasoline for numerous combustion programs, along with treating hospital waste, has garnered significant attention.

The adoption of hydrogen as a primary fuel for incineration should lead to greater environmentally pleasant waste control practices, decreasing.

II. Literature Review

The primary sorts of residues made out of municipal stable waste incineration (MSWI) are bottom ash (BA), fly ash (FA), and air pollution manipulate (APC) residues. Bottom ash is the most sizeable spinoff from MSWI and is commonly considered nonhazardous waste, even as fly ash is assessed as risky waste because of its excessive content material of chlorides, heavy metals, and organic compounds. APC residues are also generated at some point of the incineration process and require proper dealing with and control to make sure environmental sustainability.

The presence of lead, zinc, and polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/F) in MSWI solid residues can appreciably impact the environmental assessment of those residues.

Lead and zinc are predominant metals determined in MSWI residues, with better concentrations in fly ash and APC residues compared to backside ash. These metals, originating from diverse sources in municipal strong waste, can affect the environmental best while found in extended concentrations.

PCDD/F, which are poisonous natural compounds, are also discovered in fly ash and APC residues because of the chlorine content material within the waste. The presence of PCDD/F provides to the unsafe nature of fly ash and APC residues, requiring cautious managing and management to prevent environmental infection.

Overall, the presence of lead, zinc, and PCDD/F in MSWI solid residues underscores the significance of conducting thorough environmental assessments to assess the capability impacts of those contaminants on ecosystems and human health.

Specifically, the paper discusses the styles of residues generated from MSWI, such as bottom ash, fly ash, and air pollutants manipulate residues, highlighting their composition and the challenges related to their management. It additionally addresses the environmental implications of contaminants along with lead, zinc, and polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/F) found in MSWI residues, emphasizing the significance of environmental checks to ensure sustainability.

Overall, the paper objectives to offer insights into the sustainable control of MSWI residues, exploring opportunities for useful resource recuperation, reuse, and addressing environmental concerns related to those waste streams.

The key limitations to developing sustainable waste management practices in developing nations encompass deficiencies in waste remedy, including the predominance of landfills, loss of diagnostic and remediation mechanisms, absence of specialized technical workforce, and inadequate systematized records. On the other hand, important success elements for sustainable waste control include the transformation of waste into renewable power, overcoming monetary, institutional, and organizational obstacles, reducing the proliferation of open dumps and landfills, and lowering the weight and extent of waste. Implementing these vital achievement factors aligned with pillars which include public regulations, disposal strategies, prison factors, public-personal partnerships (PPP), and power recuperation can assist address the challenges surrounding municipal strong waste control in developing nations.

MATERIALS AND METHOD

The experimental setup is depicted in Figure 1 and includes an improvised incinerator, information, and an electrolyzer (version: H260, manufacturing capacity: 1.5 LPM with the aid of 6 inches by means of 18 inches.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 08 Issue: 05 | May - 2024 SJIF Rating: 8.448 ISSN: 2582-3930

Additionally, as seen in discern 2, this incinerator is blanketed with ceramic wool this is one inch thick. Layers of brick kiln

Figure2. Variety of municipal waste used for incineration

(figure 1s, supplemental facts).

Thermocouples (K-type), and a logger (TENMARS TM-747D). The two electrolyzes' mixed waft fee turned into hydrogen 3.5LP. Mand oxygen had a 1.5LPM. The combustion chamber was provided with a stoichiometric combination of oxygen and hydrogen. Temperature sensors were placed at precise points, and a facts logger became used to report the temperature records. An correct statistics recording step of one 2d has been distinct for the tracking of temperature modifications in relation to operating time.

The incinerator is composed of a 1mm-thick stainless-steel sheet that measures 10 inches result, the incinerator depicted in discern 2 as soon as it changed into absolutely assembled had an active area of 32 in2 (8 in 4 in) and a extent of 384 in3 (8 in 4 in 12 in).

At the lowest of the incinerator, a burner manufactured from 10 mm copper pipe

became

cement had been implemented from the internal out to toughen the interior surface

wrapped around the device. Using tiny hand drills and micro tungsten carbide drill bits, those burners were made.

A metallic mesh that would be indifferent from the incinerator's backside changed into used to acquire ash. After the waste were burned, this turned into utilized to cast off the ash from the incinerator burned inside the hearth.

Batch Number	Type of waste	Amount of waste (gram)	Composition of waste
Waste 1	Food	1000	Eggshells, onion peels, potato peels, cabbage, spring beans, long beans
Waste 2	Paper	1000	N/A
Waste 3	Textile	1500	N/A
Waste 4	Mixed Waste Food = 500 Textile = 300 Paper = 300	1100	Eggshells, onion peels, potato peels, cabbage, spring beans, Watermelon rinds, paper, and cloth
Waste 5	Mixed Waste Food = 400 Textile = 300 Paper = 300	1000	Onion peels, eggs, Water Spanish, curry leaves, Methi leaves
Waste 6	Mixed Waste Food = 500 Paper = 500	1000	potato peels, eggshells, onion peels
Waste 7	Mixed Waste Food = 700 Paper = 300	1000	Onion peels, eggs, Water Spanish, curry leaves, Methi leaves, and paper

TABLE1. Composition of waste collected for the experiment

The contemporary look at is grounded in the Kuala Lumpur, Malaysia, situation. This examines focused on family kitchen garbage (organic waste), as it's far a tremendous supply of municipal waste. Figure 2, which centers the examine situation, depicts the haphazard collection of municipal waste from homes and restaurants. Furthermore, as a way to provide simulated waste for evaluation, the paper and fabric wastes have additionally been purposely wetted. The composition of the seven distinct trash experiment runs was recorded.

Both homogeneous and heterogeneous rubbish have been collected for moisture content material dimension previous to incinerator combustion. Since a high moisture stage poses a good-sized problem for burning.

In order to test the incinerator, the use of this new method in excessive moisture content conditions, water become delivered, as shown in table 1. For each test lot, the waste's composition is disclosed.

Figure 3. (a) Residue samples of seven different incinerated waste under test. (b) Sample heating in the oven for calculating moisture content of fly ash. (c) Sample heating in a muffle furnace for calculating loss on ignition of waste residue.

Using five separate, 50-gram tiny samples from every trash object that became reduce into smaller pieces, the moisture content turned into calculated. Next, a scale is used to weigh them and record the results. After that, those samples have been baked for twentyfour hours at a hundred and five degrees Celsius. To prevent any absorption of surrounding moisture, these samples had been positioned in a desiccator to sit back down after a 24-hour length. After that, samples had been weighed once more.

To obtain accurate content, the four values of moisture content for every trash sample were then averaged.

The combustion efficiency of the incineration residue has been tested. Using an A&D HK-250AZ precision weighing balance, the residual weight was determined, and the loss on ignition (LOI) was calculated in accordance with ASTM D7348. To put it briefly, samples of the ash residue that remained after garbage was burned were gathered and weighted in the crucible that is depicted in Figure 3a. The samples in the crucible were first cooked in a preheated oven for an hour at 110C (figure 3b). The sample was then taken out of the oven and allowed to cool for 60 minutes in a desiccator before being reweighted.

The moisture content material of fly ash was the reason of the weight reduction that was seen on this step.

After that, this dried ash became put in a muffle furnace (a Berkeley Thermolyne 30400 furnace muffle oven) for the second time, and it was heated in steps of two hours to attain 950C (discern 3c) for two hours. To compute LOI, the samples had been weighted and furnace cooled.

RESULTS AND DISCUSSION

A. BURNERS SELECTION

The desire of burners was made after massive experimental checking out the usage of numerous orifice diameters.

Because numerous engineering factors are taken into account while figuring out if a petrol or gasoline is like minded with an equipment. The most popular and simple technique to envision this compatibility is the Wobbe index. The Wobbe index for hydrogen is round 48MJ/m3.

Because hydrogen fuel falls below the purview of herbal fuel protection regulations for burners, it's far deemed suitable. Hydrogen cannot be at once utilised in natural gasoline burners, even though the wooden index is inside natural gasoline protection. This is a end result of the homes of combustion, which includes common velocity. It is necessary to decrease the burner orifice size in assessment to herbal fuel.

As a end result, unique burners were created and provided with hydrogen and oxygen that have been mixed in advance.

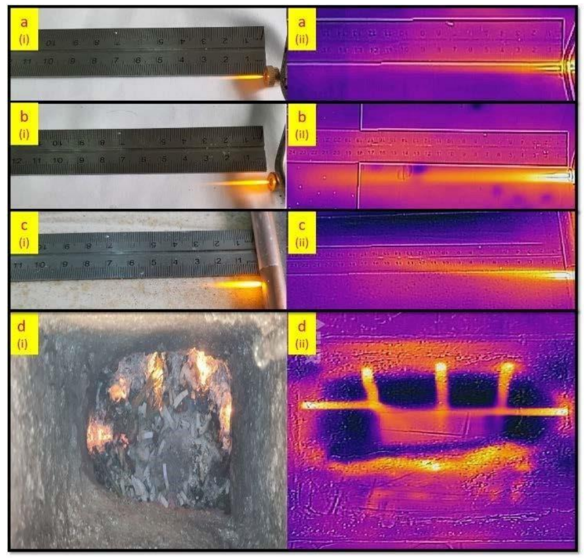

FIGURE 4. Testing of the flame length of the burner with the different orifices. Left side visible image, Right side FLIR image (a) Burner with an orifice of 0.4mm. (b) Burner with an orifice of 0.5mm. (c) Burner with an orifice of 0.6mm. (d) Inside view of the incinerator with burning flames.

The mass drift (a stoichiometric mixture of oxygen and hydrogen) has been maintained at 0.8 lpm at some point of the experimentation the use of orifices of diameters of 0.2 mm, 0.3 mm, zero.4 mm, zero.5 mm, zero.6 mm, and

0.7 mm. The FLIR images from different orifice diameters and the seen flame lengths are displayed in Figure 4. There became no consistent flame seen for aperture sizes of 0.2 and 0.3 mm. This ended in flame blow-off because of excessive gasoline velocities brought at the tiny orifice diameters. With a zero.4mm burner orifice length

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 08 Issue: 05 | May - 2024 SJIF Rating: 8.448 ISSN: 2582-3930

and 0.8lpm fuel drift, a steady flame became produced. The flame duration become seen to decrease with larger orifice diameters and to a point upward thrust with an growth in orifice length.

The approximate length of the FLIR imaging for 0.5mm and 0.6mm orifices is the same, but the burner with the 0.6mm orifice diameter displayed a more effective flame (figure 4c(i) & d(i)). Our additional research will awareness at the 0.6mm orifice diameter, which turned into selected primarily based on the results of the experiments and to provide uniform heat distribution inside the combustion chamber (chamber go-segment location: 6 6 inches). The best diameter and range of openings were modified (discern 2s, supplementary information) for the combustion chamber's move-sectional region and three lpm gas drift. The picture photograph and FLIR image of the changed range of burners are displayed in Figure 4d (i & ii), respectively. A reduction in flame length and potential flashbacks result from adding more burners.

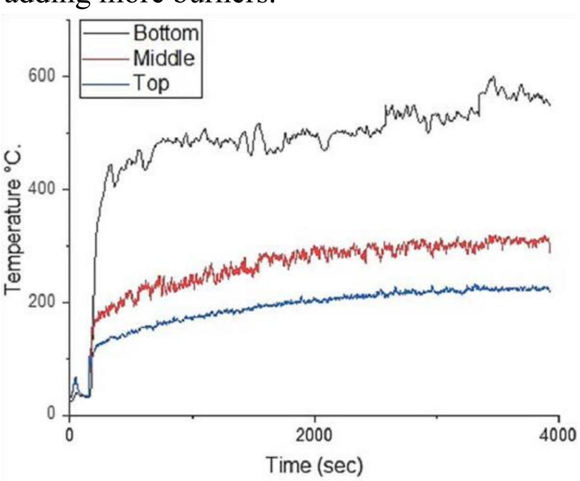

FIGURE 5. Temperature data at three different positions of empty incinerator using hydrogen as combustion fuel.

Batch Number	Moisture Content %	Energy Required (Wh)	Temperature °C	Time (Sec)	H2 given (liters)	Energy from H2 (Wh)	Energy from waste (Wh)	Percent energy provided by H2
Waste 1 (Food)	87	545.19	580	3200	107.2	321.6	312	58.99%
Waste 2 (Paper)	60	375.9	780	1100	36	108	1840	28.73%
Waste 3 (Textile)	90	845.9	800	2200	73.7	221	720	26.13%

*Additional 50% of moisture by weight is added using water in paper & textile used as waste

TABLE 2. Data of the respective homogenous waste during incineration.

B. INCINERATION PROCESS

The incinerator, fueled via a stoichiometric mix of hydrogen and oxygen, aimed for green MSW incineration. Temperature profiles confirmed speedy rise: 400°C close to the flame in 2 hundred sec, stabilizing at 600°C after 3500 sec. Middle segment hit 200°C in 500 sec, stabilizing at 300°C in 2700 sec. Top temps rose to a 150°C in six hundred sec, stabilizing at 200°C after 3500 sec. Hydrogen gasoline sustained surest 600°C. Initial exams used paper, fabric, and food waste (Figure 6a). Incinerator's MSW procedure unique in Figure 7b and Table 2

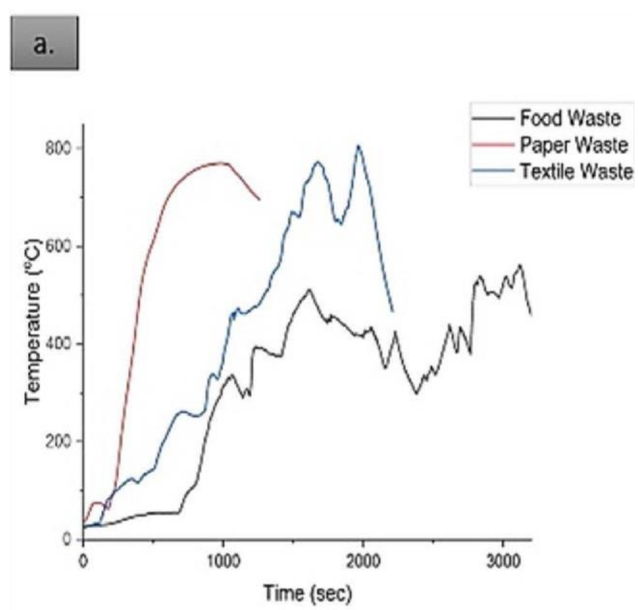

FIGURE 6. (a) Temperature graphs for the homogenous respective wastes;

After attaining a temperature plateau, the incinerator persisted strolling without hydrogen supply, facilitated by way of the blower for complete combustion. In the experiments distinctive in Figure 7a, meals waste weighing 1000g with 87% moisture content material reached 580°C in 3200 seconds, eating 107.2 liters of hydrogen, equivalent to 321.6Wh of energy. Textile waste of one.5 kg with ninety% moisture content material reached 800°C in 2200 seconds, requiring 73.7 liters of hydrogen, or 221Wh of energy. Paper waste, because of its excessive combustibility, most effective wanted 36 liters of hydrogen to reach 780°C in 1100 seconds. Further evaluation (Table 2) discovered meals waste yielding 312Wh/kg, paper 1840Wh/kg, and fabric 720Wh/kg primarily based on caloric values and moisture content material. The burners normally ate up hydrogen to burn and dry the wet MSW, while the blower furnished oxygen for entire combustion. The vertical shaft design aided in partly drying incoming feed (Figure 6b). Food waste processed at decrease temperatures because of its lower caloric price as compared to paper and textile waste, with moisture content drastically impacting the time wished for temperature upward push, as preliminary electricity turned into used to evaporate water content material Testing the actual-time incineration of combined waste kinds, which includes food, fabric, and paper, revealed sizable versions in combustion conduct. The higher moisture content in certain waste batches brought about longer incineration instances and elevated strength consumption, more often than not to evaporate water. As combustion commenced, temperatures rose because of the introduction of premixed hydrogen and oxygen. The waste itself acted as fuel as moisture content reduced at excessive temperatures. Notably, as incineration neared final touch, temperatures dropped swiftly because of the depletion of combustible cloth. Waste batches four, 5, and 7 required about 2100, 2000, and 2200 seconds for incineration, respectively, while waste batch 6 burned within 1200 seconds. Batch 6 exhibited a speedy upward push to 800°C and sustained this top temperature longer, attributed to its lower moisture content material compared to other batches. Batches 4, five, and seven wished time to dry off extra moisture earlier than igniting, ensuing in a sluggish temperature increase and shorter length at peak temperature. Conversely, the lower moisture content material in batch 6 facilitated speedy ignition and temperature upward thrust.

Batch Number	Moisture Content (%)	Energy Required (Wh)	Max Temp. (°C)	Time (seconds)	H2 given (liters)	Energy from H2 (Wh)	Energy from waste (Wh)	Percent energy provided by H2
Waste 4	72.2	497.69	820	2100	70	210	1082.5	42.20%
Waste 5	77	482.52	850	2000	68	204	869.4	42.28%
Waste 6	60.8	381.00	780	1200	40	120	1372	31.5%
Waste 7	81.9	513.23	830	2200	74	222	553.86	43.30%

TABLE 3. Data of the respective heterogeneous waste during incineration.

Table three shows the strength had to completely burn every form of waste in addition to the highest temperature that can be attained.

Using the experimental waste's blending ratio and its calorific values, it became determined that wastes 4, five, 6, and 7 could launch 1082.5Wh, 869.4Wh, 1372Wh, and 553.86Wh of electricity while burned.

Waste 4 wanted 497.69Wh of electricity to completely dry out so that it may be burned as it had a moisture stage of 72.2%.

Similarly, the moisture content material of wastes five, 6, and seven changed into 77%, 60.8%, and 81.9%, respectively, requiring 482.52Wh, 381Wh, and 513.23Wh of electricity.

However, rubbish 4 is furnished as a gasoline-assisted incineration method, which uses 70litres of hydrogen and 210Wh of power. This suggests that, relying on the moisture percentage of the waste, 53.58% less power is used to start the combustion process. Similarly, waste5 of moisture content material 77% turned into furnished.68litres of hydrogen and 57.72% less electricity had been used; waste 6 of the

60.8% moisture content material changed into added. 132litres of hydrogen and waste 7 with an 81.9% moisture content material were supplied, resulting in 68.5% less strength. 244litres of hydrogen with 56.7% less strength.

C. RESIDUE ANALYSIS

Batch Number	Initial Moisture Content %	Amount of waste (gram)	Residue Left (gram)	Reduction in weight %	Loss on ignition %
Waste 1	87	1000	111.2	88.88	1.74
Waste 2	60	1000	28.6	97.14	2.80
Waste 3	90	1500	52	96.50	6.41
Waste 4	72.2	1100	90.2	91.80	6.12
Waste 5	77	1000	136	86.41	5.38
Waste 6	60.8	1000	87.6	91.24	2.97
Waste 7	81.9	1000	54.8	94.52	3.72

TABLE 4. Reduction in weight of waste and LOI after incineration.

After burning, the residue turned into accrued and examined for life-of-use. The leftovers remaining for each homogeneous and heterogeneous garbage batch are displayed in Figure nine. Table four provides the unique factors in element. The weight loss for batches 1 through 7 is 88.88%, 97.14%, 96.50%, 91.80%, 86.41%, 91.80%, and 94.52%, respectively. These effects are in first-rate agreement with the usual discount values for incineration, which range from 75% to 90%.

Furthermore, wastes with better moisture contents have been shown to have decrease weight discounts than wastes with decrease moisture contents. As said in the materials and approach segment above, LOI values were computed for every waste batch making use of a high-temperature furnace.

FIGURE 7. Bottom ash for incinerated waste (a) waste 1, (b) waste 2, (c) waste 3, (d) waste 4, (e) waste 5, (f) waste 6, (g) waste 7.

and 3.72%. This is because there is less moisture content and a one-of-a-kind type of meals waste. The findings recommend that the form of trash may have an effect at the incineration overall performance.

Furthermore, the advised design is capable of dealing with a moisture content material of approximately 80%.

Nevertheless, garbage that has a moisture content greater than ninety% performs less properly for the duration of combustion.

Type of Waste	Initial Moisture Content %		Ash Content %		Loss on ignition %		References
	Measured	*Literature*	*Measured*	*Literature*	*Measured*	*Literature*	*Authors*
Food	87	51.4	11.12	[a] 5.5 [b] 10.92	1.74	[a] 6.2	[a] O. Nam-Chol & W. G. Kim [48] [b] Götze et al [49]
Paper	60	3.5	2.86	[a] 10.7 [b] 8.1	2.80	[a] 14.2	[a] O. Nam-Chol & W. G. Kim [48] [b] Götze et al [49]
Textile	90	N/A	3.5	[b] 9.2	6.41	N/A	[b] Götze et al [49]

TABLE 5. Comparison of characteristic behavior of current study and reference studies.

The massive percentage of tough-toincinerate meals waste (specifically watermelon rind, and many others.) resulted in a 6.12% LOI value for waste 4, which contained 500g of food waste, 300g of textile trash, and 300g of paper waste, with a 72.2% moisture content material. The LOI fee of waste five, which consisted of 400g meals waste, 300g textile waste, and 300g paper trash, was somewhat lower than waste four's five.38%. The absence of hard crust food waste become the purpose of this. Nevertheless, wastes 6 and 7 had moisture contents of 60.8% and eighty 1.9%, respectively, and lower LOI values of 2.97%

CONCLUTION

For sustainable waste management, inexperienced and sustainable fuels are required. This paper affords the effects of a methodical assessment of the viability of using hydrogen as the primary gasoline for waste management. The garbage turned into burned in a shaft-style incinerator chamber prepared with burners made to reserve. The burners have been furnished with a precombination of hydrogen and oxygen in a stoichiometric ratio, and that they had been configured efficiently to distribute warmth uniformly. Different combos of solid waste with various moisture concentrations were used, which includes food waste, paper trash, and textile waste.

For MSW (meals, textile, and paper waste) with a moisture content of 77%, a most temperature of 850C has been discovered.

For every kilogram of MSW, 68litres of hydrogen had been used, ensuing inside the consumption of 204Wh of strength.

Similar findings also indicate that additional hydrogen and time have been wanted, at the side of a waste of high moisture content.

Additionally, it has been decided that every one dealt with waste samples had weight reductions and LOI reductions falling between 1.64% and 6.41%, respectively, thus assembly the necessities of incineration overall performance. With a maximum moisture degree of approximately 80%, the gadget functioned efficiently with a whole lot of MSW. The feature high temperature (2800C) and focused quantity of hydrogen are connected with the exceptional overall performance at excessive moisture content material. Nevertheless, overall performance is decreased when the moisture stage is raised to 90%.

REFERENCES

[1] E. B. Tirkolaee, I. Mahdavi, M. M. S. Esfahani, and G.-W. Weber, "Ahybridaugmentedantcolonyoptimizationforthemulti-tripcapacitated arc routing problem under fuzzy demands for urban solid waste management," *Waste Manage. Res.*, vol. 38, no. 2, pp. 156– 172, Feb. 2020.

[2] S. Kaza, L. Yao, P. Bhada-Tata, and F. Van Woerden, "Country-level dataset," *What Waste*, vol. 2, 2018. [3] L. Makarichi, W. Jutidamrongphan, and K.-A. Techato, "The evolution of wasteto-energy incineration: A review," *Renew. Sustain. Energy Rev.*, vol. 91, pp. 812–821, Aug. 2018. [4] S. Ahmad, N. Iqbal, F. Jamil, and D. Kim, "Optimal policy-making for municipal waste management based on predictive model optimization," *IEEE Access*, vol. 8, pp. 218458–218469, 2020.

[5] X.-G. Zhao, G.-W. Jiang, A. Li, and L. Wang, "Economic analysis of waste-toenergy industry in China," *Waste Manage.*, vol. 48, pp. 604–618, Feb. 2016.

[6] M. Saeed, M. Ahsan, M. H. Saeed, A. Mehmood, and S. El-Morsy, "Assessment of solid waste management strategies using an efficient complex fuzzy hypersoft set algorithm based on entropy and similarity measures," *IEEE Access*, vol. 9, pp. 150700–150714, 2021.

[7] B. Ž. Bajić, S. N. Dodić, D. G. Vučurović, J. M. Dodić, and J. A. Grahovac, "Wasteto-energy status in Serbia," *Renew. Sustain. Energy Rev.*, vol. 50, pp. 1437– 1444, Oct. 2015.

[8] M. Gautam and M. Agrawal, "Greenhouse gas emissions from municipal solid waste management: A review of global scenario," in *Carbon Footprint Case Studies*, 2021, ch. 5, pp. 123–160.

[9] R. W. Ahmad, K. Salah, R. Jayaraman, I. Yaqoob, and M. Omar, "Blockchain for waste management in smart cities: A survey," *IEEE Access*, vol. 9, pp. 131520–131541, 2021.

[10] I. S. Abdelli, F. Y. Addou, S. Dahmane, F. Abdelmalek, and A. Addou, "Assessment of methane emission and evaluation of energy potential from themunicipalsolidwastelandfills,"*Energy Sources,Recovery,Utilization, Environ. Effects*, pp. 1–20, 2020.

[11] T. Inaba and T. Iwao, "Treatment of waste by DC arc discharge plasmas," *IEEE Trans. Dielectr. Electr. Insul.*, vol. 7, no. 5, pp. 684–692, Oct. 2000.

[12] M. T. Munir, I. Mardon, S. Al-Zuhair, A. Shawabkeh, and N. U. Saqib, "Plasma gasification of municipal solid waste for waste-to-value processing," *Renew. Sustain. Energy Rev.*, vol. 116, Dec. 2019, Art. no. 109461.

[13] C. Ducharme, "Technical and economic analysis of plasma-assisted wastetoenergy processes," M.S. thesis, Dept. Earth Environ. Eng., Earth Eng. Center, Columbia Univ., New York, NY, USA, 2010.

[14] B. Wilson, N. Williams, B. Liss, and B. Wilson, *A Comparative Assessment of Commercial Technologies for Conversion of Solid Waste to Energy*. Boca Raton, FL, USA: EnviroPower Renewable, 2013.

[15] A. Ramos and A. Rouboa, "A technoeconomic approach to plasma gasification," in *Proc. AIP Conf.*, 2018, Art. no. 030038.

[16] *Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report of the*

Intergovernmental Panel on Climate Change, IPCC Climate Change, Geneva, Switzerland, 2014, p. 147, vol. 1454.

[17] C. Pellerin, "Alternatives to incineration: There's more than one way to remediate," *Environ. Health Perspect.*, vol. 102, no. 10, pp. 840–845, Oct. 1994.

[18] T. J. Appleton, R. I. Colder, S. W. Kingman, I. S. Lowndes, and A. G. Read, "Microwave technology for energyefficient processing of waste," *Appl. Energy*, vol. 81, no. 1, pp. 85–113, 2005.

[19] G. Flesoura, N. Dilissen, G. Dimitrakis, J. Vleugels, and Y. Pontikes, "A new approach for the vitrification of municipal solid waste incinerator bottom ash by microwave irradiation," *J. Cleaner Prod.*, vol. 284, Feb. 2021, Art. no. 124787.

[20] H. Shi, N. Mahinpey, A. Aqsha, and R. Silbermann, "Characterization, thermochemical conversion studies, and heating value modeling of municipal solid waste," *Waste Manage.*, vol. 48, pp. 34–47, Feb. 2016.

[21] S. Yang, A. Saffarzadeh, T. Shimaoka, and T. Kawano, "Existence of Cl in municipal solid waste incineration bottom ash and dechlorination effect of thermal treatment," *J. Hazardous Mater.*, vol. 267, pp. 214–220, Feb. 2014.

[22] *Incinerator Market: Global Industry Trends, Share, Size, Growth, Opportunity and Forecast 2022–2027*, IMARC Group, Cheyenne, WY, USA, 2021.

[23] Y. Liu, P. Xing, and J. Liu, "Environmental performance evaluation of different municipal solid waste management scenarios in China," *Resour., Conservation Recycling*, vol. 125, pp. 98–106, Oct. 2017.

[24] E. K. Paleologos, P. Caratelli, and M. E. Amrousi, "Waste-to-energy: An opportunity for a new industrial typology in Abu Dhabi," *Renew. Sustain. Energy Rev.*, vol. 55, pp. 1260–1266, Mar. 2016.

[25] M. S. Korai, R. B. Mahar, and M. A. Uqaili, "Optimization of waste to energy routes through biochemical and thermochemical treatment options of municipal solid waste in Hyderabad, Pakistan," *Energy Convers. Manage.*, vol. 124, pp. 333–343, Sep. 2016.

[26] H. K. Jeswani and A. Azapagic, "Assessing the environmental sustainability of energy recovery from municipal solid waste in the U.K.," *Waste Manage.*, vol. 50, pp. 346–363, Apr. 2016.

[27] P. J. Reddy, *Municipal Solid Waste Management: Processing-Energy Recovery-Global Examples*. Boca Raton, FL, USA: CRC Press, 2011. [28] J. W. Son, S. H. Kim, and C. H. Sohn, "On burnout performance of a rocketengine-based incinerator devised for high burning rate of solid particles," *Fuel*, vol. 117, pp. 478–487, Jan. 2014. [29] D. Chen and T. H. Christensen, "Lifecycle assessment (EASEWASTE) of two municipal solid waste incineration technologies in China," *Waste Manage. Res., J. Sustain. Circular Economy*, vol. 28, no. 6, pp. 508–519, Jun. 2010.

[30] B. Stanley, "Summary of waste conversion technologies," Environ. Res. Educ. Found., Raleigh, NC, USA, Tech. Rep., 2013.

[31] G. Stoltz, J.-P. Gourc, and L. Oxarango, "Characterisation of the physicomechanical parameters of MSW," *Waste Manage.*, vol. 30, nos. 8– 9, pp. 1439–1449, Aug. 2010.

[32] J.-W. Lu, S.-K. Zhang, J. Hai, and M. Lei, "Status and perspectives of municipal solid waste incineration in China: A comparison with developed regions," *Waste Manage.*, vol. 69, pp. 170–186, Nov. 2017.

[33] K. D. Sharma and S. Jain, "Municipal solid waste generation, composition, and management: The global scenario," *Social Responsibility J.*, vol. 16, no. 6, pp. 917–948, Jun. 2020.

[34] A. Maalouf and A. Mavropoulos, "Reassessing global municipal solid waste generation," *Waste Manage. Res.*, 2022.

[35] *The Incinerator Guidebook*, PATH, Seattle, WA, USA, Mar. 2010. [36] G. Komitov, V. Rasheva, and I. Binev, "Determining the expenses for heating of a residential building using different energy sources," *IOP Conf. Ser., Mater. Sci. Eng.*, vol. 595, Sep. 2019, Art. no. 012046.

[37] O. M. Butt, T. Saeed, H. Elahi, U. Masud, U. Ghafoor, H. S. Che, N. A. Rahim, and M. S. Ahmad, "A predictive approach to optimize a HHO generator coupled with solar PV as a standalone system," *Sustainability*, vol. 13, no. 21, p. 12110, Nov. 2021.

[38] M. S. Ahmad, M. S. Ali, and N. A. Rahim, "Hydrogen energy vision 2060: HydrogenasenergycarrierinMalaysianpri maryenergymix—Developing P2G case," *Energy Strategy Rev.*, vol. 35, May 2021, Art. no. 100632.

[39] K. S. Prommaneewat and Sathiracheewin, "Developing of incinerator with hydrogen gas for hospital wastes treatment," *Int. J. Environ. Rural Develop.*, vol. 10, pp. 158–163, 2019. [40] E. Cetinkaya, I. Dincer, and G. F. Naterer, "Life cycle assessment of various hydrogen production methods," *Int. J. Hydrogen Energy*, vol. 37, no. 3, pp. 2071–2080, Feb. 2012.

[41] M. S. Cellek and A. Pınarbası, "Investigations on performance and emission characteristics of an industrial low swirl burner while burning natural gas, methane, hydrogen-enriched natural gas and hydrogen as fuels," *Int. J. Hydrogen Energy*, vol. 43, no. 2, pp. 1194–1207, Jan. 2018.

[42] O. M. Butt, M. S. Ahmad, H. S. Che, and N. A. Rahim, "Usage of ondemand oxyhydrogen gas as clean/renewable fuel for combustion applications: A review," *Int. J. Green Energy*, vol. 18, no. 13, pp. 1405–1429, Oct. 2021.

[43] P. E. Dodds, I. Staffell, A. D. Hawkes, F. Li, P. Grünewald, W. McDowall, and P. Ekins, "Hydrogen and fuel cell technologies for heating: A review," *Int. J. Hydrogen Energy*, vol. 40, no. 5, pp. 2065–2083, 2015.

[44] J. Zachariahwolff, T. Egyedi, and K. Hemmes, "From natural gas to hydrogen via the Wobbe index: The role of standardized gateways in sustainable infrastructure transitions," *Int. J. Hydrogen Energy*, vol. 32, no. 9, pp. 1235–1245, Jun. 2007. [45] M. Hermesmann and T. E. Müller, "Green, turquoise, blue, or grey? Environmentally friendly hydrogen production in transforming energy systems," *Prog. Energy Combustion Sci.*, vol. 90, May 2022, Art. no. 100996. [46] S. Kumar and S. Ankaram, "Waste-toenergy model/tool presentation," in *Current Developments in Biotechnology and Bioengineering*. Amsterdam, The Netherlands: Elsevier, 2019, pp. 239– 258.

[47] O. K. M. Ouda, S. A. Raza, A. S. Nizami, M. Rehan, R. Al-Waked, and N. E. Korres, "Waste to energy potential: A case study of Saudi Arabia," *Renew. Sustain. Energy Rev.*, vol. 61, pp. 328– 340, Aug. 2016.

[48] O. Nam-Chol and W.-G. Kim, "Investigation of characterization of municipal solid waste for refused-derived fuel, a case study," *Energy Sources, A, Recovery, Utilization, Environ. Effects*, vol. 39, pp. 1671–1678, Aug. 2017.

[49] R. Götze, K. Pivnenko, A. Boldrin, C. Scheutz, and T. F. Astrup,

‘‘Physico-chemical characterisation of material fractions in residual and sourcesegregated household waste in Denmark,’’ *Waste Manage.*, vol. 54, pp. 13–26, Aug. 2016.