DESIGN AND ANALYSIS OF AN EMISSION CONTROL SYSTEM FOR A PORTABLE PLASMA INCINERATOR FOR MEDICAL WASTE TREATMENT

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Abstract

The Medical Waste Tracking Act of 1988 defines medical waste as "any solid waste that is generated in the diagnosis, treatment, or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biologicals". Over 90% of potentially infectious medical waste is incinerated according to Environmental Protection Agency (EPA). Plasma incinerators provide a relatively safe and easy way to dispose medical wastes[1-3]. A small-scale portable plasma incinerator can provide a feasible, cost-effective and environmental-friendly solution to problems such as high cost of waste transportation, storage, and treatment and improper handling during transportation and storage resulting in serious health and pollution risks for people and communities. Medical incinerators generally burn biological waste, needles, plastic gloves, and other items[4]. The resulting emissions are a particularly toxic mix of heavy metals, acid gases, and other contaminants[5]. This paper describes design of an emission control system to be used in a portable plasma incinerator for treating medical wastes. Emissions from surrogate medical wastes were computed using an equilibrium calculator, GASEQ. A wide range of pressures and temperatures were considered and resulting emissions were used as baseline emission data for the design of emission control system.

Keywords: Medical waste; Incineration; Plasma incinerator; Emissions; Emission control systems.

1. Introduction

Medical waste has become a major environmental problem in terms of pollution and public safety. Hospitals, dental practices, physicians, surgeries and veterinarian practices produce daily a series of infectious and hazardous materials[6]. However, several terms like "Hospital waste", "Medical waste", "regulated medical waste", and "infectious waste" remain poorly defined. The diversity of interest among persons, groups and agencies involved in the medical waste issue, and often these differences are not surprising. The collaboration of Congress and EPA adopted a regulatory agency Medical Waste Tracking Act(MWTA-1988) that dictates the definitions for each of the above terms, by their requirement of special handling and treatment. "Hospital waste" refers to all waste, biological and non-biological, that is discarded and not intended for further use. "Medical waste" refers to materials generated as a result of patient diagnosis, treatment, or immunization of human beings or animals. "Infectious waste" refers to that portion of medical waste that could transmit an infectious disease[7]. In MWTA-1988, the term "regulated medical waste" was used rather than "infectious waste". Here, "Medical waste" is generally defined as "any solid waste that is generated in the treatment, diagnosis or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biologicals"[8]. According to the US-MWTA, medical waste (i.e., regulated medical waste) can be further classified into seven categories, including cultures and stocks, pathological wastes, human blood and blood products, sharps, animal wastes, isolation wastes, and unused sharps.

According to the EPA, the documents acknowledge that much of the medical waste that washed ashore in the summer of 1988 was syringe-related (65%) and came from home healthcare and illegal intravenous drug use[9]. Chemical analysis of a few syringes collected during the EPA Harbor Studies Program has identified insulin and cocaine in 60%[10]. Additionally, over 90% of potential infectious medical waste was incinerated.

After examining the designation of waste as infectious by the Centers for Disease Control (CDC) and the EPA guidelines, one recognizes agreement of five types of waste, i.e., microbiological, pathological, animal, blood, and sharps. In the MWTA, the EPA modified its position on "communicable disease isolation waste" by including only certain "highly" communicable disease waste such as Class 4 etiologic agents as regulated medical waste.

2. Incineration Process

Incineration is the most widely used treatment of medical waste. Incineration of medical waste has many advantages, because the infectious waste is burned, resulting in the reduction of waste volume, savings in landfill costs and, at the same time, production of energy. The process has been found in this regard to reduce the volume of medical waste and destroying the pathogens and hazardous organic matters. However, the incineration of medical waste is known to be associated with the emission of some unwanted pollutants and hence, might limit the use of the technology.

Infectious medical waste is often burned in incinerators, normally of three types: 'multiple chamber', 'controlled-air' and 'rotary kiln' which are either located on-site in hospitals or at municipal waste facilities that specialize in handling medical waste[11].

In 1992, Walker and Cooper intensively investigated the emissions of traditional pollutants (such as carbon monoxide, nitrogen oxides, sulfur oxides, particulate matters, acid gas, trace metal elements, and volatile organic carbons) and dioxin/furan from medical waste incinerators (MWIs). They found wide variations in various emission factors for both controlled and uncontrolled MWIs[12]. However, it should be noted that the emission of polycyclic aromatic hydrocarbons (PAHs) are main culprit for the production of toxic substances. As a result, new stringent emission regulations make medical waste incineration very costly.

The disadvantage is that incineration may emit trace amounts of unwanted pollutants such as the polychlorinated dioxins and furans (PCDD and PCDF) and metal particulates if incinerators are not well designed and operated. In particular, emissions from on-site hospital waste incinerators require special attention, due primarily to the typical hospital's proximity to cities. According to the American Health Association in 1983, about 70% of medical waste was incinerated onsite, 15% autoclaved, and 15% treated offsite[13,14].

3. Plasma incineration

Plasma, the fourth-state-of-matter, formed by removing the bound electrons from atoms, is an electrically conducting fluid consisting of charged and neutral particles. The charged particles have high kinetic energies. The presence of charged and the ionized particles render the plasma environment highly reactive, which can catalyze homogeneous and heterogeneous chemical reactions. In plasma incineration, the most likely compounds that form from carbonaceous matter are methane, carbon monoxide, hydrogen, carbon dioxide and water molecules.

Plasma incineration uses extremely high temperatures of plasma-arc in an oxygen starved environment to completely decompose waste material into simple molecules. Hot plasmas are appropriate for treatment of medical waste and can also be employed for destruction of toxic molecules by thermal decomposition. Unlike incinerators, segregation of chlorinated waste is not essential in this process. The reduction in volume of organic matter is more than 99% after process. The quantity of dioxins and furans is much below the accepted emission standards and it does not require segregation of hazardous waste. In addition, the pathogens are completely killed and there is a possibility to recover energy.

The workhouse of plasma-based waste destruction technology is the plasma torch. Plasma torches are electrical discharge plasma sources with the plasma being extracted as a jet through an opening in the electrode and out of the confines of the cathode-anode space. The inherent thermal and electromagnetic instabilities of the arc column are stabilized by force gas flow along the current path or by interaction with a guiding wall or by external magnetic fields. DC, rf and microwave power sources can be used to produce the arc.

4. Portable Plasma incinerator

In this paper, a proto-type plasma incinerator with the volume of 3ft*3ft*3ft chamber size is estimated. The portable one can be used in small dispensaries, doctor's room, small nursing homes where daily medical waste disposal is made in batch size. The general use of this portable plasma incinerator is to incinerate the medical wastes like medical gloves, needles, blood vials, surgical wraps or bands, syringes, and other infectious medical wastes.

The portable plasma incinerator can handle the medical waste of 120 kg/day in batch size. As shown in fig.1, the Pro-E model of plasma chamber in four different views consists of single-torch setup. The torch is filled with argon gas and is generated from the cathode. The working gas argon is set steadily with 15 slpm from the nozzle electrode cathode. The maximum DC arc current to be supplied is 100 A. The total arc length will be 3 cm to 5 cm. The close isometric view of the plasma chamber is shown in fig.2. The 90^0-elbow is made to allow the passage of electrical wiring for spark plug (torch) inserted. The waste is placed at the bottom of the torch and is passed to the secondary chamber where it will be water-quenched, converting it into dross.

The water-quench role is to cool the combustion gases quickly to 75^0C so as to minimize any production of furans, dioxins, or other organic compounds. The quench nozzle provides 2l/min of water flow and it turns controls the gas temperature that is exiting. The shock like cooling avoids the formation of aforementioned compounds from elementary molecules in the synthesis gas due to the de-novo synthesis back reactions[15].

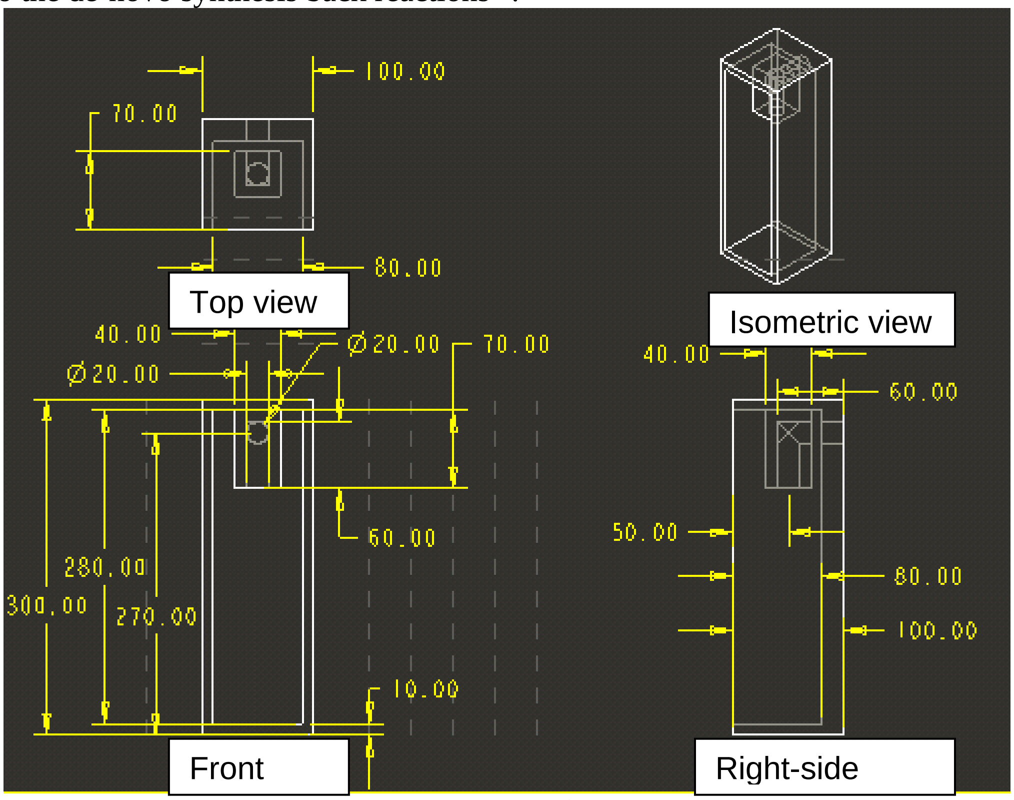

Fig. 1., The Pro-E model of plasma chamber.

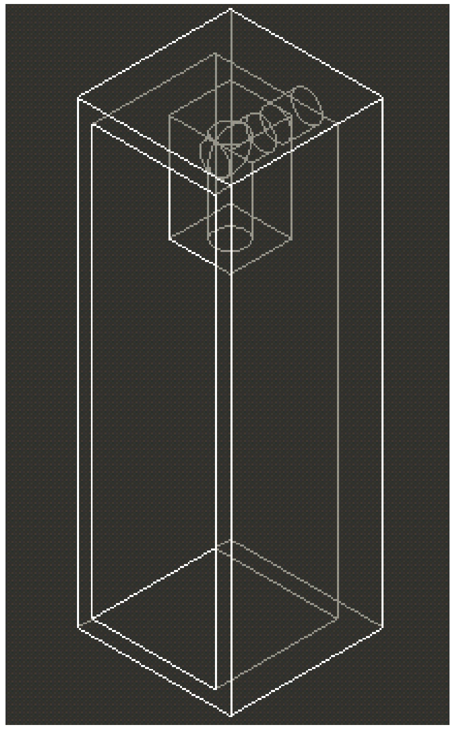

Fig.2., The close isometric view of the plasma chamber.

5. Emission considerations

The plasma temperature at the cathode is at the range of 10000^0C, and the medical waste during combustion is different temperature ranges in the plasma chamber, as shown in fig.3. The emission calculations are done only at the temperature of +/- 1000^0C after the combustion took place in the plasma chamber. The gases formed were taken as the products and the waste as the reactants into the input of the GASEQ software. The gases after combustion result in the formation of CO_2 and H_2O along with other products. The hot solid waste at 2230^0C is leaving to the secondary chamber. The water-quench process is preferred to avoid the formation of dioxins and furans. The fore mentioned products are formed in the presence of halogenated organic materials when secondary chamber is below 500^0C and residence time is less than 2 seconds.

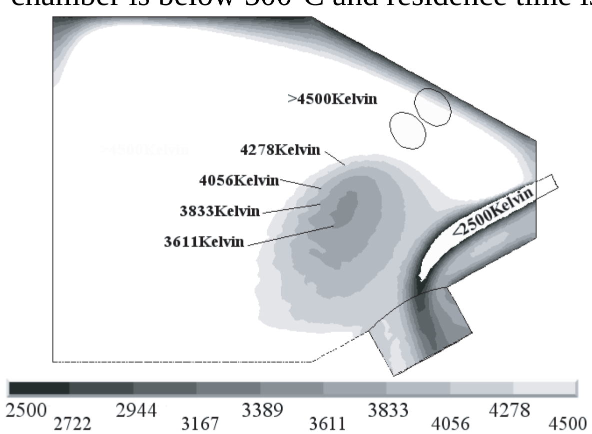

Fig.3.The combustion temperatures of plasma chamber using CFD tools.

The maximum operating temperature for the formed products is taken as 5000^0C in the input. Another important aspect taken into consideration were the materials used in general at the dispensaries, doctor's room, and other nursing homes. In general, the medical gloves used are made of neoprene $[(C_4H_5Cl)_n]$, vinyl $[(C_2H_3)_n]$ compounds. The needles and syringes are made of low density polyethylene, with addition of stainless steel in needles. While, polypropylene $[(C_3H_6)_n]$ in blood vials and styrene-butadiene (which are aromatic in nature) in case of wraps/bands[16].

According to the U.S. EPA, the hospital/medical/infectious waste incinerators (HMIWIs) emit the air emissions with regarding to the above mentioned medical wastes. The nine air pollutants are hydrogen chloride (HCl), carbon monoxide (CO), lead (Pb), cadmium (Cd), mercury (Hg), particulate matter (PM), dioxins/furans (PCDD/Fs), nitrogen oxides (NO_X), and sulfur dioxide (SO_2)[17].

6. Emission control systems

According to EPA and under sections 111 and 129 of Clean Air Act (CAA) for the above discussed emissions by HMIWI, the three main emission control systems are suggested for the portable plasma incinerator upon the base-line data values obtained from GASEQ software. The emission systems are discussed as below:

6.1. Dry Scrubbers

A dry scrubber utilizes absorption and adsorption for the removal of acid gases, primarily hydrogen chloride, sulfur dioxide and hydrogen fluoride. The scrubbers can be grouped into three major categories: (1) spray dryer absorbers (SDAs); (2) dry injection adsorption systems; and (3) combination spray dryer and dry injection systems. The main differences between the various systems are the physical form of the alkaline reagent and the design of the vessel used for the contacting the acid gas-laden stream.

6.2. Wet Scrubbers

A wet scrubber is a device which uses a liquid to clean a gas stream. The pollutants controlled by wet scrubbers include particulate matter and the acid gases (HCl and SO_2). The device uses a variety of methods to wet the contaminant particles and then impinge the wetted and un-wetted particles on collecting surfaces followed by their removal from the surfaces by a flush with a liquid. It can handle hot gases containing sticky particulates and droplets. Scrubbers, which remove gases by absorption, remove particulate larger than 0.5 µm in size. Smaller particles require much higher pressure drops. Scrubbers can reportedly be effective for particles less than 0.1µm if pressure drops of 40-50 in. of water are utilized. The types of wet scrubbers include mechanical scrubber, packed bed tower, spray chamber, venturi scrubber, and wet filter[18].

6.3. Electro-static Precipitator (ESP)

Electro-static Precipitators (ESPs) are used to remove particulate matter from flue gas streams. Particulate matter is first charged with electricity before it can be collected in an ESP. Once the particles or liquid aerosols that makeup the particulate matter are charged, they move toward an oppositely charged surface because of electrostatic attraction (opposite charges attract each other, the similar charges repel each other). The collected particles are removed by rapping or washing the collecting surface. This charging, collecting, and removal process is commonly referred to as precipitation. ESPs can be classified according to a number of design features. These features include the method of charging (single-stage or two-stage), the method of particle removal from collection surfaces (wet or dry), the temperature of operation (cold-side or hot-side), and the structural design and operation of the discharge electrodes (tubular or plate)[18].

6.4. Comparison of three emission systems

The following table shows the comparison of above suggested three emission systems:

Parameter/Components	SDA	Venturi	Packed Bed	Dry ESP
Particulate Removal	Poor to Fair	Good	Poor	Excellent
Heavy Metal Removal	Excellent	Good	Poor	Good
Acid Gas Removal	Good to excellent	Good	Excellent	Poor
Residue	Fly ash	Scrub liquor	Scrub liquor	Fly ash
Auxiliary Equipment	Bag house ash	Demister	Demister	Ash handling
Needed	Handling	Liquid Storage and Treatment	Liquid Storage and Treatment	-
Turndown	3:1	2:1	5:1	5:1
Plume Suppression	Easy	Difficult	Difficult	Easy
Pressure Drop	Low	High	Moderate	Low
Capital Cost	Moderate	Low	Low	High

Table.1.

7. Results and plots

The GASEQ Software is so helpful in the regard of emission calculations. It calculates the chemical equilibrium of combustion gases by choosing the type of calculation we wish to perform. In the following results, the equilibrium temperature with constant volume as the primary condition was used.

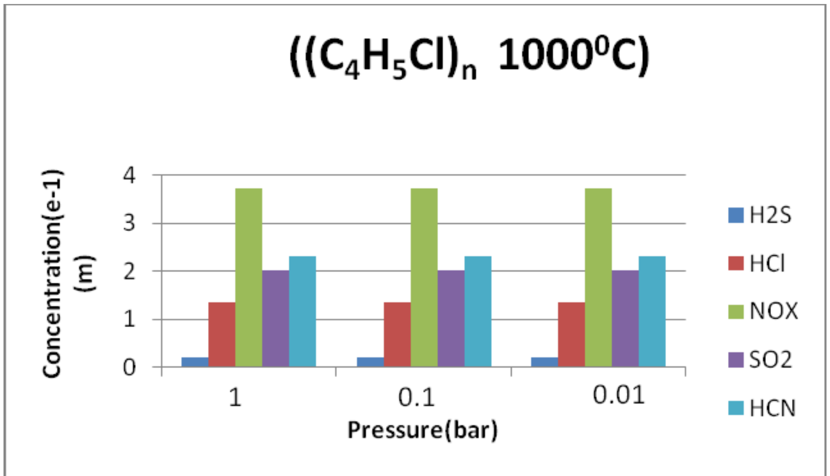

Fig.4(a), Results for Poly-neoprene(at 1000^0C)

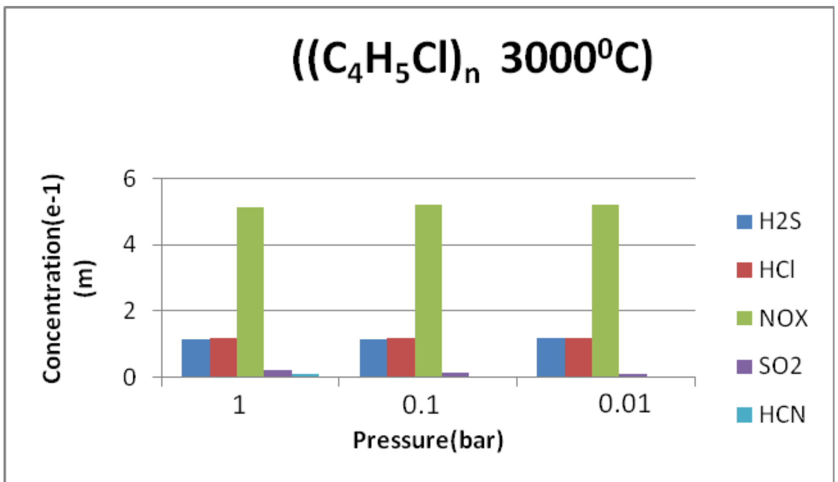

Fig.4(b), Results for Poly-neoprene(at 3000^0C)

The input is given by entering the species in the reactants list and the product to be obtained in the product's list. We can alter the amount of reactant as required by clicking on the species. The values of the temperature and the pressure can be changed in the properties box at the reactants column. Atlast, by clicking the calculate button one can get the results of the equilibrium concentrations of the product species in the products box.

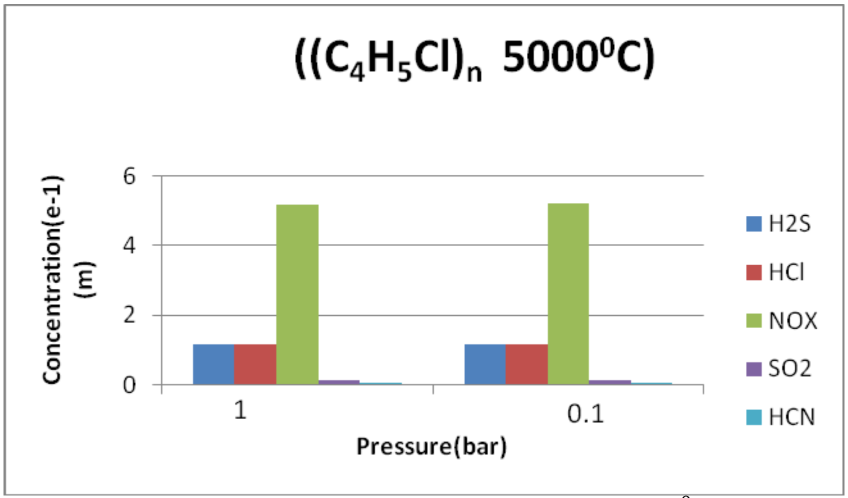

Fig.4(c), Results for Poly-neoprene(at 5000^0C)

From fig.4 (a-c), the graphs are plotted between pressure (in bar) and concentration (in moles) of the emissions. The waste in this regard is neoprene [$(C_4H_5Cl)_n$] used in preparation of surgical gloves. It is entered as the reactant in the input list of the GASEQ software. The products obtained are in high concentration of nitrogen oxide (NO_X) followed by Hydrogen chloride (HCl), as shown in plots, while H_2S concentration also increases along with temperature.

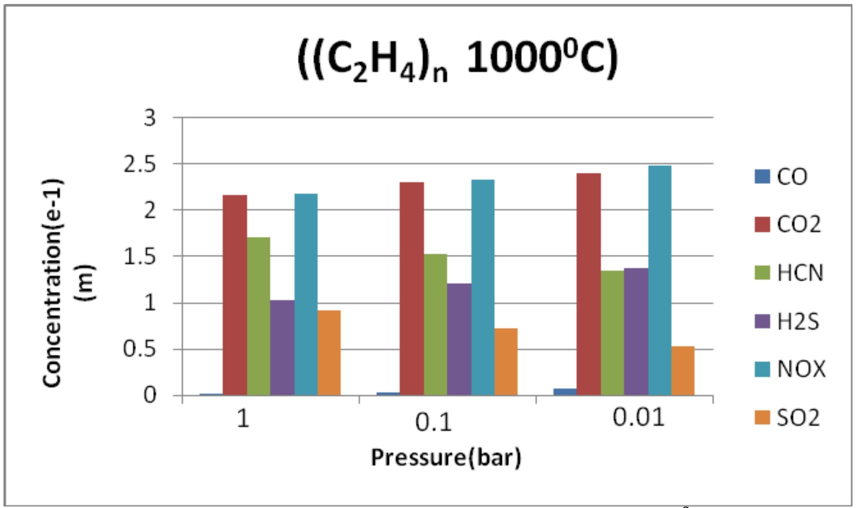

Fig.5(a), Results for Poly-ethylene(at 1000^0C)

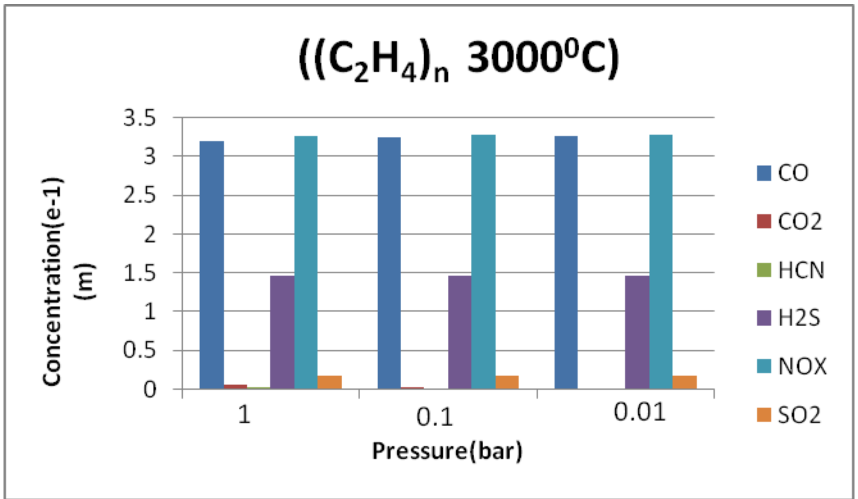

Fig.5(b), Results for Poly-ethylene (at 3000^0C)

Polyethylene [$(C_2H_4)_n$] is another important compound found in medical waste products like needles and syringes. The results of the above mentioned reactant, using GASEQ software, are shown from fig.5(a-c). It can be inferred from the above results that the emissions of CO and NO_X are increasing with temperature, while H_2S is constant and other emissions get lower in levels.

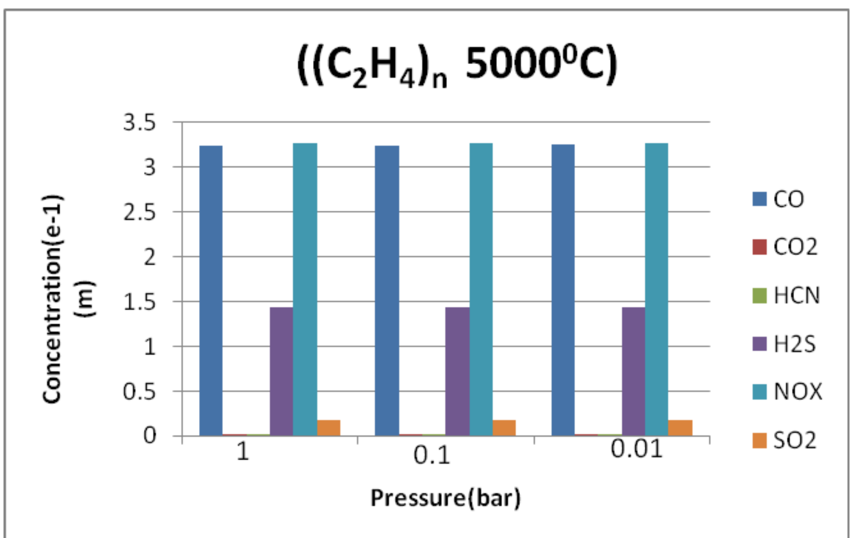

Fig.5(c), Results for Poly-ethylene (at 5000^0C)

The vinyl compound [$(C_2H_3)_n$] is used for the preparation of plastic or transparent gloves. From fig. 6(a-c), the results of vinyl compound is shown. With the increase in temperature, here the concentrations of CO and NO_X remained at higher levels, H_2S and CO_2 were reduced, CS and SO_2 started increasing.

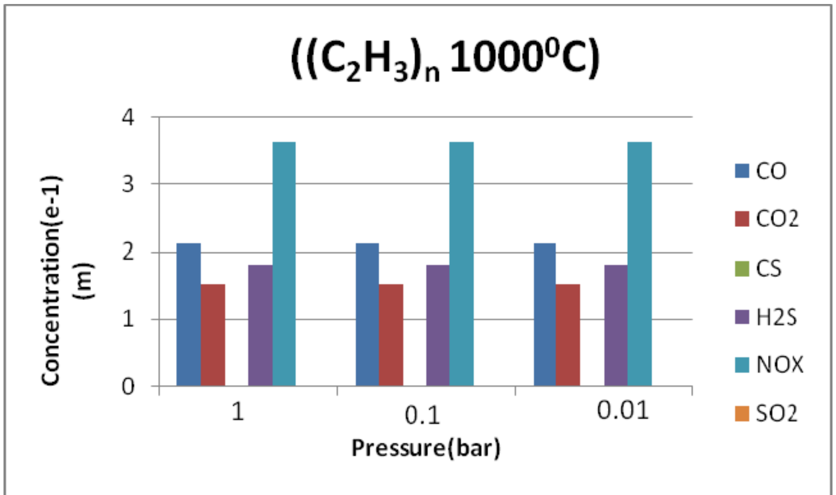

Fig.6(a), Results for Vinyl compounds(at 1000^0C)

From the graphs plotted, it can be inferred that certain toxic gas emissions like sulfur dioxide (SO_2), and carbon monoxide (CO) are formed with reduce in pressure and increase in temperature values. These calculations which are done through the GASEQ software for the operation of incineration process are taken as base-line data for the design of emission systems for the portable plasma incinerator. The concentration units taken are to be mole fraction in software with regard to certain species like nitrogen oxides (NO_X) and sulfur oxides (SO_X).

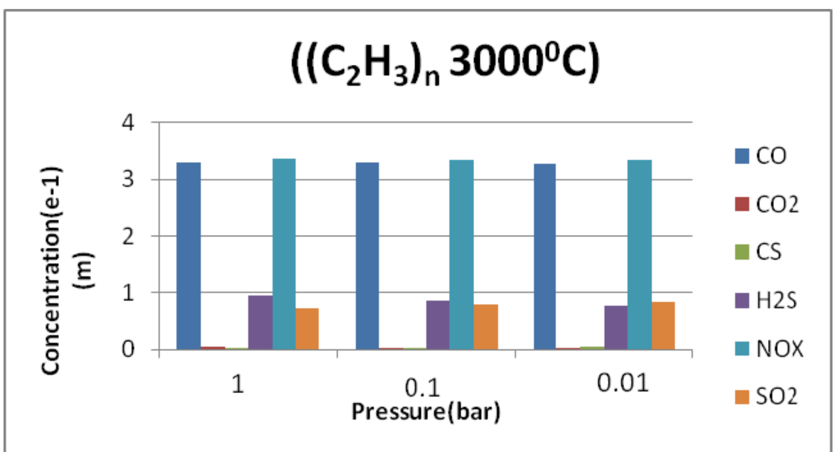

Fig.6(b), Results for Vinyl compounds(at 3000^0C)

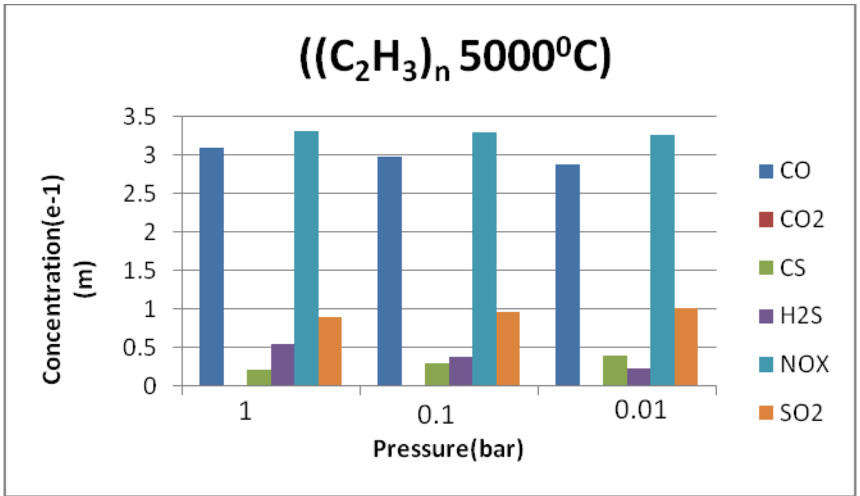

Fig.6(c), Results for Vinyl compounds(at 5000^0C)

8. Conclusion

The technical feasibility and viability of the emission systems can be observed from the Table.1, where the capital cost is ranging from the moderate to low, except in the case of ESPs. The best achievable emissions limits for each type of pollution control equipment assumes that the equipment can be combined in the same system and that the emission limits of each system are additive. For example, fabric filters are used for PM removal, wet-scrubbers for the HCl removal.

Particulate Matter is one of the main concerns in the case of emission aspects. To control it, a bag house is efficiently effective. It removes solid particulate matter from the flue gas stream by filtering the flue gas through fabric bags, usually made of cloth or glass fibers. Small particles are initially captured and retained on the fibers of the cloth by means of interception, impingement, diffusion, gravitational settling, and electrostatic attraction. Once a mat or cake of dust is accumulated, further collection is accomplished by sieving or other mechanisms. The cloth then serves mainly as a supporting structure from the dust mat responsible for the high collection efficiency. Periodically, the accumulated dust is removed for disposal.

Finally, the transportation cost can be reduced by the usage of portable plasma incinerator as the on-site processing in the places like hospital dormitories, doctor's room, nursing homes, etc. It is one kind of green technology that can be promoted for future prospects.

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