MEDICAL WASTE INCINERATION IN NABLUS CITY, WEST BANK: A CASE STUDY

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الخلاصـــــة :

تتم عملية جمع النفايات الطبية من المستشفيات والمراكز الطبية في الضفة الغربية من فلسطين عن طريق وضعها في أكياس بلاستيكية وبعدها توضع مع النفايات الأخرى وتؤخذ إلى المكب للتخلص منها . ونتيجة لهذا الخطأ في عملية الجمع — دون الفصل والحرق — يحدث تلوث للهواء المحيط بالمحرقة إضافة إلى انتشار الفيروسات والبكتيريا . وخلال الثلاث سنوات الماضية اعتُمدتْ عملية فصل المخلفات الطبية عن المخلفات الأخرى في المصدر ثم حرق هذة المخلفات الطبية عن طريق محرقة طبية معدة خصيصاً لهذا الغرض .

هذا البحث يعرض دراسة لأنواع وأحجام المخلفات الطبية الناتجة عن أربعة مستشفيات ومركزين طبيين في مدينة نابلس لمدة شهر متواصل وتم تدوين جميع المعلومات يومياً . وقد بيَّنت الدراسة أن المخلفات الطبية المصنوعة من البلاستيك (PVC) تمثل أغلبية المخلفات الطبية . ولتمثيل عملية حرق المخلفات الطبية فقد تم وضع برنامج مُحَوْسَب مبني على أساس أنظمة عالمية تحاكي عملية انبعاث الغازات وطرق تقديرها حيث يقوم بحساب كمية ومعدل هذة الغازات الملوثة الناتجة عن عملية الحرق اخذين بعين الاعتبار ظروف الحرق الحالية . وعليه فقد بيَّنتْ النتائج أن كمية الغازات الملوثة المنبعثة من حرق البلاستيك وزجاجيات الأدوية تمثل النسبة الكبرى من كمية الملوثات ، كما بينت الدراسة أن نسبة الملوثات المحتوية على الهيدروكربونات الكلورية التي تمثل الأساس في انبعاث مادتي Furans, Dioxins عالية وتزداد مع زيادة كمية ألـ HCl الموجودة ونقصان درجة الحرق . وبناءً على نتائج البحث فقد تبيَّن أن هنالك حاجة ماسة إلى وضع أسس لعملية التحكم بالملوثات وتقليل انبعاثها من المحرقة للتقليل من مخاطر النفايات الطبية وإرشاد الجهات المسؤولة إلى الظروف الملائمة لعملية الحرق .

ABSTRACT

Medical waste generated in West Bank hospitals and medical centers is collected in plastic bags and then dumped together with other domestic waste without any separation. This malpractice usually leads to air pollution and the danger of spreading viruses and bacteria widely. It is only in the last three years that medical waste has been separated from municipal waste in Nablus city and disposed of in a medical waste incinerator

In this paper, the type and quantity of the medical waste generated from four hospitals and two medical centers in Nablus City was recorded (on daily basis) for one month. It was found that PVC plastic waste represents the largest amount of waste. A computer reaction program was written to simulate the combustion process taking place during medical waste incineration and to calculate the emission factor and the amount of pollutant emission gases from the medical waste incinerator. It has been found that the highest amount of pollutant emission gases was from burning plastic and glass medical waste. In addition, chlorinated hydrocarbons emissions, such as dioxins and furans, from the incineration process were also calculated using an existing model from the literature. It has been found that the dioxins/furans emissions increase with increasing HCl concentration and decreasing combustion temperature. This confirms the need to control these pollutants from the medical waste incinerator.

Key words: Medical waste, Solid Waste, Incinerator, Dioxins/Furans.

MEDICAL WASTE INCINERATION IN NABLUS CITY, WEST BANK: A CASE STUDY

1. INTRODUCTION

Medical waste is defined as all wastes generated from health care or health related facilities. It is characteristically heterogeneous, consisting of objects of many different sizes and composed of many different materials. It can be classified into two categories: general waste and special waste. The general waste consists of all waste material that is not defined as hazardous. It comprises a heterogeneous mixture of paper, cartons, plastics (organic materials), food scraps, glassware, and metals. These wastes can sometime be contaminated with the special medical waste of biological, contagious, and sharp object wastes. Therefore, the medical wastes require special handling, treatment, and disposal methods to protect the people from potential health, safety, or environmental hazards.

Quite apart from the problem of professional disagreement on the best approach to the thermal treatment of medical waste, major public perception problems have reached a point where emotions and fear of infectious diseases rather than reasons of quantitative data usually dominate public policy discussions. Yet the eradication of infectious agents by fire is the major advantage of the incineration method for medical waste disposal, when compared with alternative treatments such as steam sterilization, microwave heating, and chemical treatments. Incineration has been the most widely used treatment technology for medical waste disposal. The objective in treating medical wastes is to reduce their hazardous nature with respect to human contact in the short term and to protect the environment in the long term.

The major advantage of incineration process is that the volume of material can be reduced, and pathogens and hazardous organic are destroyed. Solid waste incineration, especially the medical waste is one of the causes of air pollution if not operated properly. In this regard, the emission of the dioxins/furans from the medical waste incinerator should be seriously considered and monitored. Therefore, the disadvantage of the incineration process may produce unwanted pollutants such as Polychlorinated Dibenzo-*p*-Dioxins (PCDD), Dibenzofurans (PCDF), and metal particulates if incinerators are not well designed and operated.

Municipal and industrial incinerator combusting organic materials and chlorinated compounds appear to be the major sources of PCDDs and PCDFs in the environment. The chlorinated benzenes–biphenyls (ClBz) and chlorinated benzenes–phenols (ClPh), which are present in high concentrations in emissions from waste incinerators, act either individually or in combination as precursors or intermediates of PCDDs and PCDFs.

Incineration is still somewhat controversial, particularly among environmental groups. The major argument against incineration appears to be about the amount of carbon dioxide liberated into the atmosphere and the need to minimize this greenhouse gas. The second argument is about the emission of heavy metals and products of incomplete combustion such as dioxin. The majority of pollutants emitted from incinerators are classified as criteria pollutants, which include particulate matter (PM), acid gases (HCl, HF, and SO_2), nitrogen oxides (NO_x) and carbon monoxide (CO). Beyond the criteria pollutants, incinerators also emit small amounts of trace organic and trace metals, which are classified as toxic pollutants [1]. The toxic pollutants, dioxins/furans, and mercury were shown to be particularly resistant to the traditional control methods [1].

Alternative strategies for the medical waste that is not clearly of an anatomical nature propose that the medical waste be handled in one of the following ways:

1. landfilled;
2. treated in an autoclave and then landfilled;
3. treated in a purpose-built microwaving unit and then landfilled;
4. treated in a chlorinated hammermill, with liquid effluent being discharged into a sewer and the solids at a landfill site.

The scope of these methods is beyond the objectives of this paper, therefore it will concentrate on the incineration process.

The generated medical waste from various medical institutions in the West Bank is collected and disposed of with domestic waste without special treatment. This practice places the public in danger of being exposed to epidemic diseases.

Recently, a study on the characterization and management of incinerator waste was published by Ibanze *et al.* [2]. They found that characterization of the type of residues from theses incinerators are an essential step toward recommending management options.

Prior to 1997, no medical waste incinerator existed and all medical wastes generated in Nablus city were collected on a daily basis in plastic bags, and then dumped together with other domestic wastes, without any separation. This malpractice usually leads to air pollution and the danger of spreading viruses and bacteria widely, especially when residents pick through these wastes for recyclable metals. Another dangerous disposal practice is in the maternity unit of the hospitals, where operational waste, placenta, and tissue cultures are disposed of directly into municipal garbage.

By the end of 1997, the combustion process for the medical waste began by a medical waste incinerator donated by the Spanish Government to Nablus municipality. Since the time the incineration was installed and commenced operation, no special care was given to it and no training was given to the operating staff.

The dioxins/furans pollutants, which may require controls beyond those required for other toxic pollutants, are the focus of this paper. Therefore, the amount of PCDD and PCDF emitted from medical waste incinerators will be predicted in this paper. In addition, suggestions for future experimental work to measure their concentrations and reduce their emissions to the environment in Nablus area will be proposed.

2. INCINERATOR PCDD/PCDF EMISSION

2.1. PCDD/PCDF Formation in Incinerators

PCDDs and PCDFs enter the environment as unwanted trace impurities in products derived from chlorinated phenols; commercial mixtures of polychlorinated biphenyls, polychlorinated naphthalenes, and through diverse combustion processes. PCDF is also produced by overheated polychlorinated biphenyls in malfunctioning transformers or capacitors. Based on the author's knowledge, no known biogenic source, nor any commercial use, for PCDDs/PCDFs has yet been discovered.

Organic materials may be converted into inorganic matter, or changed in form, by high temperature processes. This results in partial or complete reduction in the degree of hazard of the material. The general class of such thermal processes is termed incineration [3].

From different experiments such as that carried out by Olie *et al.* [4], it is found that PCDDs and PCDFs are readily formed when lignin is burned in the presence of HCl. This suggests that, in such a process, phenolic compounds, which are readily derived from lignin, can be chlorinated and dimerized to form PCDDs and PCDFs [5].

A number of theoretical approaches have been proposed to explain the formation processes of PCDD/PCDF in incinerators. In brief, these include the following.

1. The PCDD/PCDF output represents the unburned PCDD/PCDF in the input feed.
2. Chlorophenols combine in the incinerator to form PCDDs/PCDFs.
3. Incompletely combusted hydrocarbon compounds form unchlorinated dioxins or furans; then chlorine donors displace one, two, three, or more hydrogen atoms to form PCDDs/PCDFs.
4. Certain metallic fly ash particles catalyze the combination of unchlorinated dioxins and furans with chlorine from chlorine donors.

The formation of PCDF and PCDD on fly ash has been proposed by Christmann *et al.* [6]. The study showed that during combustion and pyrolysis of pure PVC and PVC-cable sheathings in air, PCDD/PCDF are formed in significant amounts up to the ppm level. The PCDFs/PCDDs are mainly formed in laboratory reactors by reactions between Cl_2 and phenol at a rate proportional to temperatures [7, 8]

2.2. Relation to Furnace Temperature and Combustion Efficiency

Medical waste incinerators were designed on the theory that a high temperature and combustion efficiency would destroy organic components in the fuel and thereby prevent hazardous emissions. However, actual tests of operating incinerators show that, despite of this theoretical expectation, in practice medical waste incinerators emit a variety of organic compounds, of which PCDDs and PCDFs are the most hazardous [5]. The PCDD/PCDF emission rates may, of course, be influenced by the possible effect of incinerator design, fuel composition, and other variables among different plants.

High combustion temperature prevent the formation of dioxins/furans in the combustion process, but too high temperature in the post-combustion zone promote the reformation of dioxin/furans precursors and inhibit collection of dioxin/furans emissions in the vapor phase [1].

3. MEDICAL WASTE INCINERATOR IN NABLUS CITY

Before installment of the medical waste incinerator, medical waste was disposed of in the municipal incinerator. This caused emissions of dangerous pollutants such as PCDD and PCDF, that may cause cancer, as a result of combustion [10, 11].

The current incinerator occupies an area of 56 m^2. It is a rotating incinerator with a capacity of 250 kg/hr. The diameter of the rotating cylinder is about 1.5 meter, and the length of the cylinder is about three meters. During the combustion process the speed of the rotary part was measured to be one revolution every six minutes [0.48 inch/sec]. This value is reasonable when compared with literature values [0.2–1 inch/sec] [8].

The municipality with the cooperation of the city health department started collecting and separating the medical waste from the municipal waste in an attempt to treat the medical waste in the medical incinerator.

The collected medical waste from all Nablus City hospitals is transported to the incineration site where it is loaded to the incinerator semi automatically. The incineration start up process can be divided to three stages: the first stage is a manual opening of the loading door. After that, the waste is dumped and the door is closed. The loading cycle begins automatically as the sluice moves up, and the loading cylinder moves forward, this causes the waste to fall into the rotating burner chamber. The loading cylinder moves back and the sluice moves down. This causes no more waste to be fed to the incinerator until the waste batch is burned. The batch time takes approximately 15 minutes for each 6–7 kg of waste batch.

The second stage of the combustion process occurs in the rotating cylinder burner, which has two chambers. The first chamber has a switch-off point (SP) of 700°C, and is used for burning the waste. The other chamber’s SP is at 950°C. It has a tolerance of 150°C and once it reaches 1100°C the hydraulic system stops working. After the combustion process is finished, the third stage of incineration process begins. The incinerator is automatically switched off, and the ash is removed outside the incinerator with a hoist. The ash is treated by mixing it with water, and then transported to Beit-Furik area where it is dumped and burned with the municipal waste.

An excess amount of air is used to guarantee that the waste combustion is complete. In the incinerator, there are two motor fans; the burner motor fan is located at the front of the incinerator, which supplies the needed air for burning. The other burner motor fan is located on one side of the combustion chamber, supplying air for complete combustion.

The incineration process requires a fuel to run. Diesel oil is used for this purpose. A polyethylene tank of 700 liter is located at a distance of 2 m from the incinerator. This tank supplies the two burners with the required fuel through a tube of 15 mm diameter.

The medical wastes to be incinerated include liquid and solid medical waste. The municipality requested all hospitals and medical waste centers to comply with their medical waste composition (No heavy metals should be in the waste, such as mercury). Unfortunately, this is not seriously checked. Another request was put forward to all hospitals to dispose their liquid medical waste into special plastic containers.

4. METHODOLOGY

In this study a field survey was carried out on the quantity and quality of the medical waste generated in Nablus City. An estimation of the theoretical amount of pollutants emitted and the emission factor for complete and incomplete combustion was calculated. This was followed by recommendation for management strategy for operating the medical incinerator in more efficient way.

Different steps commenced the methodology of this work:

Step 1: *Data collection:* a questionnaire was prepared and distributed to all sections in four hospitals, and two medical centers in Nablus area. The questionnaire included inquiries about quantities of the most commonly generated medical waste, such as plastic, paper, and liquid medical waste, for a duration of thirty days.

Step 2: A field visit was made to the medical waste incinerator. The incinerator is located to the east of Nablus City.

Step 3: *Estimation of PCDD and PCDF emissions:* a computer program was written to calculate the amount of PCDD and PCDF emitted to the atmosphere from the incineration process. The program enables calculation of the emission rate of the pollutants generated by the medical waste incinerator. The program uses a published model [9], to relate chlorinated hydrocarbon emission to HCl emissions.

Step 4: *Control methods:* a recommendation regarding control of the present medical waste incinerator in Nablus city is presented.

5. RESULTS

5.1. Analysis of Nablus Medical Waste

The qualitative and quantitative medical waste data collected during the thirty days allocated for this purpose are shown in Table 1. The quantity shown in Table 1 represents approximately 75% of the total medical waste generated in Nablus City. The other 25% of the medical waste are the sum of the waste disposed to the municipal waste bags and the amount not recorded by other medical centers and dental surgeries. The total amount of medical waste generated in Nablus City is more than 55 tons per year. This amount is proportional to the total medical waste generated in the neighboring cities of Tulkarem and Jenin [12].

Table 1. Qualitative and Quantitative Amount of Medical Waste Generated from Nablus Medical Centers and Hospitals.

Type	Quantity (kg/month)					
	Hospital A	Hospital B	Hospital C	Hospital D	Medical Center E	Medical Center F
Cotton	117.5	100	56.2	192	1.69	83
Plastic	218.9	329	13.6	478	88.2	264
Paper	60	42	14.1	111	4.05	124
Glass	758	55	8.24	128	21.6	79
Wood	1.2	2	1.8	9	------	3
Aluminum	6.9	21	12.0	48	1.5	5
Total	**1162.5**	**549**	**105.9**	**962**	**117.0**	**558**

From this table, it can be seen that the medical waste of hospital 'C' is small compared to other hospitals, as we were not allowed to collect data from all of hospital's sections. The average medical waste generated per bed per day is 0.27 kg. This number is based on bed and not patient. If the value is per patient it will be higher than this number, as the number of patients treated at the emergency section will be counted. The term plastic waste covers various kinds of plastics such as polyethylene, polypropylene, polyvinyl chloride, polystyrene, polycarbonate, and mixed plastics. The percentage of polyethylene and PVC are the highest among these plastic types and their chemical compositions are used in the pollutant emission factor calculation. Hospital A generates a large amount of glass waste whereas hospital D generates the largest amount of plastic waste. Hospital A has the only clinical emergency department in the city and the biggest laboratory, this explains the large amount of glass and cotton waste.

5.2. Emission Factors

Pollutant emission factors (EFs) for each medical waste incinerator facility can be determined by using either average pollutant emission and waste feed rates or by using average pollutant concentrations, combustion as flow rates, and waste feed rates reported for each facility. In this paper, the average EFs was determined by using the average pollutant concentration produces for each facility when it is grouped and averaged with facilities burning similar waste. The calculation procedure used in this study is as follows.

Step 1: pollutant concentration is calculated using Equations (1) and (2) [1] and reported in units of parts per million (ppm) at standard conditions are converted to mass concentration. Also actual values reported as flow rates are adjusted to standard conditions.

$$C_{\text{mass}} = 40.9\, C_{\text{ppm}}\, M.W_{\text{p}} \tag{1}$$

$$F_{\text{std}} = F_{\text{rep}} \left(1.5 - 7.14 \left(\frac{\%O_{2\,\text{rep}}}{100} \right) \right) \frac{298}{T_{\text{rep}}} \; . \tag{2}$$

Step 2: mass emission rates, mass of pollutant/min, are calculated using Equation (3):

$$ER = f\, C_{\text{mass}}\, F_{\text{std}} \; . \tag{3}$$

Step 3: the emission factors, ng/kg waste, were calculated as follows:

$$EF = \frac{ER}{WR} \; , \tag{4}$$

where

C_{mass}	pollutant mass concentration (μg/m^3)
C_{ppm}	reported pollutant concentration at standard condition
$M.W_{\text{p}}$	molecular weight of pollutant (g/mole)
$D_{\text{std}}, F_{\text{rep}}$	stack gas flow rate at standard and reported temperature (m^3/min)
T_{rep}	reported stack gas temperature (k)
$\%O_{2\,\text{rep}}$	percent of O_2 reported in stack gas (%)
ER	emission rate (mass of pollutant /min)
f	conversion factor to convert micrograms to nanograms or milligrams as required
WR	average waste feed rate (kg/min)
EF	emission factor (μg or ng/kg of waste).

Table 2 shows the calculated emission factors assuming a complete combustion of the medical waste. These calculated numbers are in agreement with theoretical published data [8].

Table 2. Emission Factor of Incinerated Medical Waste.

Flue Gas	EF (ng/kg)
CO_2	415.2
N_2	11122.6
O_2	126.8
SO_2	$5.2*10^{-3}$
HCl	0.64

5.3. PCDD and PCDF Emissions

The equations presented in the previous sub-sections were used to calculate the concentration of the PCDD, PCDF, ClBz, and ClPh pollutants which are considered as the most dangerous pollutants emitted from the medical waste incinerator. Their formation depends on the concentration of HCl. Table 3 shows the computed emitted quantities of PCDD, PCDF, ClBz, and ClPh for incomplete combustion process for the following two test conditions:

(1) assuming that the plastic waste is separated from the medical waste;
(2) assuming no pre-separation of the plastic waste from the medical waste.

Table 3. Calculated Chlorinated Hydrocarbon Emissions Values.

Test condition	HCl (kg/t)	T (°F)	CO (ppm)	PCDF (μg/t)	PCDD (μg/t)	ClBz (mg/t)	ClPh (mg/t)
Plastic separately	33.21	1410	21.6	834.24	257.214	11.7178	235.997
Plastic (with all medical waste)	18.43	1410	80.41	462.964	142.742	6.50276	14.7015

As PVC is the main source of HCl, it can be seen in the table that a higher concentration of HCl emitted from burning a separated PVC medical waste than that from non-separated medical waste.

Therefore, it can be concluded that burning medical waste in which phenolic compounds and lignin present are the main cause of PCDDs and PCDFs pollutants. A high concentration of HCl produces high concentration of pollutants.

The effect of medical waste incineration under three different temperatures, namely: 1410°F; 1600°F; and 1800°F, for different concentrations of HCl, is shown in Figure 1 (*a*), (*b*), (*c*), respectively.

From Figure 1, it is quite clear that the concentrations of all pollutants, except ClPh, decrease with increasing the concentration of HCl until the HCl concentration reaches 10 kg/t and then the pollutant concentrations increase with increasing HCl. This means that chlorinated hydrocarbon concentrations are inversely proportioned to operating temperature. Therefore their concentrations decrease with increasing temperature for the same HCl and CO concentrations

Increasing the burning temperature, at 1600°F and 1800°F, results in slightly increasing concentrations of both PCDD and PCDF at very low HCl concentrations and, on the other hand, does not affect the PCDD and PCDF concentrations at high HCl. This is shown in Figures 2 and 3, respectively.

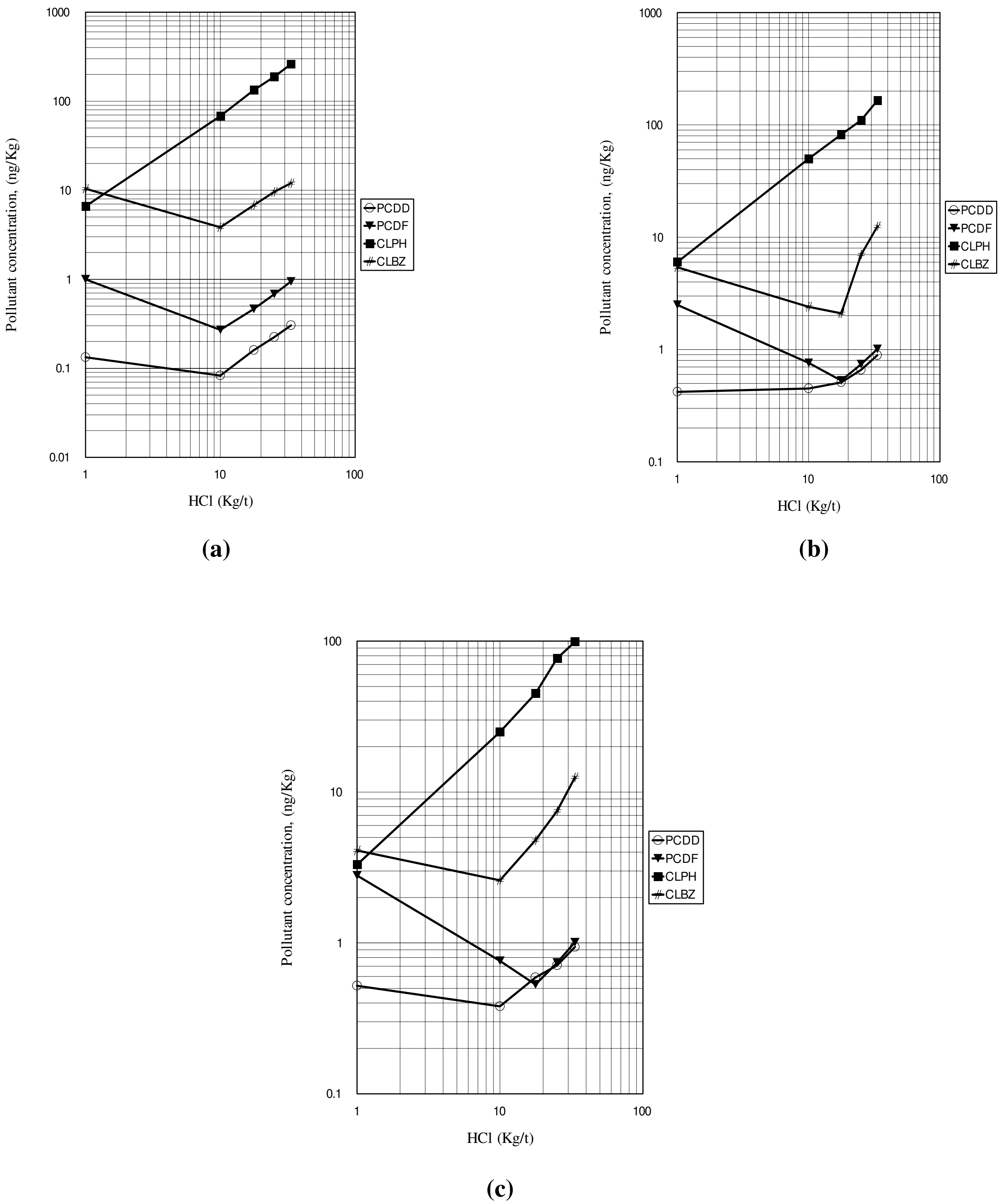

Figure 1. Relationship between the chlorinated hydrocarbon emissions and the concentration of HCl at different temperatures, namely: 1410°F; 1600°F; and 1800°F, ((a), (b), (c), respectively) for different concentrations of HCl.

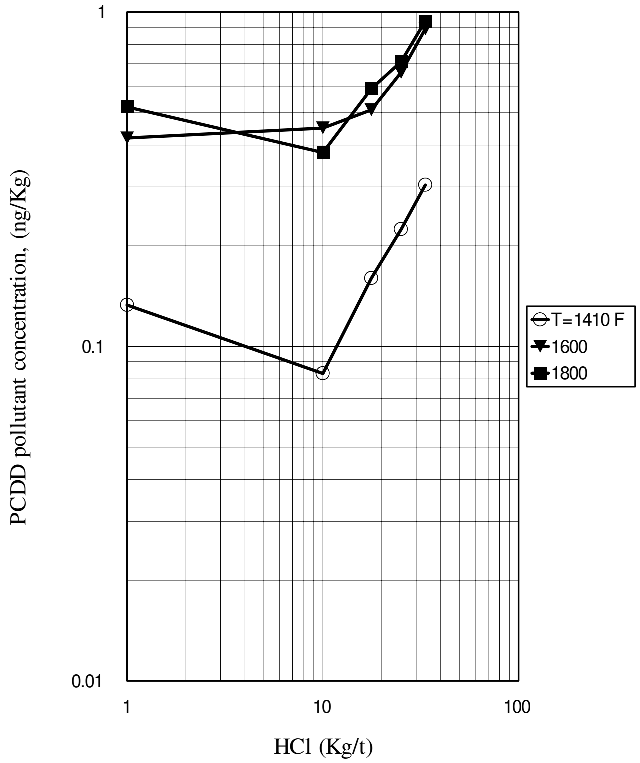

Figure 2. Variation of PCDD concentration at different combustion temperature.

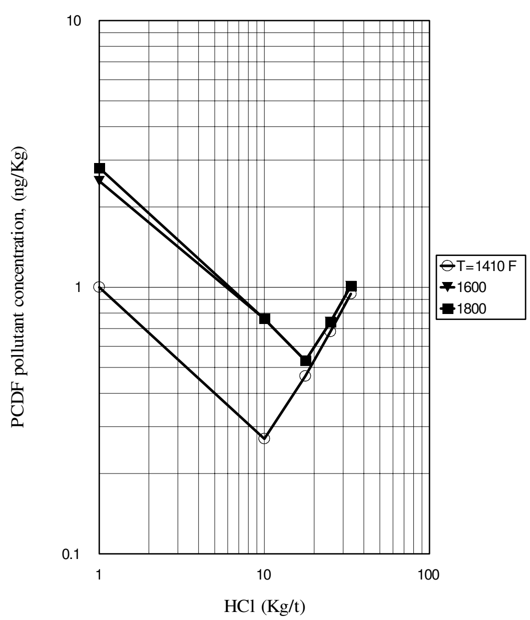

Figure 3. Variation of PCDF concentration at different combustion temperature.

6. MEDICAL WASTE INCINERATOR CONTROL

In the past five years, more cases of cancer were registered in Nablus hospitals without any attention being given to the main causes behind it. For a long time, medical waste was burned with the municipal waste. As cancer may take a long time before being discovered, the number of newly discovered cancer cases is increasing and threatening the lives of many people who are living near to the municipal waste landfill, which remains not far from the medical waste incinerator. The increasing number of cancer patients resulted in the establishment of the Palestinian National Cancer Registry, PNCR, in 1998, where more detail information about cancer patients is recorded. The combustion process for medical waste in use causes the emission of pollutant gases that contribute to cancer. In a report published by the PNCR [11], the number of cancer cases reported in 1990 was 365 and increased in 1997 to 652, while in 1998 it increased sharply to 999 cases. The number of cancer cases in Nablus city is 187. Most of these cases are found in the area around the medical incinerator. Since these pollutant gases were reported to cause cancer [10, 11, 13], strict control of medical waste incineration and the emitted gases is highly necessary. The objectives of this control are as follows.

(1) To ensure complete burning of any smoke or particulate generated in the primary combustion chamber.

(2) To destroy any unavoidable products of incomplete combustion that might be generated in the primary combustion zone.

(3) To destroy any toxic materials that may be charged into the incinerator.

(4) To ensure a minimum risk for the medical waste incinerator.

To achieve these objectives, incinerators must have a minimum of two combustion chambers. Both chambers are required to operate at the same time at a temperature in excess of 1000°C at all times, an excess amount of oxygen from 6 to 10 percent, and a residence time of at least 1 second [8]. Unfortunately, there is no oxygen flow meter on the equipment and the workers operate the incinerator with no indication of the amount of air used.

Because combustion temperatures must be kept high and post-combustion temperatures must be kept low, it is necessary to quench the temperatures quickly after combustion. Several methods are available, including installation of a spray dryer (also called a quench reactor) or a wet scrubber, which cools the flue gas and promotes dioxin formation [1]. Work is underway in cooperation with The Palestinian Save the Children Federation. In addition, a way to reduce the precursors for formation of dioxins/furans is to reduce the chlorinated compounds. This is more typically controlled by adding lime to the furnace, which neutralizes most chlorinated acidic compounds. Spray dryers and direct reagent injection are common methods for introducing lime into flue gas. This can also be done by the installation of wet scrubbers on the incinerator chimney.

7. CONCLUSIONS

The following conclusions can be drawn from this work.

- A theoretical calculation of the emitted pollutants from Nablus medical waste incinerator is calculated. The numerical values give an indication of the urgent need for minimizing and controlling the pollutants concentrations.

- Burning medical waste in which phenolic compounds and lignin present are the main cause of PCDDs and PCDFs pollutants. A high concentration of HCl produces a high concentration of pollutants.

- In Nablus area, the concentration of all pollutants, except ClPh, decreases with increasing the concentration of HCl until the HCl concentration reaches $10\,\mathrm{kg/t}$ and then the pollutant concentrations increase with increasing HCl. On the other hand, at 1600°F and 1800°F, the concentrations of PCDD and PCDF are not affected by high HCl concentrations.

- The increasing number of recorded cancer patients in Nablus city can be correlated to the improper medical waste burning process practiced for quite long time.

- Due to the increase in cancer illness registry in Nablus city, there is a need to give more attention to the separation of medical waste from municipal waste. Despite the small amount of medical waste generated by the health care centers such as hospitals and medical laboratories, in Nablus City, it must be separated from domestic waste and collected in a special container. Applying a national management program can carry this out.

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