Energy recovery from proper recycling and incineration of waste absorbent hygiene products for environmental sustainability

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Abstract

The wastes generated by absorbent hygiene products desires to be properly recycled and disposed. This paper provides an energy assessment method to appraise the complete performances of an integrated incineration system. This paper aims to find the feasible criteria of environmental compatibility and the societal aspects of the recycled waste. The prime focus is given on the effects of sanitation coverage of children and menstrual hygiene of women. Sanitation is defined as the hygienic significances of encouraging health through preventive measures with the hazards disposed from these wastes which need to be improved by awareness campaign. Proper segregation, reuse and recycle by scientific approaches are the most important criteria of waste management. A gasket with a sorting machine is designed which sterilizes the waste and separates its plastics and utilizes the cellulose in a fluidized bed gasifier, to produce steam nearly at 850^0*C to* 900^0*C for sterilization and an ash collection chamber for proper disposal. The experimental results prove technological feasibility, and identify the working conditions for recycling of absorbent hygiene waste products efficiently without taking any help from external energy support. The results also render an authentic inventory of this recycling scheme and the cost effective design methodology of a waste incinerator, and its easy disposal techniques. The other objective is to provide effective suggestions and recommendations to improve the waste management practices in India which is socially acceptable for better environmental sustainability. This paper also aims for proper cleaning and sterilization of wastes by recycling and incineration and recovering environmental friendly renewable energy for the society. High electrical energy is generated by this incineration method with low cost.*

Keywords: Energy recovery, incineration, recycled waste, sanitation, menstrual hygiene.

1. Introduction

Population and pollution are strongly inter-related with the development and modernization which generates huge municipal solid waste (MSW) in India. Compared to direct landfill of MSW, incineration provides an effectual means for reduction of the mass and the volume of MSW by 80% and 90%, respectively. In India, the rural and the urban bodies are incapable to handle huge quantities of solid waste due to financial and institutional encumbrance. In 2016, Mani et al. [1] concluded out of enormous collection of MSW daily, only 10% is properly treated and the rest are disposed unhygienically in engineered landfills (NIUA, 2013). Indian cities are facing huge problems of inadequate availability of finance and proper incineration technique for waste disposal and its proper conversion to renewable energy source. Proper management of MSW is the most challenging criteria in today's arena and its proper recycling can lead to a more hygienic and sustainable environment. Moya et al. [2] generated renewable energy from MSW by biological and thermal treatment of waste, utilized gas from landfill and bio refineries. Song et al. [3] PESTEL analysis for the treatment of MSW in China. Waste-to-energy (WTE) incineration is considered to be an efficient way for MSW treatment widely used in many countries nowadays. Meanwhile, many natural resources (such as mineral resources, fossil energy resources, etc.) are reducing because of exploitation and huge waste. Wang et al. [4] investigated in China about 65.5% MSW disposals occurred in landfills and the rest in incineration. The research concluded the land filling disposal method was not at all a sustainable way, due to high occupancy of land and methane gas leakage. But, MSW incineration is very much effective in converting most waste into heat and electricity reducing nearly 80% mass and 90% volume.

In 2018, Makarichi et al. [5] communicated a review on the fruition of waste-to-energy incineration (WTE-I) focusing on the key intention of progress in problem solving of energy recovery from MSW by maximizing its potential but more innovations can be done in future scope. However, Bose et al. [6] designed a simple, cost effective pyrolysis design for the gasoline, kerosene and diesel generation by the recycling of plastics. A clean combustion chamber with use of proper disinfectants was the key component of this experimental setup which saved the environment leading to the sustainable development. In 2018, Gurgul et al. [7] concluded three fundamental lofty temperature ways of electronic waste processing, firstly smelting/incineration, secondly pyrolysis and then steam gasification. Then again in 2018, Ghouleh et al. [8] evaluated the viability of the establishment of a cementing material through novel steps using the waste carbon dioxide and ash and energy outputs within an incinerator facility. In this year, Liu et al. [9] obtained two types of incineration ash residues are commonly found after incineration, the incineration bottom ash (IBA) which is the noncombustible residue of combustion that falls on the bottom of incinerator and the incineration fly ash (IFA) which is the fine residue that is driven out from the incinerator with flue gases. Proper biomedical management of waste is the bastion of the efficient hygiene. Apposite management of wastes in hospital is an indispensable component of quality assurance in hospitals. Rajan et al. [10] aimed at the deterrence of disease and fortification of environment by proper biomedical waste management method and anticipated bioremediation techniques in the usage of solar energy in biomedical methods.

Based on the literature review, it is found that solid waste management includes managing actions like collection, transportation, treatment and disposal of solid waste in an environmentally attuned comportment considering economy, conservation of energy. Because of the improper design, propensity, location and contemptible thoughts of the community uncollected waste are often scattered polluting the society. This uncollected waste is generally burnt in open areas resulting in excessive air pollution which is a serious environmental threat. Hence, the main objective of this paper is to incorporate a proper cost effective incineration design where waste absorbent hygiene products and other solid wastes will be properly disposed and recycled with minimum investment and maintenance. This paper also aims to find the feasible criteria of environmental compatibility and the societal aspects of the recycled waste where the prime focus is given on the effects of sanitation coverage of children and menstrual hygiene of women. Reduce the wastes, reuse after proper cleaning and recycle with negligible cost are the 3 basic steps followed in this paper. The other objective is to provide effective suggestions and recommendations to improve the waste management practices in India which is socially acceptable for better environmental sustainability.

2. Treatment of waste absorbent hygiene products

Different treatment methods of solid wastes are classified and hence energy can be recovered. Much emphasis is given on biological treatment, thermal treatment, landfill gas utilization and bio refineries techniques.

2.1 Gasification

Fig. 1 represents the gasification process which produces energy from waste that has been developed over the recent years. This process involves incomplete oxidation and reduces the waste mass and volume to a large percentage (80% approx) and its main product is fuel gas. A case study indicates that this thermal treatment of waste is a feasible option for WTE conversion, limiting greenhouse emissions and reducing landfill disposal options. The main advantages are reduction of organic contaminants, lessening of mass and volume of waste which saves land, diminution of emissions, and environmental compatible for green energy production. High range of working temperatures (700-900°C) is needed. Biogas produced from gasification process is clean and efficient to produce energy in a gas turbine or engine. This fuel is a combination of hydrogen, carbon dioxide and methane which is an impending source of electricity in a turbine-based power plant.

2.2 Incineration

Process: Firstly, waste is directly burned in the combustion chamber at 800-950°C using flue gas and pre-heated air shown in Fig. 2. Then, the produced superheated steam is used within a co-generation system to produce energy and heat. The electric energy is generated by a turbine coupled to a generator. Emission of greenhouse gas is the highest environmental impact of MSW incineration. Therefore proper controlling of these detrimental emissions is mandatory. Some superior technologies like implementing an amalgam plant using incineration and gasification have been developed to diminish these volatile heavy metals.

Energy evaluation of an integrated MSW incineration system: The bottom ash (BA) is solidified with cement and water and there is no emission of methane as it cannot decompose. The main scope of this paper is to recover energy and reutilize it without any active input power supply. The bottom ash is firstly pretreated by drying and sterilized. A ball milling machine is used for proper filling. Proper screening is a must and this process continues. The screened BA and other materials are properly mixed (34% BA, 15% cement, 15% gravel, 36% sand. Sodium hydroxide (NaOH), Sodium silicate (Na_2SiO_3), and Sodium sulfate (Na_2SO_4) has the percentage of 0.81%, 0.86% and 3% of the mass of BA respectively), and then the mixture is poured into brick model with high pressure [4].

MSW incineration into a cleaner cement production: According to Ghouleh et al. [8] fly ash was improved and waste lime was unruffled further downstream. Waste lime collected were dried and then pulverized. The powder form fly ash had a wide range of particle size. To guarantee homogeneity in composition and dimension, these dregs were passed through a 212 mm sieve. The analysis started from ambient temperature to 1475^0C at a heating rate of 10^0C/min which measured the %weight loss of the wastes. But the total setup was expensive which need to be optimized which is also another scope of our paper.

3. Design Methodology

MSW incineration (MSWI) plays the most crucial role in managing this huge waste and its energy recovery techniques. MSW comprises of food waste, paper, plastics, glass, textiles, scrap metals, wood, etc., cannot naturally degrade, therefore proper MSWI techniques are implemented for recovering energy. Fig. 3 and Fig. 4 represent the MSWI capacity over the years in India (till 2018) and other countries (till 2015) which clearly indicates the increasing MSWI capacity of all the countries. There are certain essential steps which are to be followed during the design and methodology of the incineration process.

3.1 Segregation

Scientific method of organized segregation is the most decisive criteria in rural villages. It needs proper sorting of waste in a controlled and safe condition which can enhance the effectiveness of segregation resulting in higher economic return in the recycling market.

3.2 Collection

Household waste is usually collected and transferred into metal and concrete made communal bins that are installed in our society. While transferring this waste may scatter to the roads leading to enormous gas emissions resulting in a toxic environment, so proper cleaning and collection are mandatory [11].

3.3 Separation

The waste now undergoes process of separation and partition of organic and inorganic wastes. Inorganic wastes are avoided in the incinerator as they produce harmful gases on burning; hence the organic wastes are properly channeled through the incineration process.

3.4 Cremation

Waste is cremented or burned directly in the combustion chamber at a sufficient temperature of 850-900°C using flue gas and pre-heated air. BA collected in the base is treated and utilized for making cement. Dual filtration method is implemented in this research which will filter the smoke twice before releasing. This unused hot smoke can be recycled further for energy recovery. Greenhouse gas emissions (GHG-E) are the most dangerous cause of public health issues. However, efforts like introducing a hybrid plant have been put forward for the reduction of these harmful emissions.

4. Results and Discussions

In this paper a Catia design (Fig. 5, 6) is proposed where in the smoke pipe two novel filtration techniques are introduced where doubled filtration is proposed. Primary filtration will sterilized the hot superheated steam and the secondary filtration will thermally treat the superheated steam and will utilize 65% of this steam for energy recovery. A thermocouple in the combustion chamber will record the temperature. An insulator coating is provided on the walls for restriction of heat leakage. Thermal analysis and optimization will be done in Catia and Ansys in future. Ash collector chamber will collect the bottom ash and can be processed for production of cement [8].

Specifications of the incinerator: Volume: 11/2 cft, Space required: 3 sq.ft, Chimney height: 10 ft, Body material: Stainless steel (SS) / Mild steel (MS) [Item code: AIM-INECO-D2, INDIAMART]

Fig. 7 represents the percentage composition of MSW and Fig. 8 shows the collection efficiency of different states of India in 2018 till date by a short survey. This paper focuses on sustainability and eco-friendly waste disposal technology for local communities with MSW generation of less than 5 tons per day in India [12].

For analysis and usage considerations three materials have been tested for our incinerator making purpose as given in Table 1. Fig. 9 and Fig. 10 represents the von Mises equivalent stress contours of the incinerator where steel aermate alloy is proposed for the combustion chamber which is better compared to steel and iron as it provides the lowest von Mises stress (maximum) at higher temperature at 850^0C and 900^0C, respectively. Maximum von Mises stress for steel aermate alloy is 1.59e+009 N/m^2 at 850^0C and 1.68e+009 N/m^2 at 900^0C which are lesser than the ultimate tensile strength 2.430e+009 N/m^2 resulting in safe design. Thermal expansion value is also lower than the other two materials (6.02e-006 /Kdeg) which indicate a better thermal behavior for the combustion chamber. Maximum von Mises stress for steel is 3.16e+009 N/m^2 at 850^0C and 3.36e+009 N/m^2 at 900^0C and maximum von Mises stress for iron is 1.97e+009 N/m^2 at 850^0C and 2.09e+009 N/m^2 at 900^0C. Steel aermate alloy is obtained to be the best material after analysis in Catia as it provides the lowest von Mises stress at higher temperature as obtained from Fig. 11-14 compared to steel and iron.

5. Cost Analysis

The idea of designing incinerator it must be cost effective, user friendly and readily installed at different rural villages as per ground level requirement. Hence, estimated cost analysis is mandatory for the prototype development. It is made of steel aermate alloy and a thermostat for sensing the temperature rise. Air blower is used for constant oxygen supply inside the chamber. Smart materials have also been considered as working person should be safe to handle waste. Bottom ash collection storage is being also made available, as well as waste product storage, place for collection and storage of waste materials which can be incinerated. Table 2 represents the cost analysis as per recent market research of required items of incinerator which may be optimized further at lower cost.

6. Conclusions

The waste absorbent hygiene products prove to be a valuable renewable energy resource which can be recovered by this incineration method. Direct incineration of these wastes produces superheated steam which needs proper filtration before recovering energy for turbines and generators. Therefore, in this paper two novel filtration techniques are introduced where doubled filtration is proposed before emissions. Primary filtration separates high toxic fumes and secondary filtration neutralizes gas and releases green smoke to atmosphere. A novel material named as steel aermate alloy is used in the combustion chamber which raises the efficiency of incineration. This paper also provides a solution with energy recovery from waste, to manage MSW in an effective and efficient way. Huge tonnes of waste are generated per year which needs proper incineration for alternating energy recovery for sustainable development of the society. This amount of municipal waste can be recycled for proper inventory and renewable energy can be recovered. The working temperatures vary from 300 to 900°C in pyrolysis. Approximately 80% of volume of waste can be abridged by gasification. This design methodology is compatible for the environmental sustainability for electricity generation at high range of working temperatures (700-900°C). This design methodology along with proper management systems of MSW is proposed where a novel incinerator can be manufactured at extremely low cost estimated to 51,500 INR for rural areas.

Acknowledgement

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Tables

Table 1. Material Properties

Material Name	**Yield Strength (N/m^2)**	**Modulus of Elasticity (N/m^2)**	**Poisson's Ratio**	**Ultimate Tensile Strength (N/m^2)**	**Density (kg/m^3)**	**Thermal Expansion (/Kdeg)**
Mat 1 (Steel Aermate alloy)	2.16e+009	1.94e+011	0.3	2.430e+009	7888.773	6.02e-006
Mat 2 (Steel)	2.5e+008	2e+011	0.266	4.14e+008	7860	1.17e-005
Mat 3 (Iron)	3.1e+008	1.2e+011	0.291	4.5e+008	7870	1.21e-005

Table 2. Cost analysis of the required items of the Incinerator

Sl no.	**Item name**	**Estimated price (INR)**	**Quantity**	**Estimated Cost (INR)**
1	Metal required for incinerator body (combustion chamber) of steel aermate alloy	100/kg	180-220 kg	20000
2	Joining ailments, stand	40/kg	10	400
3	Insulation (thermal)	200/sqft	30-35sqft	6000
4	High temperature filter material for primary filtration (high toxic fumes separation)	1500/piece	2	3000
5	Water scrubber for Gas neutralization for secondary filtration (making environmental friendly smoke release to air)	10000-15000	1	10000
6	Pipe line (from primary filter to top of chimney) iron pipe	40/ kg	4m	4000
7	Bottom ash collection Storage (need to make by bricks)	1000	1	1000
8	Waste collection storage (need to make by	1000	1	1000

	bricks)			
9	Thermostat	4500/piece	1	4500
10	Air blower (for oxygen supply)	600/piece	1	600
11	Miscellaneous (safety gloves, masks, cleaning, handling things)	1000		1000

Estimated Total Cost = 51,500 INR

Figures

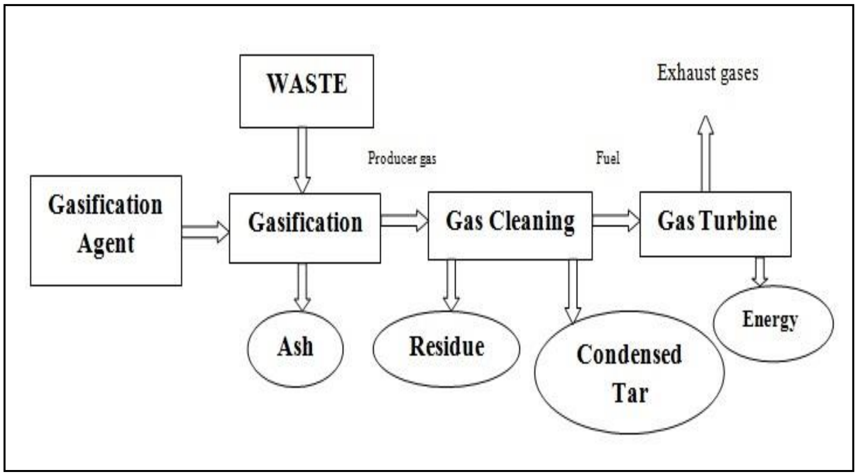

Fig. 1 Gasification Process [2]

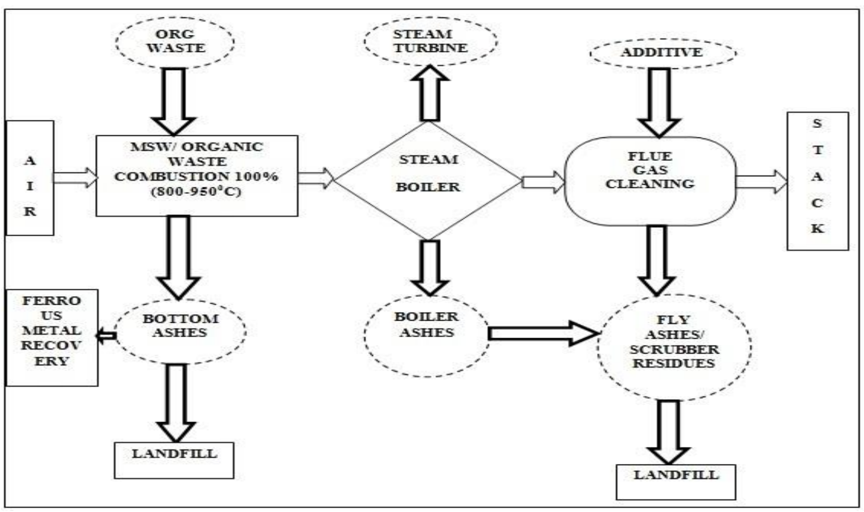

Fig. 2 Incineration Process [2]

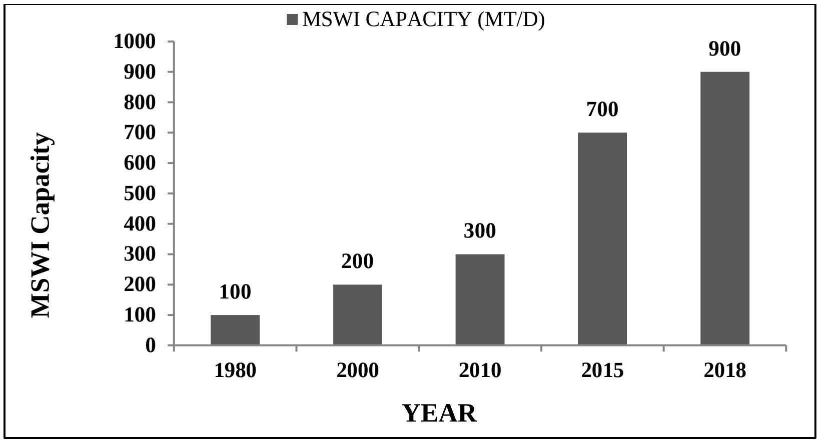

Fig. 3 MSWI Capacity of India between 1980 to 2018

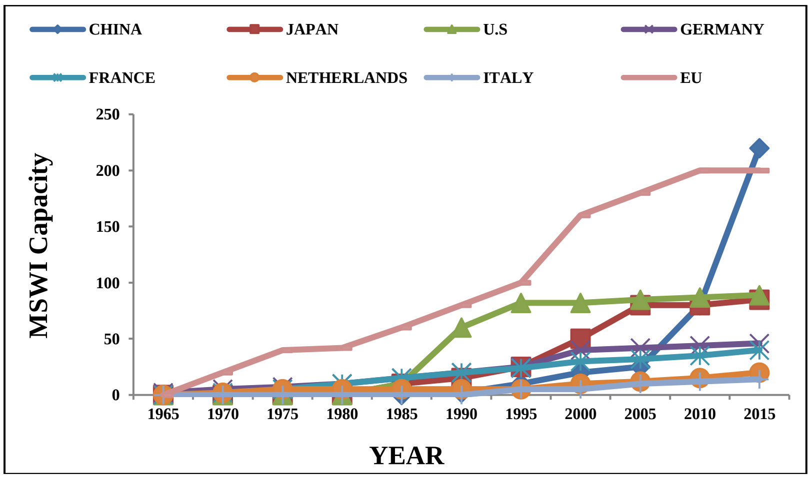

Fig. 4 MSWI capacity for various countries between 1965 to 2015

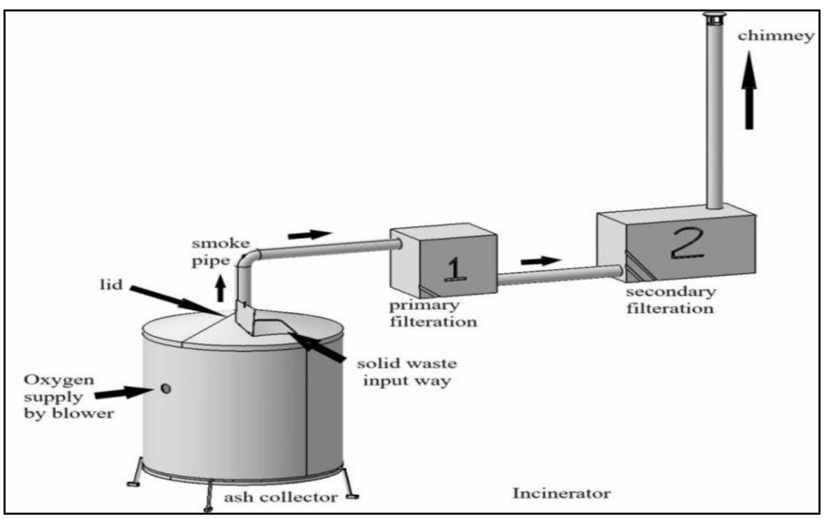

Fig. 5 Catia Design of the Incinerator

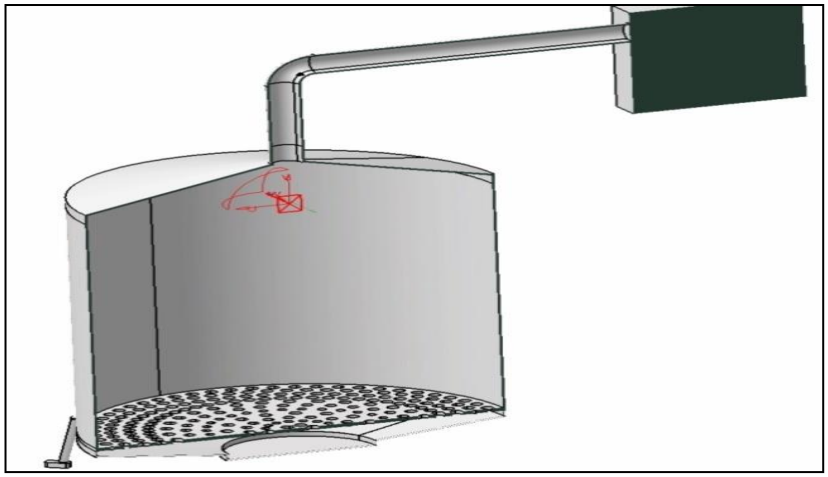

Fig. 6 Catia Design of the Half section of the Incinerator

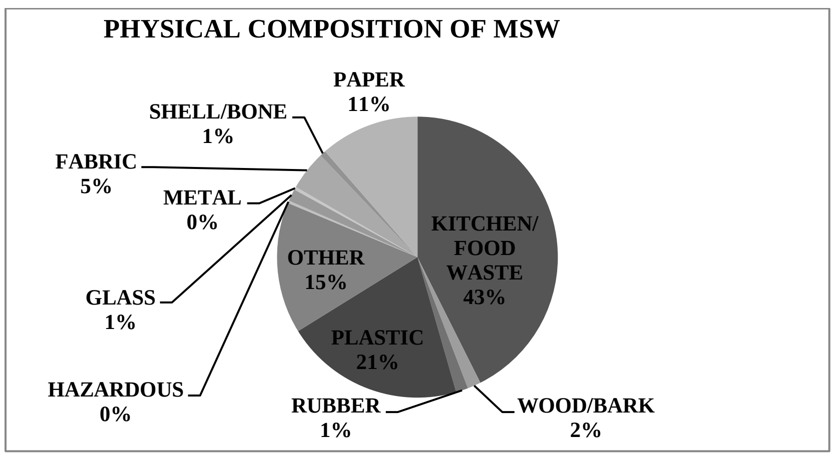

Fig. 7 Composition of MSW

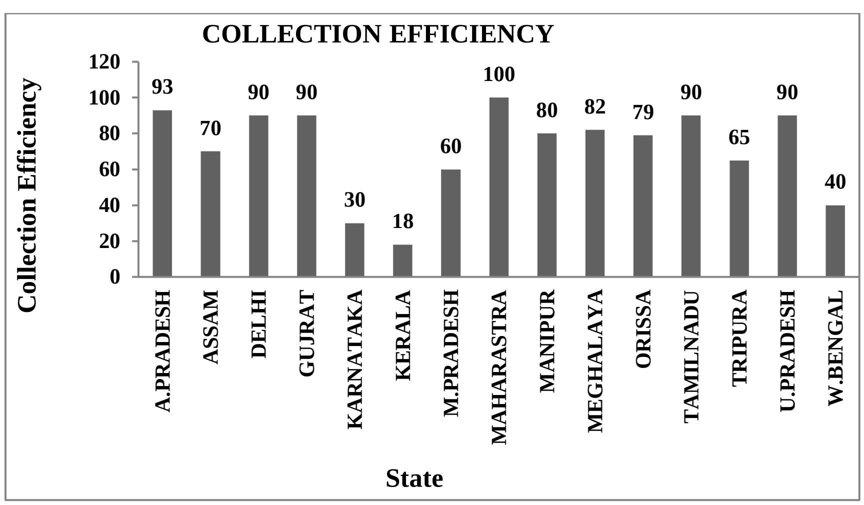

Fig. 8 Collection Efficiency of MSW

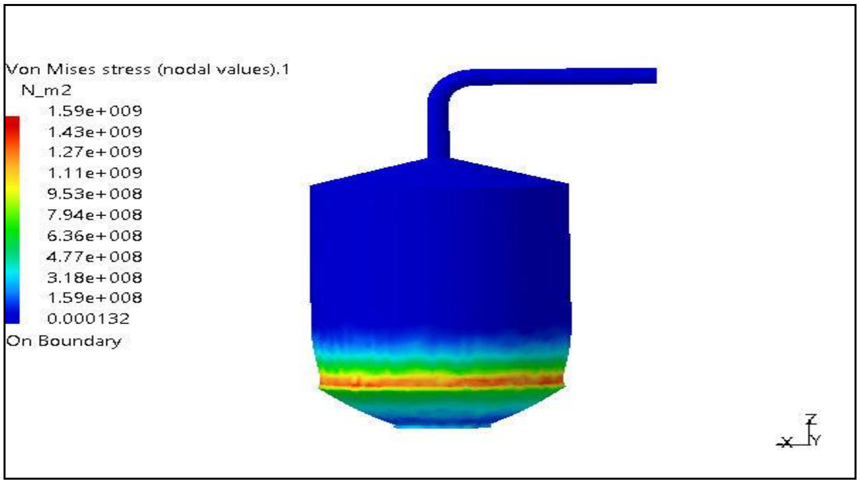

Fig. 9 Maximum von Mises stress of steel aermate alloy at 850^{0}C

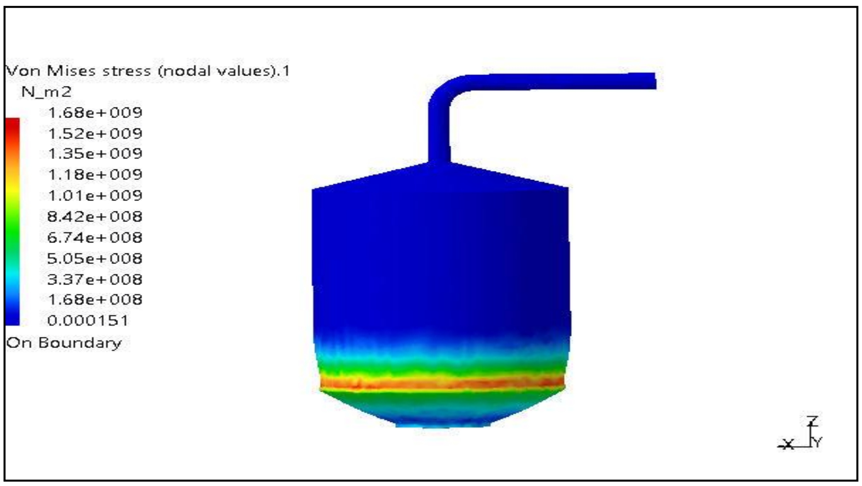

Fig. 10 Maximum von Mises stress of steel aermate alloy at 900^{0}C

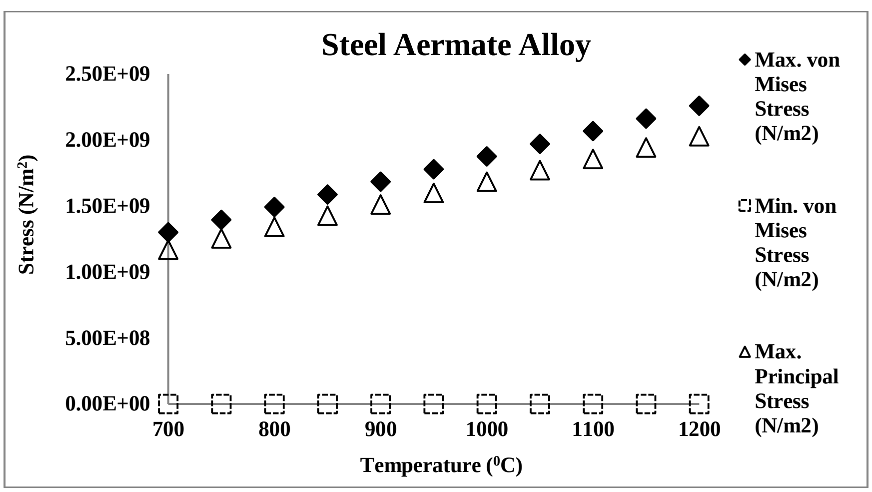

Fig. 11 Stress Analysis of Steel Aermate Alloy at different temperature

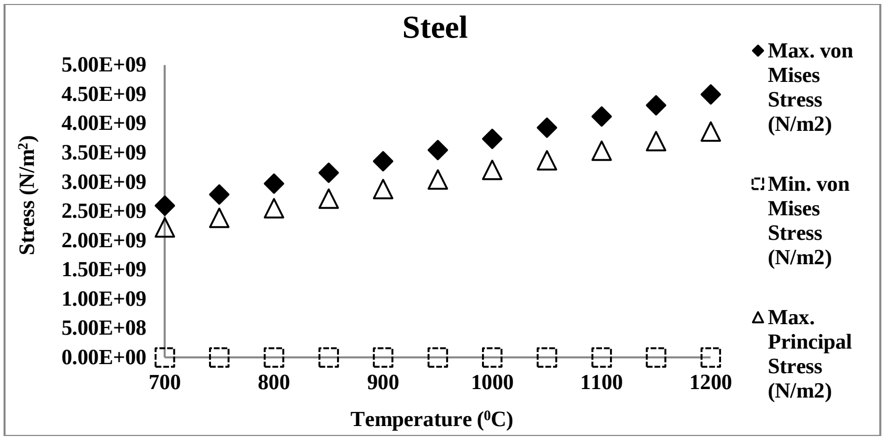

Fig. 12 Stress Analysis of Steel at different temperature

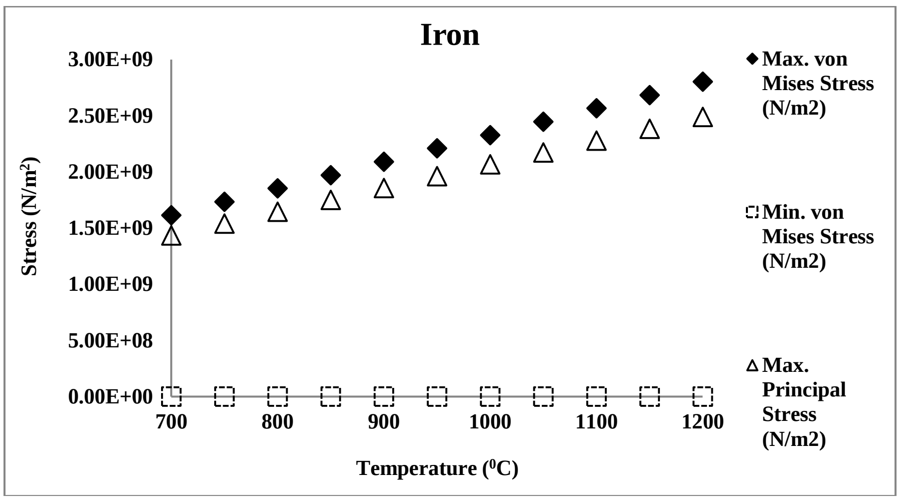

Fig. 13 Stress Analysis of Iron at different temperature

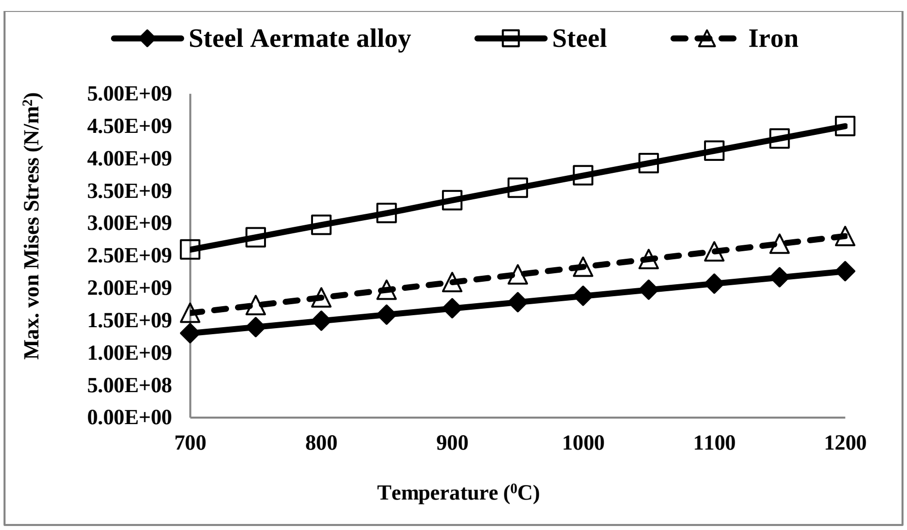

Fig. 14 Max. von Mises Stress Analysis of different materials at different temperature