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EFFECTIVE MANAGEMENT OF HOSPITAL AND MEDICAL WASTE IN RURAL AREAS OF PAKISTAN: A CASE STUDY

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ABSTRACT

The proper management and safe disposal of increasing amount of solid wastes has been recognized as a global problem of the recent age. Toxic and hazardous constituents present in the solid wastes, make this problem even more critical and challenging. Exposure of such solid waste, when not managed properly significantly effects the local environment and public health. For example, bio-hazardous wastes generated from hospital and other clinical settings possess heterogeneous constituents with potentially infectious properties imposing a significant threat to the public health as well as the natural environment. This becomes more curious in case of epidemic diseases treatment and cure procedures. There are several techniques used to treat the infectious wastes, however, adoption of either technique depends upon the type of material and available resources. Thermal treatment or incineration has been found as one of the common and efficient methods for toxic waste management in which waste materials are ignited and burnt under controlled conditions destroying the toxic constitutes of the hazardous materials. The present study has been taken up in order to study the toxic waste management with emphasis on hospital waste. The case of basic health unit has been taken in order to assess and quantify toxic waste potential and its management. The study has also come up with a proposed design of small-scale fixed bed incinerator for hospital waste.

***Keywords*:** Hospital waste, Public Health, Environment, Infection, Incineration

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1. INTRODUCTION

Solid waste is generated in different domestic, agricultural, institutional, commercial, and industrial activities. With the rapidly growing population, the amount of solid waste is also increasing significantly. Proper management and safe disposal of huge amount of solid wastes has been recognized as a global problem of the recent age. This becomes more crucial when solid waste materials contain hazardous and toxic constituents (Guerrero et al. 2013; Song and Li 2014; Ghinea et al. 2016). Protection of the environment and natural resources is extremely important for sustainability of agriculture, food and living styles. Exposure of solid waste, particularly, hazardous, and toxic wastes significantly effects the surrounding environment and the society. For example, solid wastes generated from biochemical applications and processes, i.e. bio-medical laboratories, hospital, and other clinical settings, have different constituents with potentially infectious agents which impose significant threat to the public health as well as the natural environment. Solid waste generated from such sources consists of contaminated culture and petri dishes, flasks, infectious agents, wastes from bacteria/viruses, attenuated vaccines, waste contaminated with excretions, paper towels, bench paper, anatomical specimens, animal carcasses and exposed body parts, empty specimen containers, bandages or dressing containing dry blood, clinical plastics, cardboards, packaging stuff etc. Such materials are readily reactive and toxic in nature to produce harmful effects to the living community, therefore, termed as bio-hazardous and toxic wastes. Such type of waste materials, are extremely important to manage and need proper and safe collection, handling and disposal protocol (Patil and Pokhrel 2005; Hossain et al. 2011; Soares et al. 2013).

Bio-hazardous and toxic waste produced from different biomedical research laboratories/workstations, clinics and hospitals significantly affect the society and environment in several ways. This results in bacterial and viral infection in the local environment. It becomes more curious in case of epidemic diseases treatment and cure

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procedures. A minor exposure of contaminated material can result in severe health problems. On the other hand, these materials, when disposed and discarded in the landfill sites, create severe environmental problems. Because of poor management of the landfill structures and accidental flows, the contaminants leach down to the groundwater and hence, pollute the natural resources. Similarly, the toxic contaminants can also flow during runoff and pollute the nearby canals and rivers. In uncovered landfills, evaporation of the fumes from such solid wastes also effects the air quality (Tsakona et al. 2007; Sawalem et al. 2009; Kumar and Samadder 2017). There is a dire need of the time to introduce efficient technologies for the management of toxic and hazardous wastes.

Commonly, such types of wastes are collected and treated before final disposal. There are several techniques used to treat the infectious wastes, i.e. autoclaving, gas sterilization, radiation and microwaves, thermal treatment and/or incineration. Autoclaving and sterilization are done by applying high pressured steam along with chemical reagents to disinfect the toxic materials produced from biomedical activities. However, this has been found as an expensive technique which required sophisticated apparatus. On the other hand, there are also the chances of contaminated toxic contents to be present after being sterilized. Similarly, application of radiation is also a very technical and risky method to disinfect the toxic wastes.

Thermal treatment or incineration has been found as one of the common and efficient method of toxic waste management in which waste materials are ignited and burnt under controlled conditions. As the combustion takes place at very high temperatures, the toxicity of the material is destroyed more effectively. Moreover, it also reduces the volume of the original waste up to 90% and hence comparatively less space is required for the disposal of the remaining residue (ash). The reduction of waste is immediate and quick as there is no need of long term residence times in the landfills and disposal sites (Gidarakos et al. 2009; Rajor et al. 2012; Rajan et al. 2018). Additionally, thermal energy is produced which may be used in the power generation, hence making it as a waste-to-energy technique. The energy produced as a result of the incineration process can be used for power production and hence costs of the running operations of the system can be met by itself. Emission levels can be controlled and avoided by designing the efficient combustion system. The resulting ash residue from the incineration process is most commonly non-putrescible and hence comparatively stable material. The energy produced as a result of the incineration process can be used for power production and hence costs of the running operations of the system can be met by itself. Emission levels can be controlled and avoided by designing the efficient combustion system. In this way, the hazardous solid waste can be management and treated on site without transporting it to some remote or distant area (Arshad et al. 2011; Windfeld and Brooks 2015; Baidya, et al. 2016). Olanrewaju and Fasinmirin (2019) reported that management of medical waste through incineration has been recognized as an appropriate technique. However, design of incinerator and its flue gas monitoring is very important for successful adoption of this technique. Basak et al. (2019) and Vavva et al. (2020) stated that incineration of hospital waste can be a best practice to manage and properly dispose toxic and hazardous hospital wastes. The knowledge of waste generated at the medical and hospital waste facilities is very important for proper handling and safe disposal of hazardous wastes, reported by Ali et al. (2020). Zolfagharpour et al. (2020) concluded that controlling temperature and waste residence time can help to reduce the secondary pollutant formation during incineration of medical waste.

However, it is important to note that incineration is a very complex process and it is very important to provide controlled conditions during the burning process. This can be achieved by burning the waste in a closed structure, i.e. incinerator or kiln where the supply of air and feedstock can be controlled to control the flame and resulting flue gases (Farid et al. 2017). Moreover, continues monitoring is also required.

The present study has been taken up to study the toxic waste management with particular emphasis on hospital waste. The case of basic health unit has been taken to assess and quantify toxic waste potential and its management. The study has also come up with a proposed design of small-scale fixed bed incinerator design for BHU facilities.

2. METHODOLOGY

2.1. Site Selection

The present study was planned to assess the hospital waste management of biomedical facilities with particular focus on rural health units. In order to provide clinical and medical health facilities to the remote and rural areas, several Basic Health Units (BHUs) and Rural Health Centres (RHCs) have been established by Punjab Health Facilities Management Company (PHFMC) under the umbrella of Primary and Secondary Health Care Department, Government of the Punjab. The PHFMC aims to improve the health care services in line with growing population of Punjab province. There are around 2500 BHUs and 318 RHCs in different rural vicinities of Punjab rendering services to the rural population at their doorstep (Primary and Secondary Healthcare Department 2020; PHFMC 2020). A number of people visit and are treated at these facilities; therefore, it is very important to assess the solid waste management practices at these centres.

Thus, in the present study, the case of Basic Health Unit (BHU) Dadra Bala, Sahiwal was taken to assess the hospital and medical waste management. This BHU is located at the Chak Dadra Bala, Sahiwal (30°41'10.7"N and 72°51'31.9"E) and covers 15 villages in its radius having a total population of approximately 26000.

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2.2. Basic Structure and Operational Capacity of BHU

The BHU is functional 24/7 with expert staff led by a Medical Officer with a team including Dispenser, LHVs, School Health and Nutrition Supervisor, Midwife, Outreach Staff and Supporting Staff. BHU Dadra Bala is a 2-Beds medical centre which deals with mostly outdoor patients and maternity emergency cases. According to an estimate, on an average 50 patients are facilitated per day at the BHU. It also depends upon the season, for example more patient visit in intense weather conditions due to illness and seasonal diseases. However, it has been observed that monthly outdoor deals with around 1300-1500 patients.

2.3. Existing Waste Management Practices at BHU

2.3.1. *Waste Generation and Segregation*: At the BHU, solid waste is generated and categorized into two broader forms, i.e. risk waste and none-risk waste. Risk waste is further classified into special or medical waste and infectious waste. Special or medical waste (hereafter medical waste) consists of waste which is generated during the diagnostic and treatment activities including used pharmaceutical materials, injections, tablets and drips, gloves, masks, tubes or glasses, broken thermometers, anaesthetic agents and radioactive waste from radiotherapy etc. Infectious includes the waste generated from pathologic laboratory activities and operation/surgery process including cultural dishes, wasted tissues, used blood samples, and wasted blood, vaccines, slides, pipets, body parts and contaminated bandages and cotton etc. On the other hand, non-risk waste also termed as general waste is the non-infectious waste which includes food waste, wasted packaging, paper, dust, cardboards etc.

2.3.2. *Collection of Solid Waste*: Protective mechanism is followed at the BHU to collect the solid waste. The solid waste is identified and is segregated at the source level. For this purpose, three coloured bins are placed at the BHU solid waste collection unit, i.e. red, yellow, and white (Fig. 1). Red bin is used for the collection of medical waste, infectious waste is collected in yellow bin while white bin is used to collect general waste. Each bin has a total capacity to contain and average 10kg of solid waste. As BHU is operated continuously (24 hours), solid waste generated from all three categories is collected and managed on daily basis in order to avoid infection, odour and other public health issues generated from the accumulation of the solid waste in the bins.

2.3.3. *Incineration and Disposal of Solid Waste*: Pit incineration method is used for the management/treatment of solid waste. For this purpose, a pit has been constructed in the vicinity of BHU site (away from clinical facility). The square shaped pit has three sections with 4’ x 4’ x 4’ (Fig. 2) namely section A, B and C.

Fig. 1: Waste segregation bins installed at Basic Health Unit.

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The bottom and walls of the pit sections are lined in order to avoid the leaching of solid waste from pit to the ground (Fig. 2). Section A is used to dispose the general waste directly on daily basis while section B is used for the placement of infectious waste (bloods etc.) while section C is used for the combustion of medical waste. Solid waste (medical waste) is incinerated daily and after burning of complete material, it is covered with soil. Similarly, general waste and infectious waste are also covered with daily cover, i.e. soil. This process is continued until the pit is filled completely. It was observed from the survey that it takes approximately three to four months for complete filling of pit sections. After the filling of pit, it is closed and covered with soil and vegetation, and a new pit is constructed for further management of solid waste.

Fig. 2: Pits for solid waste management.

2.4. Data Collection and Evaluation

In order to assess the hospital waste management practices at the selected BHU, a survey form was developed, and different attributes of the survey were interviewed from the staff and local people for example patients visits on daily and monthly basis, amount of waste generated per day, waste management tools and practices etc. Additional survey was conducted for the assessment of energy demand and requirement for BHU. The data was collected from September 2019 to March 2020. The collected data was evaluated, and future recommendations were made for the targeted problem.

3. RESULTS AND DISCUSSION

3.1. Quantity of Waste

Figs. 3 and 4 represent the solid waste generation of different categories at BHU. It can be observed that infectious waste has a major share in the total solid waste generation at the BHU facilities. This is due to the fact that a lot of medical accessories and clinical items are used in the emergency cases (particularly maternity case). It can be observed that infectious waste is produced at an average rate of 1.33kg/day and maximum of 5kg/day**.** The generation of this type of waste vary greatly depending upon the nature and the treatment of emergency case. On the other hand, medical waste is generated during the outdoor patient visits and hence the share is lower as compared to the infectious waste. Similarly, general waste is also produced with a less share than the infectious waste, however, its amount is quite similar to that of medical waste.

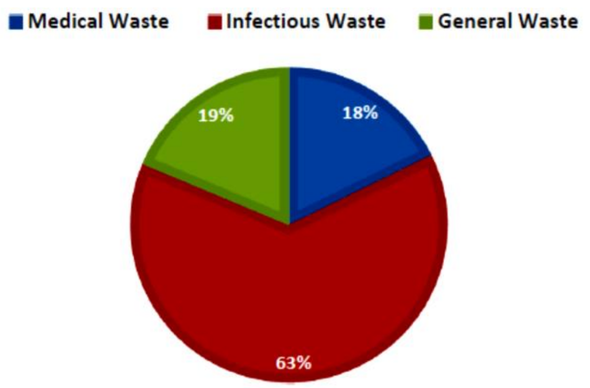

Fig. 3: Solid waste types at Basic Health Unit

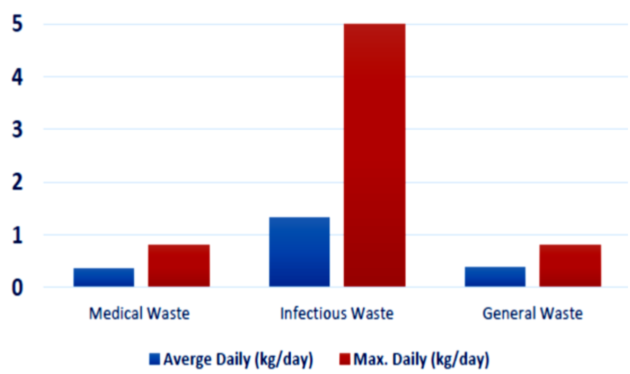

Fig. 4: Solid waste generation at Basic Health Unit (kg/day)

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3.2. Modification in Waste Collection Mechanism

It was observed that solid waste is collected in three different forms, i.e. medical waste, infectious waste, and general waste. However, it was resulted that infectious waste share is quite larger as compared to other wastes. Moreover, this waste is dumped into the pit section with soil daily cover as it contains different toxic materials like blood contaminated cotton/bandages, dead tissues, rotten blood etc. Although the bottom of the pit section is lined, yet it may cause severe environmental issues in case of infiltration of rainwater or surface run off. The water contaminated from the toxic reagents may leach down to the ground and pollute the ground water. Additionally, agricultural crops may be affected in the vicinity as water is pulled by the root zone by capillary action. This is also important in the present case as it has a larger portion in the total collected waste. This implies that a minor reduction in this kind of waste may contribute in the higher efficiency of the overall waste management system at medical facilities like BHU. Based on these facts, a small alteration in the waste collection system have been proposed (Fig. 5).

In the proposed modification in the collection mechanism of infectious waste, the portion of infectious waste which can be incinerated (consisting of paper, puss socked cotton, blood socked bandages etc.) can be collected separately while the biodegradable portion of infectious waste (consisting of placenta, vomitus, sputum, puss, blood clots and body tissues and parts). In this way, the overall burden will be reduced from the pit sections. Burning of infectious (incinerable) will help to reduce the overall waste volumes and its toxicity. Additionally, burying only biodegradable portion of waste will help to minimize the environmental impacts.

Hence, the additional setting can be implemented in the hospital waste collection and segregation. For this purpose, new bins should be installed along with the existing waste collection bins. Fig. 5 shows the new setting of bins to be implemented for hospital waste collection and segregation at the BHU. The medical waste (as being already incinerable can be collected in the red labelled bin while infectious waste now has been divided into to sections, i.e. yellow and green coated bins, yellow for the incinerable waste and green for the biodegradable portion of the infectious waste.

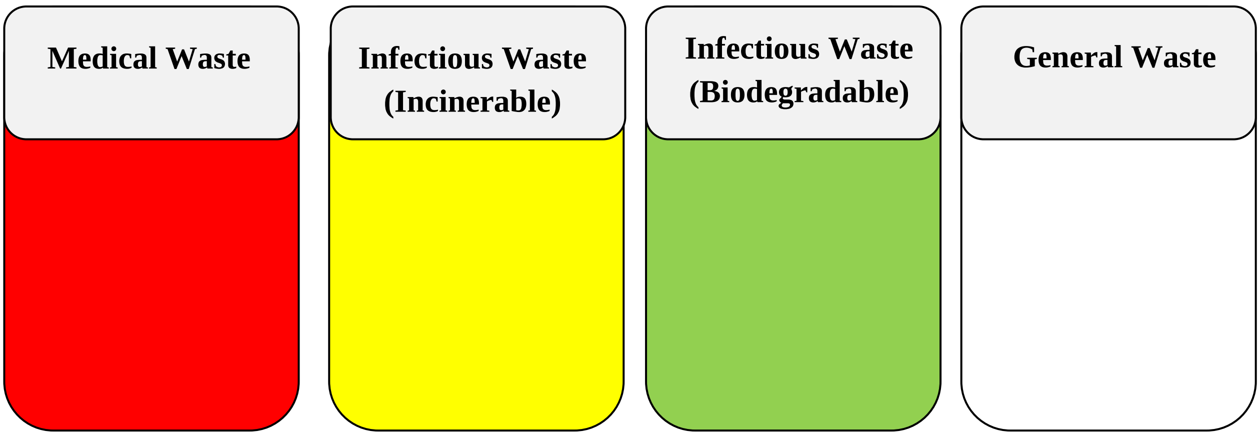

Fig. 5: Modified collection and segregation mechanism at Basic Health Unit.

3.3. Proposed Technology for Waste Incineration

Although considerable efforts are being made for the handling and incineration of hospital waste at the BHU yet some discrepancies were found. For example, pit incineration method, being followed for the incineration of medical waste, is an old technique which have certain drawbacks. The most common disadvantage of this method is uncontrolled air supply due to open firing process. This may result in incomplete combustion and environmental pollution, i.e. production of VOCs, unburnt gaseous products, dioxins etc. Such pollutants are based on air-fuel mixing ratios during the combustion process. Such problems can be avoided by improving the waste firing systems (Kimmerly and Rangwala 2020). Moreover, there is no segregation between the ash and combustible products (which remained unburnt due to insufficient supply of air) in pit incineration method. Burning the solid waste in a closed container helps to address such issues. Under this concept, the solid waste is placed inside a closed drum or a cylinder where the burning takes place under controlled air supply and temperature. In this way, the exposure to rapid releasing VOCs can be avoided efficiently and production of gaseous species can also be controlled.

In the present study, a small-scale fixed bed incinerator has been proposed for the combustion of hospital and laboratory wastes produced at the BHU. Fig. 6 represents the different parts of the propose incinerator. The medical waste and incinerable infectious waste are placed at the sliding stray of the waste inlet gate. After loading the complete batch, the tray is pushed inside to the burning chamber. The lower nozzle mounted on the left side of the

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burning chamber is used for the air supply while upper nozzle is used for initial ignition and the intervals when inside temperature is not feasible for waste burning. The batch of solid waste placed at the sieved grate is burnt under controlled conditions, i.e. controlled air supply as well as inside temperature which are main factors for pollutant formation if not controlled properly. The combustion gases i.e. smoke after burning of the solid waste leave the burning chamber via stack which is mounted at a certain height. The purpose of this heighted pipe is to prevent the operator and local workers from the smoke and gases produced by burning process. The unburnt material, i.e. ash produced as result of the combustion process is dropped down in the ash collector chamber from where ash can be removed periodically and disposed at safe point (Fig. 6).

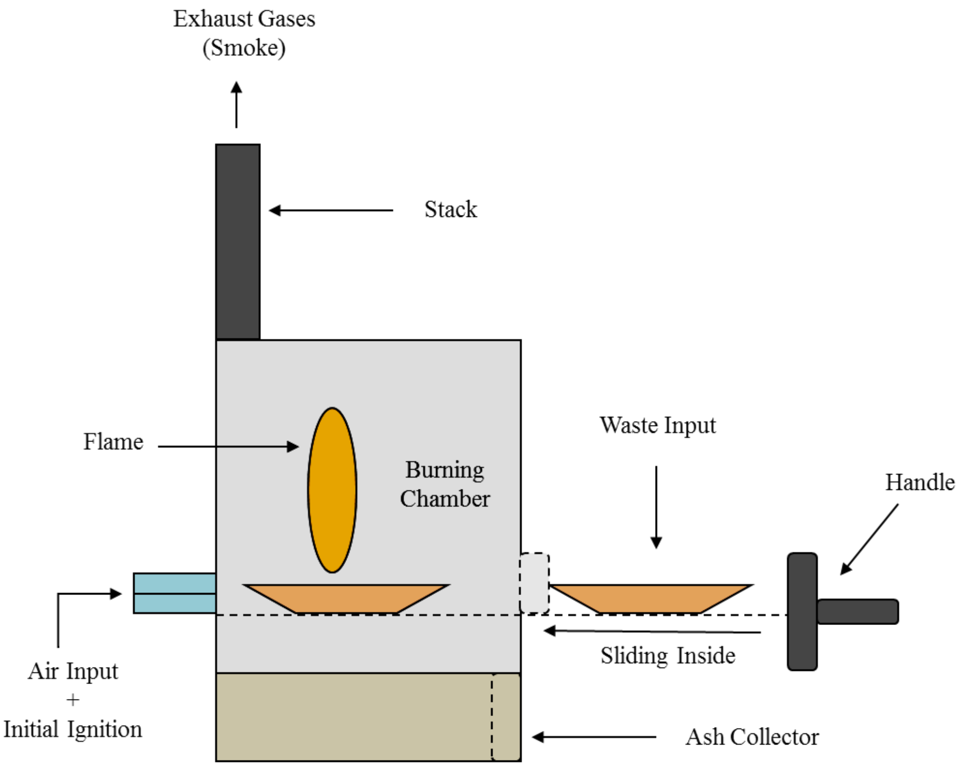

Fig. 6: Schematic diagram of hospital waste incinerator.

The incinerator was designed based on the fundamental principles and its possible operating capacity. It was resulted from the survey that during peak operating hours around 8-10kg of waste is also produced during certain months in year. Considering the increasing population and future access to BHU, the incinerator was designed for a capacity of 20kg/day. This also enables the incineration of hospital waste as one batch per day and eliminates the need to operate the incinerator on full day basis. As described in the previous section, the waste produced at the medical facilities is heterogeneous and consists of materials with different masses and volumes. According to an estimate, the density of solid waste generated at the hospital varies from 80-110kg/m^3. The present work, the density of waste was taken as 100kg/m^3. Based in the waste feed rate and its density, the volume of burning chamber for this waste was determined using Eq. 1 (Wajs et al. 2019).

$$m_w = \rho V_{bc} \qquad \text{(Eq. 1)}$$

Where, m_w is the mass of waste which is supposed to feed in during one batch (kg), ρ is the density of hospital waste (kg/m^3) and V_{bc} is the volume of the burning chamber (m^3).

Under the operating capacity described above, the volume of the burning chamber was estimated to be 0.2m^3 (7.06ft^3). However, it is also important that an enough space should be provided for re-circulation of combustible gases for complete burning, therefore, the upper part of the burning chamber was extended around 0.46m. Therefore, the complete dimensions of the burning chamber were as 1.26m × 0.5m × 0.5m. The stack i.e. exhaust pipe for the discharge of exhaust gases was installed at the height of 0.92m from the top surface of the burning chamber. An ash collecting chamber was formed below the grate at a distance of 0.46m as shown in Fig. 7 and 8.

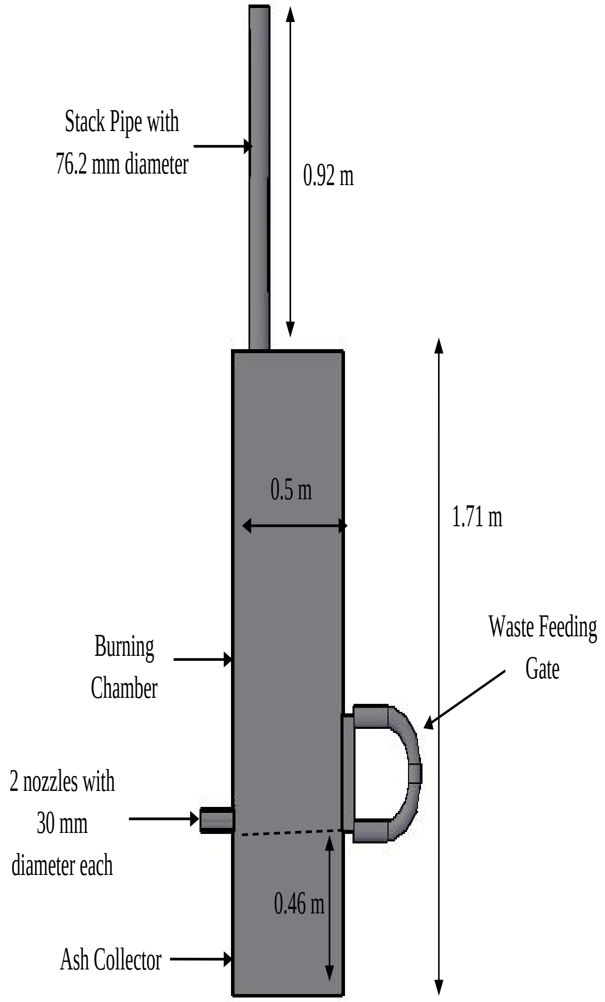

Fig. 7: 2-D view and dimensions of designed fixed bed hospital waste incinerator.

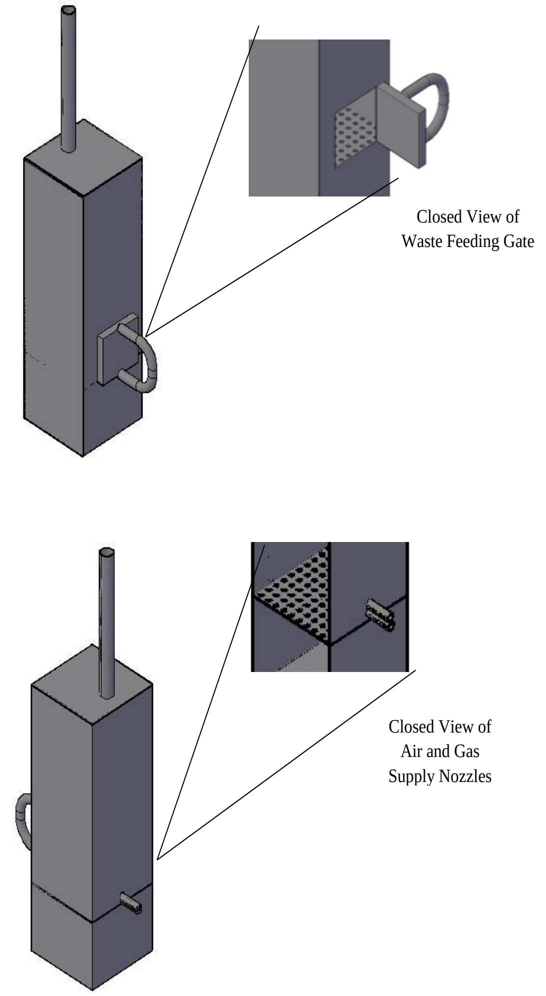

Fig. 8: 3-D view of fixed bed hospital waste incinerator.

Air supply and residence time of the combustible matter is an important phenomenon while determining of operating parameters of any combustion apparatus as it plays an important role in the formation of combustion by products. For a best practice, the temperature of the burning chamber must exceed 850^o with a residence time of at least 2s after the last supply of air in a combustion apparatus (Farid et al. 2017). However, the temperature of combustion gases should be as high as 1100^{o}C (with residence time of 2s) in case of infectious/medical waste. As described earlier that the energy required to maintain this temperature inside the combustion chamber can be supplied through a supplementary fuel (commonly natural gas). Moreover, it has also been reported that the heat required to be supplied to the burning chamber in order to maintain this temperature, i.e. 1100^{o}C depends upon heat consumed by dry combustion products, water vapours and ash. The heat generated as a result of combustion can be determined by the fuel input and the net heating value of the combustible material using Eq. 2 (Gogoi and Baruah 2016; Farid et al. 2017; Wajs et al. 2019).

$$Q_c = m_w . HV_w \qquad \text{(Eq. 2)}$$

Where, Q_c is the heat generated by combustion of solid waste (kJ/s), m_w is the mass flow rate of solid fuel, i.e. solid waste in this case (kg/s) and HV_w is the heating value of the solid fuel (kJ/kg).

Furthermore, a heat loss due to radiation (commonly 5% of the total heat produced as result of combustion process Q_c) should also be considered while determining the burner power requirements. The required energy of the supplementary fuel can be assessed by using Eq. 3 (Wajs et al. 2019).

$$Q_r = Q_c - Q_L \quad \text{(Eq. 3)}$$

Where, Q_r is the heat required to sustain the required temperature, i.e. 1100ºC (kJ/s), Q_c is the same as describe in equation (2) and Q_L is the heat loss (kJ/s) due to radiation plus the heat required to raise the temperature of dry combustion gases, ash and water vapours as shown in Eq. 4.

$$Q_L = Q_{rd} + Q_d + Q_a + Q_{water} \quad \text{(Eq. 4)}$$

Where, Q_{rd} is the radiant heat loss (kJ/s) and Q_d, Q_a and Q_{water} are the heat rates (kJ/s) required by the dry combustion products, ash and water vapours, respectively.

It should be noted that radiant heat loss depends on the total heat produced in the burning chamber while all other parameters depends upon mass flow rate (kg/s) of combustion products (m_d) , ash produced (m_a) and water vapours (m_w), specific heat capacity (kJ/kg.ºC) of combustion products (C_{pd}) , ash produced (C_{pa}) and water vapours (C_{pw}), latent heat of vaporization (kJ/kg.ºC) of water (q_L) and the temperature gradient (ΔT), i.e. the difference between required temperature, i.e. 1100ºC and temperature inside the burning chamber (ºC).
Hence, the Eq. 4 can be restructured as Eq. 5.

$$Q_L = Q_{rd} + (m_d C_{pd} \Delta T) + (m_a C_{pa} \Delta T) + (m_w C_{pw} \Delta T + m_w . q_L) \quad \text{(Eq. 5)}$$

The power of the supplementary burner can be determined by using Eq. 3. Moreover, different combustion products are produced for different fuel types, loading rates as well as the air supply. Once, the elemental compositions of the solid waste are known, the average specific heat capacity of the predicted combustion gases can be determined through mass and energy balances. Furthermore, the current study was focussed on the proposed methodology for effective hospital waste management at the rural medical facilities. Further investigation can be conducted in order to assess the combustion process and efficiency of the proposed design. Moreover, different loading rates and air supply can also be examined for the optimization of the operating parameters.

Conclusion: Solid waste produced at the medical health facilities is extremely toxic and hazardous in nature therefore, safe handling, treatment and disposal is very important. Three kinds of solid waste produced at the Basic Health Units (BHUs), i.e. medical waste, infectious waste, and general waste in which the portion of infectious waste was found to be large as compared to the other type of waste. However, the rate of waste production varies greatly with the patient visits in peak working days. It was noted that infectious waste also consists of some of the burnable materials. Hence a modification in the collection mechanism was proposed in such a way that combustible material can be separated from the infectious waste to lower the burden on direct disposal. In this way, less space is required to disposal the solid wastes as combustion of solid waste reduces the volume significantly. Pit incineration method is an old technique for the disposal of hospital waste. Incineration of the hospital wastes in a controlled container can be a sustainable solution in this regard. A design of fixed bed hospital waste incinerator was proposed for a capacity of 20kg/batch. Because of hazardous nature of the waste, it is necessary to maintain the temperature of burning chamber which can be accomplished by attaching a supplementary fuel nozzle with temperature monitoring sensors. Further investigation can be conducted to check and analyse the combustion process with different type of waste materials and inlet air and gas temperature.

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