https://doi.org/10.36375/prepare_u.iiche.a418

Replacement of coal by RDF (Refused Derived Fuel)

Soumyadip Das[a], Ritu Thakur[a], Subrata Dasgupta[a], Sankalan Das[a] , Biswajit Mandal[b], Sunil Baran Kuila[c*]

[a, b , c*]Department of Chemical Engineering, Haldia Institute of Technology, Haldia 721657, West Bengal, India.

*Sunil Baran Kuila, hithodche@gmail.com, 8972960394,

Abstract

Within Municipal Solid Waste (MSW) management, processing of several fractions that are combustible in nature but are not recyclable such as soiled paper, soiled cloth, contaminated plastics, multilayer, packaging materials, other packaging materials, pieces of leather, rubber, tyre, polystyrene (thermocol), wood etc. has remained a challenge and these fractions unwantedly ends up at landfill sites. These fractions can be processed and converted to refuse derived fuel (RDF), which carries significant calorific value, and can be utilized as alternative fuel in various industries in line with the principle of waste to wealth. The principle of RDF production is recovering quality fuel fractions from the waste, particularly through the removal of recyclable particles such as metal and glass, and converting the raw waste into a more usable form of fuel with uniform particle size and higher calorific value than raw MSW. For example, the broad specification of RDF suitable for the Indian cement plants is preferably having Moisture (< 20 %), average particle size (< 75 mm), calorific value (~ 3000 kcal/kg), Chlorine (< 0.7%), Sulphur (< 2%) and should be free of restricted items such as PVC, explosives, batteries, aerosol containers and bio-medical waste.

Keywords: *Refuse derived fuel; Garbage; Pellet; Moisture; Municipal Solid Waste.*

1. Introduction:

The recent growth of metropolitan populace along with societal and economic prosperity leading to higher energy demand and higher rate of wastage production due to accelerated populace growth. Thus, in order to meet the constant energy demand implementation of solid municipal waste material is indeed a promising feedstock for energy production. In a metropolitan region deposition of several types of municipal solid waste material gets deposited at lower elevated region, often termed as waste disposal area or waste repository. The technique or process is much economically feasible thus it is the most acceptable traditional or conventional method of waste management technique. On contradict of above-mentioned method accumulation of large amount of municipal solid waste material in combination with organic and non-degradable waste material leads to emission of hothouse gases, thus certain regulations must be stipulated in order to maintain socio, economic and environmental sustainability **[**Balasubramanian Karpana et al. 2012**]**. Henceforth the immediate search for a newly developed methodology is highly required to convert municipal solid waste materials into usable energy form **[**S., Kamyab et al. 2020**]**. Firstly, the solid municipal waste materials can be apartheid into combustive, non-combustive and moisture enriched materials. The combustive proportion of waste material is defined as refused derived fuel mainly consists of carbon enriched by-products includes several bio-degradable and non -biodegradable polymers likely polyethylene polymer and papers which contributes >50%-<80% as main components in RDF along with minor yields such as timber, textile material and biologically derived waste products [S., Kamyab et al. 2020, Ahmad Hajinezhad et al., Varun Singh Bundela et al.]. Figure 1 depicts different fractions of municipal waste materials. Henceforth, refused derived fuel in MSW may be a promising source of clean energy in the nearer future [S., Kamyab et al. 2020, J.E. Reed et al. 1983, Baharez Reza et al. 2013 , Constantinos S. Psomopoulos.2014]. The below pie-chart representation shows the recent municipal solid waste composition of India and specifying various components present in MSW [Constantinos S. Psomopoulos. 2014]. The other different methodologies other than RDF such as direct combustion process and bio-gasification.

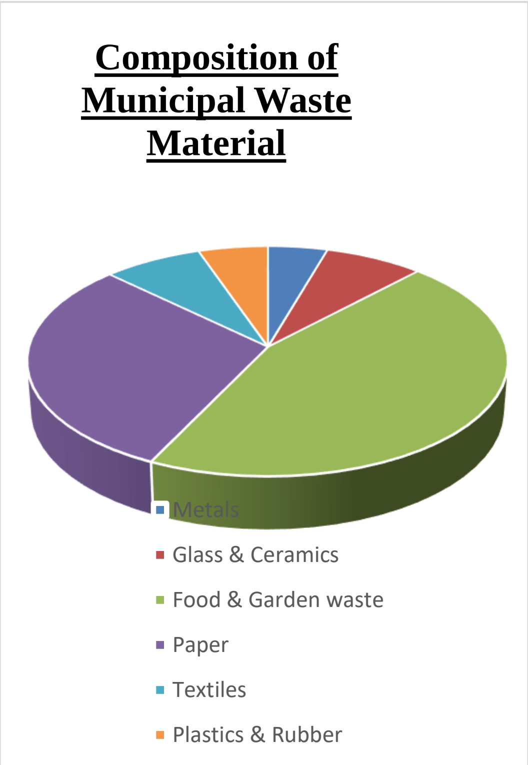

Fig. 1. Pie-Chart representation depicting percentage composition of MSW in India.

The granular forms of refused derived fuel are considered to be potent alternative over coal, since energy value (J/gm) or (J/m^3) of granules are higher in comparison with coal. It also referred to be sustainable form of energy which signifies environmental friendliness and highly competent over several fossil fuel relied industries [Balasubramanian Karpana et al 2021, Van Tubergen J et al. 2005]. Bio-gasification is an anoxygenic method responsible for methane emission which includes (>50%) of CH4 concentration. Later it has been evaluated 75 Watts of electrical energy can be synthesized per unit volume of methane gas by bio-gasification method using solidified municipal waste materials [Balasubramanian Karpana et al 2021, Archer E et al. 2005]. The direct combustion method involves explicit application of heat energy on solidified waste materials under oxygenic condition at >1073K (K-kelvin) which is responsible for emission of hothouse gases. It involves energy convalescence rate within >50% - <100% consisting mostly biodegradable waste materials. The recovered energy has several industrial applications likely for heating purpose or in industrial turbines [Balasubramanian Karpana et al 2021, A. Gendebien et al. 2003].

The above conversion methods from wastage materials to energy paves a way towards environmental sustainability. Among these conversion methods municipal solid waste is the most promising feedstock for energy extraction. It provides solution to waste management issues and provides environmental sustainability [S., Kamyab et all 2020 , Garg, A. et al. 2007]. In spite of having several energy extraction methods, gasification method is suitable technique in nearer future.

2. RDF

2.1. Preparation of Refused Derived Fuel (RDF)

Refuse-derived fuel (RDF) is a type of fuel produced from non-recyclable

https://doi.org/10.36375/prepare_u.iiche.a418

waste materials. The RDF preparation process follows following steps:

1. The process initializes by collecting non-recyclable waste materials such as plastics, paper, cardboard, textiles, and organic waste from various sources like households, industrial and commercial establishments. [Balasubramanian Karpana et al. 2021, S., Kamyab et al. 2020]
2. The collected waste undergoes some manual and mechanical methods to remove contaminants and recyclable materials to ensure that only suitable waste materials are used for RDF production.
3. After sorting, the remaining waste is shredded into smaller pieces to facilitate further processing. This can be done using industrial shredders. [Ahmad Hajinezhad et al.2016]
4. Depending on the moisture content of the waste, it may be necessary to dry it to reduce moisture levels. Lower moisture content improves the energy content of the RDF.
5. The shredded and dried waste is then compacted or pelletized to form RDF. This can be done by compressing the waste material into dense pellets or blocks using hydraulic presses.
6. It's crucial to ensure the quality of RDF by conducting regular quality control checks. This involves analyzing the composition, calorific value, and moisture content of the produced RDF to meet specific standards.
7. After that the RDF is stored in suitable containers or storage facilities before distribution to end-users, such as cement kilns, industrial boilers, or power plants. [Varun Singh Bundela et al. 2022]
8. RDF can be used as a fuel source in various applications. It can be burned in industrial furnaces, boilers, or even gasified to produce syngas for electricity generation or other energy purposes.
9. The production and use of RDF comply with local environmental regulations and emissions standards to minimize environmental impact.

The exact RDF preparation process may vary depending on local regulations, the specific waste materials available, and the intended end-use of the fuel. Additionally, technologies for RDF production continue to evolve, with an increasing focus on sustainability and resource recovery. [J.E. Reed et al. 1983]

2.2. Characteristics of RDF

The properties of RDF make it a lot different from fossil fuel and other fuels. Some of them are notably good for both environment and economics while others are not.

A few of the characteristic properties are listed below.

- The bulk density and the calorific value of RDF are comparatively lower than fossil fuels. The lower calorific value is a bit less economical for a country. **[**Baharez Reza et al. 2013**]**
- RDF also has a lower energy conversion efficiency and density.
- RDF is a heterogeneous composition that is it consists of matters of variable size, volatility, alkali content, heavy metal content, and inert material composition.
- These have partially lower combustion behavior. **[**Baharez Reza et al. 2013**]**

The chemical properties of RDF vary with the quantity and composition of MSW (Municipal Solid Waste). [Baharez Reza et al. 2013]

The feasible and desired chemical properties and characteristics of RDF; **[**Constantinos S. Psomopoulos 2014**]**

- Calorific Value – 11 to 18 MJ/kg
- Sulphur content – 0.3 to 0.8 % wt.

https://doi.org/10.36375/prepare_u.iiche.a418

- Chlorine content – 1.0 to 1.8 % wt.
- Moisture content – below 30 % wt.
- Ash content – 11 to 21 % wt.
- Carbon content – above 50 % wt.
- Humidity – below 25% wt.

The below graphical representation has been plotted to study comparison analysis with RDF and other conventional fuel sources and coal related with calorific value and proximate study respectively [Van Tubergen J et al. 2005, Archer E et al. 2005, A. Gendebien et al. 2003, Garg, A. et al. 2007, D. MVW Lechtenberg; 2008, Mustafa Kara. 2017].

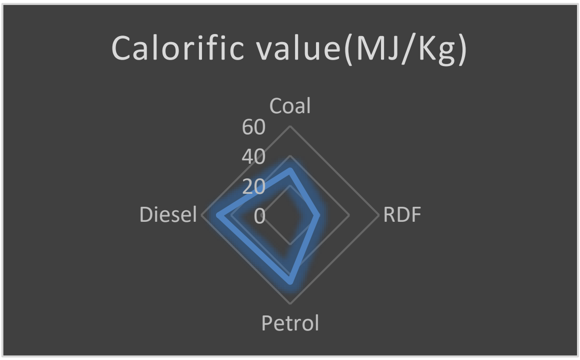

Fig.2. Comparison plot of RDF with conventional fuel on basis of calorific value

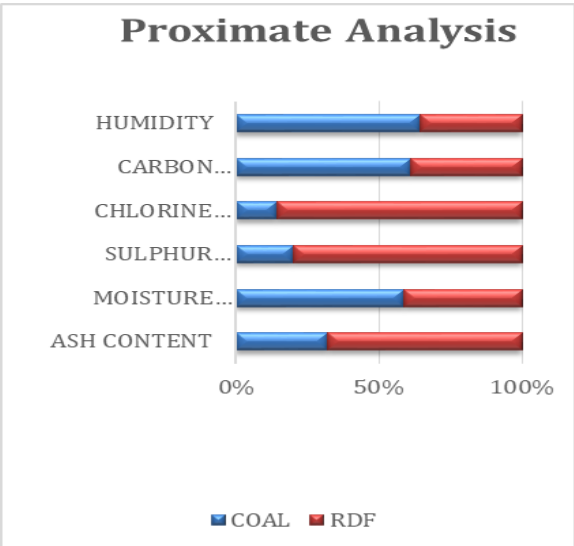

Fig.3. Comparison chart of RDF vs Coal on basis of proximate analysis.

RDF is produced in the course of Mechanical Biological Treatment (MBT) of wastes or Biological Drying Process of wastes [Rada EC and Andreottoala G 2012, Archer E et al. 2005]. The waste is basically decomposed from organic parts and recyclable solid wastes that mainly include metals, papers, plastic etc. and hence RDF is prepared [D. MVW Lechtenberg; 2008, Mustafa Kara. 2017].

Refuse-derived fuel represents a significant quantity of energy. Recovery of part of this energy content in a form with high value, i.e., fuel oil, would also reduce a growing environmental problem. The wide variety of plastics found in the RDF that are produced originally from crude oil can be thermally cracked into fuels or petrochemicals [R.C. Poller 1980, W. Kaminsky and H. Roessler 1992].

The calorific value of RDF is comparatively lower than coal but the cost of coal is much higher than RDF. This makes RDF a better substitute of coal as the former one is environment friendly [Ganesh Thirugnanam 2013].

3. Challenges and it's utilization

RDF upon combustion leads to a very minimum number of pollutants. As a result of which it has a widespread application in several domains and industries. Refused derived fuel has been in use in industries not only in India but also in several other parts of the world.

RDF is acknowledged for its cost-saving benefits, particularly visible in European nations with modern waste collection and disposal infrastructure, paired with elevated disposal expenses. Typically, roughly 55% of carbon dioxide emissions during cement clinker manufacture occur from the transformation of limestone ($CaCO_3$) into lime (CaO). Additionally, roughly 40% of the emissions occur from the combustion processes needed for commencing the reaction at a temperature of 1450°C. RDF coupled with other fuel sources can significantly reduce carbon emission from cement industry [Mustafa Kara, 2012].

Certainly RDF, or refuse-derived fuel, can undergo extra processing to obtain consistent size (60–100 mesh) and weight, coupled with an enhanced energy density. This makes it a viable input for pyrolysis or co-combustion in a typical power plant. The considerable energy content inside refuse-derived fuel presents a viable resource. Extracting a portion of this energy in the form of high-value fuel oil not only addresses environmental problems but also provides an attractive option for resource recovery through the pyrolysis of polymeric wastes to generate liquid hydrocarbons [Lin, K. S. et al 1999].

RDF can replace coal in power plant boilers, functioning as a substitute for both firewood and furnace oil in the combustion process. RDF has also been found to be immensely useful in the generation of electricity. There has been examples of implementation and utilisation of RDF in electricity generation in many parts of India. In the context of Vellore District, around 120 metric tons of solid garbage is produced daily. From this, it is possible to generate 30 metric tons of Refuse-Derived Fuel (RDF) daily, resulting in the generation of roughly 2.5 megawatts of power each day. Notably, Arcot has established a self-sufficient program where a 30-kilovolt generator is deployed to manufacture electricity from municipal solid trash, generating 265 to 285 units per day. This electricity output can illuminate around 100-150 street lights in Arcot [Thirugnanam, Ganesh & Prakasam, Vignesh 2013].

To comprehend the benchmark practices of municipal solid waste (MSW) management in India, data was gathered from various organizations, and a subset was chosen for in-depth analysis by various research scholars. A case study has been done on a company named Shalivahana (MSW) Green Energy Ltd. [S (MSW)GEL]. Located in Rebladevpally Village, (near Sultanabad) Karimnagar District, Telangana. They are using OFMSW as a feed material with a capacity of 225 TPD RDF plant capacity and 12 MW power generation capacity these two are main commercial products of this company [Ghosh, A et al. 2022].

RDF plants have been found to have some environmental impact, including the potential for global warming, the creation of non-methane volatile organic compounds, the potential for NOx-corrected photooxidative creation, the potential for acidification, and the potential for nutrification, despite their high market demand and numerous success stories [CPCB Bulletin 2016, Reza, B et al. 2013]. In addition, field surveys on RDF reveal that it has a high social approval rate and a medium to high economic aspect [PlanningCommission, G. 2015]. India's current situation, as shown by case studies, highlights the presence of many RDF plants. Thus, employing RDF followed by pyrolysis or gasification is suggested as a sustainable approach, depending on the desired outcome [Ghosh, A et al. 2022].

Now, focusing on India's current scenario describes the generation of municipal solid waste is around 62–65 million tonnes and by 2031, it is estimated to be 130 million tonnes [Sharma, P. et al. 2022, Urban, S. B. 2018, N. K. Gupta 2016]. Given the current worldwide context and the close proximity of Indian cement facilities, it is projected that approximately 13,600 tonnes of Refuse Derived Fuel (RDF) could be accessible daily, amounting to roughly 4.96 million tonnes annually [Sharma, P. et al. 2022, Urban, S. B. 2018]. The Ministry of Housing and Urban Affairs (MoHUA) has formulated guidelines for Indian RDF Grading, which are determined by the quality of refused derived fuel [Sharma, P.

https://doi.org/10.36375/prepare_u.iiche.a418

et al. 2022, Urban, S. B. 2018]. Nevertheless, the utilization of refused derived fuel is subject to certain constraints, with one key factor being TSR (Thermal Substitution Rate), which denotes the proportion of traditional fossil fuel heat substituted by alternative fuels. Reports indicate that certain cement plants in Europe have attained a TSR of 80–100% by incorporating RDF into the calciner. However, it's important to note limitations such as the occurrence of hot spots and elevated carbon monoxide emissions [Sharma, P. et al. 2022, Abbas, T. 2018]. In India, just 59 out of 148 integrated cement plants engage in co-processing waste, primarily within the calciner [Sharma, P. et al. 2022, Saxena, A. et al. 2019, Kumr S. and Verma R. 2021]. Several studies have indicated that RDF contributes merely 0.6% to the overall 4% TSR. Only a handful of cement plants have achieved a TSR exceeding 15% [Sharma, P. et al. 2022]. Recently, only two cement plants in India have installed a kiln bypass, resulting in a TSR operating percentage of 30%, with RDF serving as the primary alternative fuel in the calciner [Sharma, P. et al. 2022]. During operational phases, various constraints have been noted, including subpar waste quality, low calorific value, inadequate segregation, elevated chloride content, fluctuations in costs, flaws in system design, deficient characterization facilities, and operational challenges [Sharma, P. et al. 2022]. A report outlines numerous challenges concerning pre-processing and co-processing encountered by Indian cement plants during the utilization of RDF [Sharma, P. et al. 2022, Sharma, P. et al. 2019, Kukreja, K. et al. 2019, Kukreja, K. & Mohapatra, B. N. et al. 2019]. Another report underscores significant challenges faced by Dalmia Cement Ltd.-Dalmiapuram during RDF utilization, including a lower heating value of 1800 kcal/kg with 25% moisture content and odor issues [Sharma, P. et al. 2022, ajamohan, R. et al. 2017]. Elevated chloride content emerges as a prevalent challenge in RDF operational procedures. Consequently, particularly in India, the cement industry seeks alternative thermochemical treatment options to address these challenges. Research indicates that two other thermochemical treatment technologies, namely Pyrolysis and gasification, offer potential solutions, enabling waste reduction and significant savings of land from landfills [Sharma, P. et al. 2022]. To ensure the sustainability of society, a clear differentiation between pyrolysis and gasification has been emphasized. Gases released from the pyrolysis process often go unutilized, contributing to pollution. Research suggests that the commercial viability of this process may face challenges in obtaining approval from pollution control boards due to pollution concerns, potentially leading to increased costs for pollution mitigation. Additionally, proper storage facilities are necessary for the utilization of pyrolytic oil, incurring additional expenses for users. Numerous authors have conducted waste characterization using analytical equipment [. Mehta, A., & Rao, S. 2023, Miskolczi, N. et al. 2010, Cozzani, V. et al. 1995, Fang, D. et al. 2021, Chen, X. et al. 2019]. A report also indicates a high tar content in gas products. Therefore, while the RDF pyrolysis process can be utilized at the laboratory scale to develop kinetic models and determine product yields, it may not be suitable for larger scale or commercial purposes. In contrast, gasification presents several advantages. It generates primarily syngas, which can be directly burned in the calciner/kiln without requiring gas cleaning. Hence, gasification emerges as a viable waste treatment technology for converting solid waste into clean gaseous fuel, with impurities removed from the pyro-processing system [Sharma, P. et al. 2022, Kusz, B. et al. 2022]. Since the gasification process enables the production of syngas which signifies better ignition quality inside the calciner as compared to directly putting the pellets of solid waste material inside it. The gasification process also fixes up a challenge related to klink system the consistent contribution to hydrogen due shift reaction induces the increment of calorific value of syngas thus providing better efficiency of clinker as it also mitigates the accumulation of ash inside the clinker [Sharma, P. et al. 2022]. In India, an RDF gasification plant was established in Pune with the aim of generating 10 MW of power; however, technical issues prevented the plant from becoming operational [Sharma, P. et al. 2022, Singh, A. and Patel, R. 2023]. Cement plants encountering obstacles in increasing TSR beyond 15–20% stand to gain from gasification technology. Integration of gasification with the cement industry can facilitate the attainment of the 25% TSR target within the specified timeframe. The Indian government has established a goal of achieving 100 million tonnes of coal gasification by 2030, with an investment of Rs 0.4 trillion [Sharma, P. et al. 2022, Kumar, S., and Gupta, P. 2023, Dr. M. M. Kutty 2019]. Upon the implementation of gasified coal utilization in the cement sector, it will encourage the co-gasification of coal and waste, offering the benefit of enhanced syngas quality [Sharma, P. et al. 2022].

4. Conclusion

Recent technological advancements, coupled with an effective waste management system, play a pivotal role in realizing sustainable development objectives. This study examines the present status of refused derived fuel (RDF) in India, exploring its implementation, production methods, and accompanying case studies to grasp its challenges and future potential. RDF finds extensive use across various industries, primarily in cement production. However, challenges such as economic viability, waste sorting, and societal awareness, compounded by the absence of decision-making support systems in waste management, persist. The research also underscores the optimal production processes within the cement industry to enhance Thermal Substitution Rates (TSR). Gasification emerges as the most suitable method for RDF implementation in this context. Such primary research endeavors are deemed crucial for countries like India, aiding in the identification and mitigation of sustainability barriers within the broader system.

Acknowledgement

We are grateful to everyone who contributed to this work. We are particularly grateful to Prof. Sunil Baran Kuila (Professor and Head of the Chemical Engineering Department) and Prof. Biswajit Mondal for their invaluable guidance and insights throughout the course of this research. In addition, we'd also like to thank our friends and coworkers for their ongoing encouragement and constructive feedback. Lastly, we want to convey our heartfelt gratitude to our families for their unwavering encouragement and compassion.

References:

1. Balasubramanian Karpana, Abdul Aziz Abdul Ramana,∗,Mohamed Kheireddine Taieb Aroua Waste-to-energy: Coal-like refuse derived fuel from hazardous waste and biomass mixture Department of Chemical Engineering, Faculty of Engineering, University of Malaya, 50603, Kuala Lumpur, Malaysia b Centre for Carbon Dioxide Capture and Utilization, School of Science and Technology, Sunway University, 47500, Petaling Jaya, Selangor, Malaysia.

2. S., Kamyab, H., Pham, Q.B., Yadav, S., Bhattacharyya, S., Yadav, V.K., Bach, Q.-V.,2020. A review on municipal solid waste

as a renewable source for waste-to-energy project in India: c

3. Utilization of Refuse-Derived Fuel (RDF) from Urban Waste as an Alternative Fuel for Cement Factory: a Case Study Ahmad Hajinezhad*, Emad Ziaee Halimehjani, Mojtaba Tahani (2016) Faculty of New Sciences and Technologies, University of Tehran, Tehran, Iran

4. The Role Of Rdf In Place Of Coal Varun Singh Bundela, Dr. Arun Patel PhD Research Scholar, Professor department of Civil engineering Vedica Institute of Technology Civil engineering department RKDF University Airport by pass road Gandhi nagar Bhopal Madhya Pradesh India (2022)

5. J.E. Reed, J.L. Conrad, C.D. Price, "Co-firing of Refuse-Derived Fuel (RDF) with natural Gas, in a Cement Kiln", National Technical Information Service, March (1983). Book.

6. Baharez Reza, Atousa Soltani, Rajeev Ruparathna, Rehan Sadiq, Kasun Hewage. "Environmental and economic aspects of production and utilization of RDF as alternative fuel in cement plants: A case study of Metro Vancouver Waste Management." 2013 Elsevier B.V. http://dx.doi.org/10.1016/j.resconrec.2013.10.009

7. Constantinos S. Psomopoulos. "Residue Derived Fuels as an Alternative Fuel for the Hellenic Power Generation Sector and their Potential for Emissions Reduction". · September 2014 DOI: 10.3934/energy.2014.3.321

8. Van Tubergen J, Glorius T, Waeyenbergh E, Classification of Solid Recovered Fuels, European Recovered Fuel Organisation, 2005.

9. Archer E, Baddeley A, Klein A, et al. (2005) Mechanical-Biological-Treatment: A Guide for Decision Makers Processes, Policies and Markets (Juniper Consultancy Services Ltd.)

10. A. Gendebien, A. Leavens, K. Blackmore, A. Godley, K. Lewin, K.J. Whiting and R. Davis (2003) European Commission – Directorate General Environment, Refuse Derived Fuel, Current Practice and Perspectives (B4-3040/2000/306517/Mar/E3), Final Report, 2003.

11. Garg, A., Smith, R., Hill, D., Simms, N., & Pollard, S. (2007). Wastes as co-fuels: the policy framework for solid recovered fuel (SRF) in Europe, with UK implications. Facts and Figures, European Recovered Fuel Organisation (Erfo) (2007).

12. D. MVW Lechtenberg; 2008. Www.lechtenberg-partner.de. Mermod AY, Dömbekci B. Emission trading applications in the European Union and the case of Turkey as an emerging market. International Journal of Energy Sector Management 2011; 5:345–60

13. Mustafa Kara. "Environmental and economic advantages associated with the use of RDF in cement kilns." 09 October 2017; DOI: 10.1016/j.resconrec.2012.06.011

14. Rada EC, Andreottoala G (2012). "RDF/SRF which perspective for its future in EU. Waste Manage" 32(6): 1059–1060

15. Archer E, Baddeley A, Klein A, et al. (2005) Mechanical-Biological-Treatment: A Guide for Decision Makers Processes, Policies and Markets (Juniper Consultancy Services Ltd.)

16. R.C. Poller, Reclamation of waste plastics and rubber: recovery of materials and energy, J. Chem. Tech. Biotechnol. 30 1980 152–160. Ž . w x

17. W. Kaminsky, H. Roessler, Olefins from wastes, CHEMTECH 22 1992 108–113

18. Ganesh Thirugnanam. "Refuse Derived Fuel To Electricity". September 2013.

19. Mustafa Kara, "Environmental and economic advantages associated with the use of RDF in cement kilns, Resources, Conservation

and Recycling ", Volume 68,2012, Pages 21-28, ISSN 0921-3449, https://doi.org/10.1016/j.resconrec.2012.06.011.(https://www.sciencedirect.com/science/article/pii/S0921344912001097)

20. Kuen-Song Lin, H. Paul Wang, S.-H. Liu, Ni-Bin Chang, Y.-J. Huang, H.-C. Wang, "Pyrolysis kinetics of refuse-derived fuel", Fuel Processing Technology 60 1999 103–110.

21. Thirugnanam, Ganesh & Prakasam, Vignesh. (2013). "Refuse Derived Fuel to Electricity". International Journal of Engineering Research & Technology.

22. Ghosh, A., Debnath, B., Ghosh, S. K., Das, B., & Sarkar, J. P. (2018). Sustainability analysis of organic fraction of municipal solid waste conversion techniques for efficient resource recovery in India through case studies. *Journal of Material Cycles and Waste Management*, *20*, 1969-1985.

23. Mehta, A., & Rao, S. (2023). Sustainability challenges in pyrolysis and gasification: Environmental and economic implications. Journal of Waste Management and Sustainability, 14(2), 45-58. https://doi.org/10.1016/j.wms.2023.03.004

24. Reza, B., Soltani, A., Ruparathna, R., Sadiq, R., & Hewage, K. (2013). Environmental and economic aspects of production and utilization of RDF as alternative fuel in cement plants: A case study of Metro Vancouver Waste Management. *Resources, Conservation and Recycling*, *81*, 105-114.

25. Planning Comission Report (2014) Report of the task force on waste to energy (vol I) (in the context of integrated MSW management). Government of India. http://planningcommission.nic. in/reports/genrep/rep_wte1205.pdf. Accessed 11 May 2017

26. Sharma, P., Sheth, P. N., & Mohapatra, B. N. (2022). Recent progress in refuse derived fuel (RDF) co-processing in cement production: direct firing in kiln/calciner vs process integration of RDF gasification. *Waste and Biomass Valorization*, *13*(11), 4347-4374.

27. Ministry of housing and urban afairs Government of India: Guidelines on usage of refuse derived fuel in various industries (2018). pp. 13–14. http://cpheeo.gov.in/upload/5bda791e5afb3SBMRDFBook.pdf.

28. N. K. Gupta Central pollution control board: Guidelines for Pre-Processing and Co-Processing of Hazardous and Other Wastes in Cement Plant as per H&OW(M & TBM) Rules, 2016 2017. p. 1–34
29. Abbas, T.: Michalis Akritopoulos, Calciner challenges, in World cement. (2018).
30. Saxena, A., Chaturvedi, S., Ojha, P., Agarwal, S., Mittal, A.,Sharma, P., Ahamad, G., Mazumdar, R., Arora, V., Kalyani, K.Anupam, Singh, B., Kukreja, K., Ahmed, R., Bohra, A. Kaura,P.: Compendium The Cement Industry India. National council for cement and building materials, India. pp. 251–260 (2019)
31. Kumr S. and Verma R. (2021) Confederation of Indian industry: status paper on alternate fuel usage in Indian cement industry (2018). pp. 1–2. http://www.ciiwasteexchange.org/doc/afr2018.pdf.
32. Confederation of Indian Industry: Energy benchmarking for Indian cement industry (2019).
33. Sharma, P., Sheth, P. Mohapatra, B.N.: Waste to energy: issues,opportunities and challenges for RDF utilization in Indian cement industry. Proceedings of the 7th International Conference on Advances in Energy Research. pp. 891–900. Springer, Mumbai (2019). https://doi.org/10.1007/978-981-15-5955-6_84
34. Kukreja, K., Anupam, Sharma, P. Bhatnagar, S.: Handling of Multi type Alternative Fuels: A Challenge and

Opportunity for Cement Plant in 16th NCB International Seminar on Cement, Concrete and Building Materials. (2019): New Delhi

35. Kukreja, K., Mohapatra, B. N. Saxena, A.: Transfer chute design for solid alternative fuels. Indian cement review, May ed. (2019). 52–53.
36. ajamohan, R., Vinayagamurthi, K., Kumar, R.A.K.: Alternative fuel & raw material: our journey with in-house systems—a glimpse. In: 15th NCB International Seminar on Cement, Concrete and Building Materials (2017): New Delhi
37. Miskolczi, N., Buyong, F., Williams, P.T.: Thermogravimetric analysis and pyrolysis kinetic study of Malaysian refuse derived fuels. J. Energy Instit. 83, 125–132 (2010). https://doi.org/10.1179/014426010X12759937396632
38. Cozzani, V., Petarca, L., Tognotti, L.: Devolatilization and pyrolysis of refuse derived fuels: characterization and kinetic modelling by a thermogravimetric and calorimetric approach. Fuel 74,903–912 (1995). https://doi.org/10.1016/0016-2361(94)00018-M
39. Fang, D., He, F., Xie, J.: Pyrolysis characteristics and mechanism of hydrocarbon compounds for RDF. Fullerenes, Nanotubes and Carbon Nanostruct. 29, 13–20 (2021). https://doi.org/10.1080/1536383X.2020.1803287
40. Chen, X., Xie, J., Mei, S., He, F., Yang, H.: RDF pyrolysis by TG-FTIR and Py-GC/MS and combustion in a double furnaces reactor. J. Therm. Anal. Calorim. 136, 893–902 (2019). https://doi.org/10.1007/s10973-018-7694-9
41. Kusz, B., Kardaś, D., Heda, Ł, Trawiński, B.: Pyrolysis of RDF and catalytic decomposition of the produced tar in a char bed secondary reactor as an efcient source of syngas. Processes 10,90 (2022). https://doi.org/10.3390/pr10010090
42. Singh, A., & Patel, R. (2023). Challenges in RDF gasification: A case study of Pune's 10 MW plant. Journal of Renewable Energy Studies, 12(4), https://doi.org/10.5678/jrenenergystud.2023.004 energy, S.c.o.: Power generation from municipal solid waste.
43. Kumar, S., & Gupta, P. (2023). Enhancing TSR in cement plants through gasification technology: A strategic approach. Journal of Clean Energy Technologies, 11(3), https://doi.org/10.1016/j.jcet.2023.0301 IEA.:100 MT Coal Gasification Target by 2030—Policies.: https://www.iea.org/policies/12931-100-mt-coal-gasification-target-by-2030. Accessed 27 Aug 2021
44. Dr. M. M. Kutty India, G.o.: Five Year Vision Document 2019–2024 Group III—Resources.