



Oxygen Enriched Combustion Incinerator for Drugs and Solid fuel

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Dedication

To our parents, mentor and friends, we couldn't have done
this work without you.
Thank you for all of your supports along the way.

Acknowledgment

السلام عليكم ورحمة الله وبركاته :

نهدي مشروعنا وكل العلم الذي حصلناه وسنحصله بإذن الله لهذا الوطن، فلسطين أرض البدايات وأرض النهايات ولأن على هذه الأرض ما يستحق الحياة وما يستحق منا أن نبذل كل ما أوتينا فداها والى من افتدى هذا الوطن بعلمه ودمه أولئك الطاهرون أكرمنا.

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الى اخوتنا واخواتنا دما وروحا ولولاهم لكانت الحياة لا تطاق..
هم بلسم الروح الذي يشفي من كل الكدائر.

الى استاذنا الدكتور محمد السيد
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الى المهندس أشرف
الذي لا ننسى فضله التابع من حبه للعلم وافادة طلبة العلم دون أي مقابل .

DISCLAIMER

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List of Abbreviations

OEC	Oxygen Enriched Combustion
BPC	Birzeit Pharmaceutical Company
FCC	Fluid Catalytic Cracking
DRE	Destruction and Removal Efficiency
ICE	Internal Combustions Engine
PCBS	Palestinian Central Bureau of Statistics
O ₂	Oxygen
CO	Carbon Monoxide
CO ₂	Carbon dioxide
NO _x	Nitrogen oxides
NO ₂	Nitrogen dioxide
NO	Nitric oxide
SO _x	Sulfur oxides
SO ₂	Sulfur dioxide
Temp	Temperature
η	Efficiency

Abstract

Palestine is facing enormous problem of pharmaceutical solid waste for several reasons, the most important one is increasing the amount of solid waste without technical treatment such as dumping, open burning and depending on Israeli companies. A problem that deserves our attention to look for proper solution.

The main objective of this project is to treat expired medicine by one stage incineration with charcoal, OEC technology were applied to raise the temperature and ensure complete combustion, to convert the waste to stable compound, applying this project has importance such as attractive method for waste disposal instead of the current methods.

Completing to our graduation project, the data collection was the first step, which was a necessity to recognize the current condition and data related to the project. In addition, many modifications were done to the burner in order to fit our experimental needs to ensure applying the oxygen enriched combustion (OEC) technology by adding a pipeline of oxygen into a mixing point with the air and in the methodology section all of these modifications have been mentioned.

The fuel is charcoal besides to charcoal that mixed with the expired medicine; O₂ at different concentrations were applied which mixed with air (20%, 21%, 22%, 23%, 24%, and > 24%).

The main variable in this experiment was O₂ concentration in the intake air and the experiment included two stages the first one was burning of charcoal alone, the second was burning charcoal with expired drugs. In addition, the combustion analyzer was used to measure the burner exhaust gas temperature, NO_x emissions, CO emissions and SO₂ emissions, and CO₂ emissions, and Infrared thermometer with laser pointer, which was used to measure to maximum and instantaneous temperatures.

The main results obtained from the experiment were; mass reduction more than 90% of waste, raising the temperature from (382 – 977) C°, and raising the efficiency from (68 – 89.8) %.

Chapter 1: Introduction

1.1 Problem statement

The disposal of waste in general and medical waste in particular, have been one of this century biggest concerns because of the serious environmental destruction incurred by it. When talking about waste, it means everything that left behind from human activities, could be industrial, residential or commercial. The amount of solid waste are rapidly increasing by increasing of population growth, and industrial manufacturing. The medical waste is "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 biological" [11], the type of medical waste which is in this research is the expired medicine.

In Palestine, the Pharmaceutical industry perceived a large development in the last ten years, which occupies an important place in industries because of its contribution in increasing the national income. In spite of this importance the amount of solid waste produced by Pharmaceutical industry have been increased hazardous impacts on environment. Most waste pharmaceuticals are considered dangerous waste, they are toxic, corrosive, or reactive, and can create a serious risk to human health or the environment. Sending the waste to waste disposal facility so it can be incinerated is the safest way to handle it.

After data was collected from Birzeit Pharmaceutical Company (BPC), which represent 50% of the local production of the Palestinian market and around 25% of the total available medicine in the Palestinian market weather a Palestinian, Foreign or Israeli Pharmaceutical Companies, by numbers, the production of BPC is 42 ton/year of solid drugs and around (2-3) ton /year considered as a solid waste.

- Waste out of these companies can be classified into four major categories these are:
 - Rejected raw material that don't comply with the standard regulation, these rejected raw materials are mainly chemical materials and discarded under the control of health ministry.
 - Liquid waste resulted from companies' research labs, these chemical liquid is stored into one m3 special tank and then disposed by a commercials Israeli hazardous waste disposal companies.

- Rejected drugs products under hazardous waste chemical, the disposal method for these wastes is buried under supervision of health ministry.
- Recyclable materials such as aluminum sheets and glass wears generated in the pharmaceutical companies.

There are several ways to get rid of expired medicine, the combustion method has been chosen for many reasons, at first, here in Palestine there is a high population density and limited area of land available, thus the combustion is the solution to decrease the mass of the waste. Secondly, the goal of the environmental protection agencies is to protect our water supply. Therefore, the environmentally preferred disposal option for unused pharmaceuticals from all sources are incinerated (because of its high burn temperatures and effective emission-control systems) at authorized (permitted) incinerators, which prevents unused medications from entering our valuable water supply. In other hand, by the combustion method, there have been a great chance to raise the efficiency of the process, by the Oxygen enhanced combustion (OEC) that has become one of the most attracting combustion technologies in the last decade, two developments have increased its importance, the first one is the new technology of producing oxygen less expensive and the second one is the increased importance of environmental regulations.

In this project incineration in one stage incinerator have been chosen to treat the expired medicine with charcoal. The incinerator is a controlled combustion process for reducing solid, liquid, or gaseous combustible wastes primarily to carbon dioxide, water vapor, other gases and a relatively small, noncombustible residue, within specially designed combustion chambers, which provide introducing air for more complete combustion.

1.2 Objectives of the work

The main purpose of this study is to investigate the effects of using OEC technology on the thermal efficiency of the burner and its generated emissions, when using expired medicine as fuel with charcoal, also analyzing the output gas from the incinerator. In other hand, minimize the hazard and volume of pharmaceutical solid waste.

1.3 Scope of the work

Collecting all the needed data about the production and disposal of expired medicine in Palestine, design and modify a burner to fit the requirements of the experimental work. The combustion process have been implemented on many stages at first combustion with only air, then applied the OEC at different percentages of Oxygen (21%, 22%, 23%, 24%, > 24%) and took all the result and discuss it.

The report consists of six major chapters. **Chapter One** talks about an overview of the pharmaceutical industry in Palestine, incineration, wastes classification, problem statement, objects of the projects and the scope of the work. **Chapter Two**, present OEC method in incineration waste, in terms of the benefit of the Method in combustion, the effects of the method in pollutant emissions, and the potential problem of using OEC. **Chapter Three**, shows a previous studies, to be more knowledge about the OEC method and how it's effect in the study. **Chapter Four**, shows the methodology (experimental method) of the whole processes in details. **Chapter Five**, includes the result and discussion for the experiment. Then the conclusion and recommendation are presented in the last chapter.

Chapter 2: Oxygen Enriched Combustion

2.1 Oxygen enriched combustion

The benefits of using oxygen-enriched air (air containing more than 21% oxygen), instead of ambient air, have a long been recognized in many industrial processes such as catalyst regeneration in refinery fluid catalytic cracking (FCC), partial oxidation of sulfur in Claus plant, wastewater treatment, and combustion application for glass and foundry operations. Oxygen-enriched air can lower the capital and operating costs, reduce the CO₂ emissions, and increase the process flexibility and reliability. The use of oxygen-enriched air would become more attractive for a broader variety and scale of industrial combustion processes, if oxygen-enriched air can be produced in lower cost and more energy efficient manner. Concern about global climate change provide an additional important incentive for using oxygen-enriched air in combustion. Combustion of hydrocarbon fuels generates carbon dioxide the leading contribute to climate change.

2.1.1 Oxygen enriched methods in combustion processes

Oxygen enriched method has four commonly types used in combustion processes:

- 1. Air Enrichment:** The O₂ is injected into the incoming combustion air supply, usually through a diffuser to ensure adequate mixing. The process is shown schematically in figure 2.1. This is usually an inexpensive retrofit that can provide substantial benefits. Typically, the added O₂ will shorten and intensify the flame. However, there may be some concerns if too much O₂ is added to a burner designed for air/fuel. The flame shape may become unacceptably short. The higher flame temperature may damage the burner or burner block. The air piping may need to be modified for safety reasons to handle higher levels O₂. Depends on fuel type, burner, combustion method and enrichment method to have the optimum value of O₂.

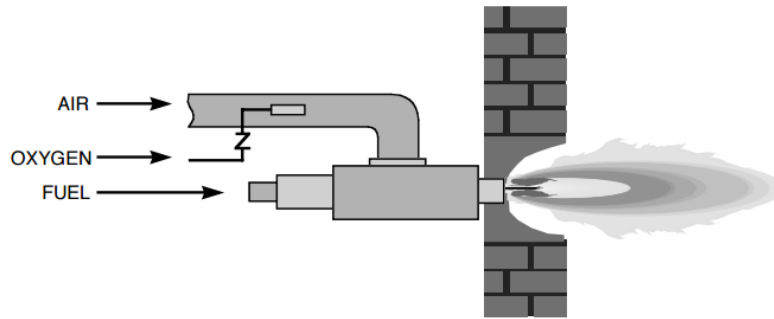


Figure 2.1 Schematic description of air enrichment method ^[2].

2. **O₂ lancing:** This method may have several advantages over air enrichment. No modifications to the existing air/fuel burner need to be made. The process is shown schematically in figure 2.2. Typically, the NO_x emissions are lower using O₂ lancing compared with premixing since this is a form of staging, which is a well-accepted technique for reducing NO_x. Depending on the injection location, the flame shape may be lengthened by staging the combustion reaction which this improves the transfer efficiency.

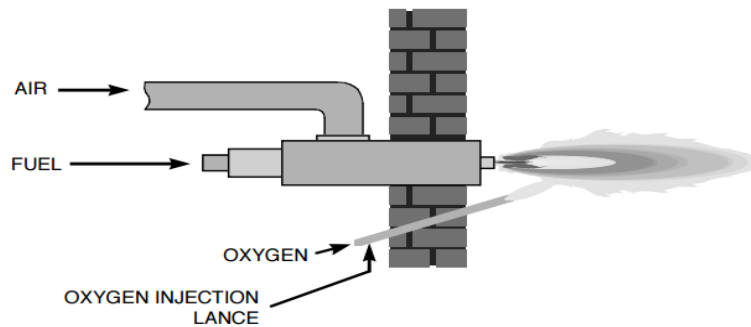


Figure 2.2 Schematic description of O₂ lancing ^[2].

3. **Oxygen/fuel:** In nearly all cases, the fuel and oxygen remain separated inside the burner and do not mix until reaching the outlet of the burner. This is commonly referred to as a nozzle-mix burner, which produces a diffusion flame. The process is shown schematically in figure 2.3. There is no premixing of the gases for safety reasons because of the extremely high reactivity of pure O₂. In this method, high-purity oxygen (>90% O₂ by volume) is used to combust the fuel. The advantage for this method that have greatest potential for

improving a processes but it also may have the highest operating cost. Also generally reduce NO_x because hot spot in the flame are minimized.

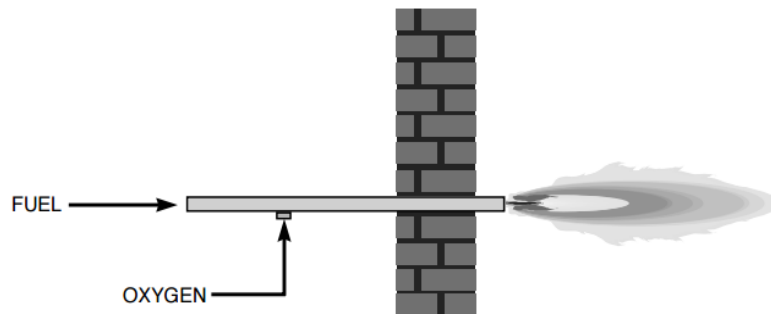


Figure 2.3 Schematic description of Oxygen/fuel ^[2].

- 4. Air-Oxygen/fuel:** This method involves separately injecting air and O_2 through a burner. The process is shown schematically in figure 2.4 schematically. In some cases, an existing air/fuel burner may be easily retrofitted by inserting an oxy/fuel burner through it. In other cases, a specially designed burner may be used. This method have several advantage. It can typically use higher levels of O_2 than air enrichment or O_2 lancing, which yield higher benefits. Furthermore, the operating costs are less than for oxy/fuel, which use very high levels of O_2 . The flame shape and heat release pattern may be adjusted by controlling the amount of O_2 used in the processes.

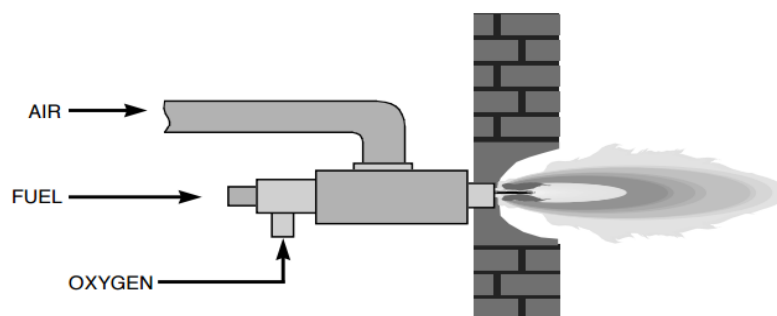


Figure 2.4 Schematic description of air-oxygen/fuel ^[2].

With this method of using OEC, the oxidizer composition may be specified in an alternative way. Instead of giving the overall O_2 concentration in the oxidizer, the oxidizer may be given as the fraction of the total oxidizer that is air and the fraction of the

total oxidizer that is pure O₂. The equivalent overall O₂ in the oxidizer can be calculated as shown in equation (2.1):

$$\Omega = \frac{20.9}{0.209 (\text{vol } \% \text{ O}_2) + (\text{vol } \% \text{ air})} \dots\dots (2.1)$$

[Ω] The amount of O₂ enrichment or the oxygen concentration in the intake air

This illustration in previous equation is graphically shown in figure 2.5.

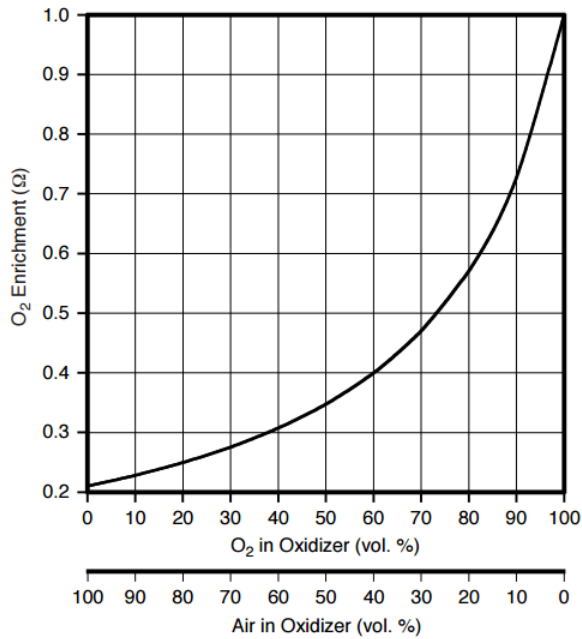


Figure 2.5 Oxidizer composition for blending air with pre oxygen ^[2]

2.1.2 General Benefits of Using OEC

Air consist of approximately 79% N₂ and 21% O₂ by volume. In the combustion reaction needs only the oxygen. By eliminating N₂, many benefits can be realized.

- **Higher thermal efficiency**

By using oxygen, instead of air, more energy goes into load instead of being wasted in heating up N₂. The energy needed to make O₂ from air is only a small fraction of combustion energy. The overall process needs less energy for a given amount of production due to the higher available heat. The increase of energy efficiency will offset the cost of

oxygen by reduce the cost of fuel. Although the process of increasing the concentration of oxygen will consume energy, but it will compensate by raising the efficiency of combustion in general and thus be economically viable.

- **Lower exhausted gas volume**

OEC has been used effectively to increase production in combustion systems that are at the limit of their exhaust gas capacity because the exhaust gas flow rate will reduce by eliminating N_2 from air. Another benefit is that it can increase the efficiency of the existing flue gas treatment equipment since the pollutant emissions are in higher concentration and therefore easier to remove. The size of post treatment equipment can be proportionally reduced because of the lower flow rates. This saves space, energy materials, and money.

- **Increase flexibility**

OEC can increase the flexibility of a heating system. In some cases, a wider range of materials can be processed compared with air/fuel combustion. In other cases, if very high melting temperatures are required OEC is useful as in some ceramic products which require firing temperatures of 1900 K and higher and this is difficult to achieve with standard air/fuel combustion with no air preheating.

- **Improve Flame Characteristics**

By using OEC technology, the flame characteristics and stability is improved.

Other benefits can be achieved by using OEC such as increase productivity, higher heat transfer efficiency, reduces equipment costs.

2.1.2.1 Specific Benefits

- **Higher destruction and removal efficiency**

The destruction and removal efficiency (DRE) is regulated for hazardous pollutants like CO, NO_x , CO_2 , and SO_x . OEC can increase the DRE in an incineration process. This is accomplished by a combination of increased residence time within the incinerator and

higher gas temperature. By reducing flue gas volume, which occurs by replacing air with oxygen, the residence time will increase. The higher flame temperature associated with OEC ensures that all hydrocarbon will be above their ignition temperature.

- **Lower combustibles**

OEC can reduce combustible gases, such as carbon monoxide and hydrogen that produced when fossil fuels are incompletely burned because of insufficient oxygen for complete combustion or insufficient mixing between fuel and the oxidizer, by adding O₂ more ability is founded to control the combustion process and reach approximately to complete combustion.

- **Higher ash burnout**

OEC can increase the completeness of combustion of the solids being processed in an incinerator because of higher temperature and more chemical reactivity.

- **Increased boiler efficiency**

Using OEC increase the burner efficiency due to the removal of N₂, this can lead to increase the boiler efficiency. OEC also can produce a cleaner burn, leading to cleaner boiler tubes and higher boiler efficiency.

2.1.3 Potential Problems of Using OEC

Any air mixture with an Oxygen content of more than 21% is considered oxygen enriched. A content of 23% oxygen in air, only 2% above the normal atmospheric content, has to be considered an extreme fire and explosion hazard. For combustion safety and burner management, the basic design principles of the safety interlock systems are the same for both air and oxygen enriched systems. Prevention of combustibles or explosive mixture in the furnace, monitoring of flame, and detection and correction of off- stoichiometric conditions, are among the most important design features. It is recommended that all safety standards for air burner systems also be incorporated into the design of oxygen enriched combustion system. In addition, special design considerations should give to prevent accidental

accumulation of oxygen enriched air in or near the furnace. With oxygen enrichment, the minimum ignition temperature of a fuel-oxidant mixture is reduced and the higher flammability limit is significantly widened compared to those of the equivalent fuel-air mixture. Thus, the likelihood of potential formation and ignition of flammable mixture tends to increase in the event of accidental accumulation of both fuel and oxygen enriched air in the furnace [3].

Many of potential problem can be generally attributed to the increased combustion intensity, these problem are:

1. **Refractory Damage:** OEC can cause refractory damage due to improper system design, this damage comes as a result of :
 - **Overheating:** Oxygen-enhanced flames generally have significantly higher flame temperature compared with conventional air/fuel flames. If the heat is not properly distributed, the intensified radiant output from the flame can cause refractory damage.
 - **Corrosion:** It is another potential refractory problem can result from the increased volatile concentration in the combustion chamber by using OEC, especially in glass industry. By removing the large quantity of diluent N₂, the volatile species are concentrated in the gas space. This can cause damage to the refractory by corrosion.

2. **Non-uniform heating:** it is important concern when retrofitting existing systems that were originally designed for air/fuel combustion. By intensifying the combustion process with OEC, there is the possibility of adversely affecting the heat and mass transfer characteristics within the combustion chamber, the common two related problems are :
 - **Hot spots:** OEC normally increase the radiant heat flux from the flame to the load. If the increased radiant output is strongly localized, then there is the possibility of producing hot spots on the load.
 - **Reducing in Convection:** the total volume flow rate of exhaust products is significantly reduced using OEC. However, the average gas temperature is usually higher, but not by enough to offset the reduced gas flow rate.

The convection heat transfer from the exhaust gases to the load may be reduced as a result.

3. **Flame Disturbance:** OEC causes flame disturbance. It can be eliminated by the proper choice of burners and their operating conditions.
4. **Increase Pollutant Emissions:** using OEC technology may increase the pollutant emissions such as NO_x which increased due to high flame temperature that increase NO_x thermal formation.
5. **Noise:** the flame velocity increase with OEC compared with air/fuel combustion. This means that the gas velocities existing the burner must be increased to compensate for the high flame speed. These higher gas velocities can increase the jet noise of the burner. Also, although the gas velocities were high, the total volume flow rate was much lower by removing N_2 from the oxidizer, which also was mitigating factor for the noise.
6. **Flashback:** The use of OEC intensifies the combustion reactions. One consequence of this reactivity is the increased risk of flashback. Flashback occurs when the gas velocity exiting the burner is less than the flame velocity.

2.2 Pollutant Emissions

The combustion of fuels can generate carbon monoxide nitrogen oxides, sulfur gases and particles .Air quality is affected by this subsistence and causes verse effects on human health. Air pollutants are either gaseous or particulate in form; gaseous pollutants are carbon monoxide, sulfur dioxide, nitrogen oxides, and ozone. Particulate matter can be made up of many different compounds including mineral, metallic, and organic compounds.

In this section each of these pollutants, their specifications, impact and how it affected by OEC are discussed.

1. NO_x Emissions

These include nitrogen monoxide (NO), nitrogen dioxide (NO_x) and nitrous oxide (NO₂). In most high-temperature heating applications, the majority of the NO_x exiting the exhaust stack is in the form of NO.

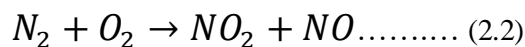
NO is a colorless gas that combines with O₂ in the atmosphere to form NO₂. NO is classified as a poisonous gas that has impacts on the human health, it can cause irritation of the eye and throat, tightness of the chest, nausea, headache and gradual loss of strength.

NO₂ is a reddish brown gas which has a suffocating odor. It is highly toxic because of its ability to cause delayed chemical pneumonitis and pulmonary edema. NO₂ Vapors are a strong irritant to the pulmonary tract. Severe symptoms may be delayed and include cyanosis, increased difficulty in breathing, irregular respiration, lassitude, and possible death due to pulmonary edema.

Beside all of these impact of NO_x on human health, there are also environmental problems associated with these emission [2]. NO can react with oxygen to form ozone. Ozone (O₃) is the most important photochemical oxidant in the troposphere there are few epidemiological studies on the chronic effects of ozone on human health, these studies approved the effect of ozone on incidence of asthma, a decrease in lung function growth and lung cancer [4].

NO₂ decomposes on contact with water to produce nitrous acid (HNO₂) and nitric acid (HNO₃) which are highly corrosive. When NO₂ comes in contact with rain, acid rain is produced that is destructive to whatever it comes in contact with such as buildings, bridges, plants and trees. Also when sunlight contacts a mixture of NO₂ and unburned hydrocarbons in the atmosphere, photochemical smog is produced.

Oxygen/fuel combustion is a recognized method for reducing NO_x emissions under carefully controlled conditions. The formation of NO_x is made by the high-temperature reaction of nitrogen with oxygen. It is given by the simplified reaction shown in equation (2.2):



NO_x emissions is one of our biggest concern in this work, because waste fuels may contain significant amounts of organically bound nitrogen. Also NO_x increases exponentially with temperature. By using OEC the oxygen concentration will increase and the nitrogen concentration will simultaneously decrease. This lower NO_x because less N₂ is available.

At the same time as the oxygen concentration increases, the flame temperature increases. This accelerates NO_x formation. So the optimum value of oxygen enrichment is needed to achieve in order to have minimum values of NO_x emissions.

2. CO and unburned fuel

Incomplete combustion occurs when the air supply is not sufficient the carbon partially is burnt to carbon monoxide (CO) and the full calorific value of the fuel will not release. The main reason for this is the lack of oxygen. But also incompleteness can be attributed to insufficient mixing between fuel and oxygen in the combustion chamber due to the short time intervals in which these combustions are occurring [2].

CO is a flammable, nonirritating, colorless, odorless, tasteless, and normally noncorrosive gas. CO affects human health by impairing the ability of the blood to bring O₂ to body tissues.

When CO is inhaled, it rapidly crosses the alveolar epithelium to reach the blood, where it binds to hemoglobin to form carboxyhemoglobin (COHb), which led to the exclusion of oxygen so that the body becomes starved for oxygen that can eventually lead to asphyxiation. Therefore, CO is regulated pollutant [5].

In order to minimize CO emissions combustion system must operate under excess air conditions to ensure complete combustion.

In our work (waste incineration), CO emissions is particularly a problem because of the varying hydrocarbon content of the waste material.

That can be solved by using OEC which generally reduces CO emissions compared with air/fuel systems, due to more- complete combustion.

3. Carbon Dioxide (CO₂) Emissions

CO₂ is a colorless, odorless, inert gas which does not support life since it can displace oxygen.

The concentration of CO₂ have huge effects on human health, concentrations of 3 to 6% can cause headaches, and perspiration. Concentrations of 6 to 10% can cause headaches, tremors, visual disturbance, and unconsciousness. Concentrations above 10% can cause unconsciousness eventually leading to death [2].

Moreover, CO₂ considered as a greenhouse gas that may contribute to global warming.

OEC can significantly reduce CO₂ emissions because of the increased fuel efficiency which means that less fuel needs to be burned for a given unit of heat output.

4. Sulfur oxides SO_x

Sulfur oxides, usually referred to as SO_x include SO, S₂O, S_nO, SO₂, SO₃, and SO₄. SO₂ tends to be preferred at higher temperatures, and because most combustion processes are at high temperatures, is the predominant form of SO_x.

It is considered to be a pollutant because of the choking effect it can cause on the human respiratory system. Also SO₂ can produce acid rain when it is released into the atmosphere by combining with water [2].

The use of OEC does not change the production of SO_x in a combustion system. On the other hand, since the flue gas volume is greatly reduced by using OEC, any SO_x in the exhaust gases is easier to remove because of its higher concentration.

Table 1 Pollutant emissions and OEC

Pollutant Emissions	The impact	Source	The effect of OEC
NO	<ul style="list-style-type: none"> ▪ Causes irritation of the eye and throat. ▪ Tightness of the chest, nausea, headache. ▪ Gradual loss of strength. 	<ul style="list-style-type: none"> ▪ Fuels with significant amounts of organically bound nitrogen. ▪ High temperature combustion 	The O ₂ concentration will increase and the N ₂ concentration will simultaneously decrease. This lower NO _x because less N ₂ is available.
NO₂	<ul style="list-style-type: none"> ▪ Cyanosis. ▪ Increased difficulty in breathing. ▪ Irregular respiration. ▪ Possible death due to pulmonary edema. 	<ul style="list-style-type: none"> ▪ Fuels with significant amounts of organically bound nitrogen. ▪ High temperature combustion. 	The O ₂ concentration will increase and the N ₂ concentration will simultaneously decrease. This lower NO _x because less N ₂ is available.
CO	<ul style="list-style-type: none"> ▪ Reduce the ability of the blood to bring O₂ to body tissues. ▪ Lead to asphyxiation. 	<ul style="list-style-type: none"> ▪ Incomplete combustion of carbon fuels. 	More O ₂ percentages will insure having a complete combustion.
CO₂	<ul style="list-style-type: none"> ▪ Concentrations of (3- 6%) can cause headaches, and perspiration. ▪ (6-10%) can cause headaches, tremors, visual disturbance, and unconsciousness. ▪ Above 10% can cause unconsciousness eventually leading to death. ▪ Global warming. 	<ul style="list-style-type: none"> ▪ Complete combustion of carbon fuels. 	Because of the increased fuel efficiency which means that less fuel needs to be burned for a given unit of heat output which s reduce CO ₂ emissions.

SO_x	<ul style="list-style-type: none">▪ Choking effect that can cause on the human respiratory system.▪ Smog▪ Acid rain	<ul style="list-style-type: none">▪ Combustion of fuels contains Sulphur at high temperature.	Since the flue gas volume is greatly reduced by using OEC, any SO _x in the exhaust gases is easier to remove because of it is higher concentration.
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Chapter 3: Literature View

In [1], Alsayed et al used seven levels of intake air oxygen enrichment levels which are 21% -27% O₂. Moreover, 1% and 19% excess air levels were used. Efficiency improvement, CO emissions reduction, SO₂ emissions reduction, and NO_x increase were achieved. In the same context, oxygen enrichment has been implemented with internal combustion engines, where 23% O₂ enrichment has been achieved. Similarly, efficiency improvement, CO reduction, and NO_x emissions increase were achieved. OEC technology was used with high emissions fuels (biodiesel and petro-diesel in different ratios) on an experimental four stroke internal combustion engine (ICE) and that by enriched the intake air by injecting pure oxygen to combustion chamber and ensure appropriate mixing before reaching the flame. The result was taken once with petro-diesel fuel, biofuel or blended fuel (petro-diesel with biodiesel) by comparing the exhaust gas temperature, NO_x emissions, CO emissions and SO₂ emissions. It has been shown that using higher intake air oxygen concentrations with pure petro-diesel or blended fuel increase the exhaust gas temperature obviously. 14% was the highest exhaust temperature improvement achieved when using 24% O₂ concentration with pure petro-diesel. When using Biodiesel fuel, it intensifies the combustion process and improves the exhaust gas temperature due to the additional oxygen quantities contained in it. In addition, when using Biofuel with ambient intake air oxygen concentration (21% O₂) improves the exhaust temperature 7.4%. As well as, using OEC with internal combustion affects the exhaust emissions by increasing or decreasing its quantities. NO_x emissions analysis has been shown increased when using blended fuel, but it has been decreased when using either higher intake oxygen concentration or higher biodiesel fuel concentrations. Moreover, CO emissions analysis has been shown decrease by using higher intake air oxygen concentrations with petro-diesel, but increase when using higher intake air oxygen concentration with higher biodiesel fuel concentration at the same time. Besides, SO₂ emissions analysis has been shown no change when using OEC or biodiesel fuel in the ICE. All the emissions analysis were taken from Bacharach module 300 combustion analyzer.

Another study which is [10], the main objective of this project is to treat hazardous pharmaceutical solid waste by incineration. Incineration at high temperature is the safe and effective technology for converting pharmaceutical hazardous solid waste to stable compound by completes combustion, applying this project has importance such as attractive method for waste disposal instead of different contaminated methods lie land fill or open burning.

The project consist of two stages, the first one was designing and constructing the pyrolytic incinerator, and the second stage was operated it at high temperature to study the mass reduction, gas and ash produced during combustion. Three experiment were done; the first one was to study the mas reduction of pharmaceutical solid waste during combustion at 920 c° in incinerator with different residence time, the second one was to analyze gas produced throughout combustion of waste and to detect the relationship between gases produced with different residence time, the final experiment was to analyze the combustion of the remained after combustion of waste.

The result obtained from the experiment are: mass reduction of (> 90%) of waste with increased the residence time, and the reducing the amount of hazard gases (CO, SO₂, NO_x) with increasing the residence time and amount of O₂.

Table 2 Gases produced from combustion of (250g) Lipovast wastes at different time and T=920 °c [10]

Time (min) Outputs	2	4	6	8	24	30	35	40	47	53	58
O₂ (ppm)	14.4	15.5	15.3	16.2	17.8	18.3	19.1	19.5	19.7	19.9	20
CO(ppm)	130	122	94	28	23	35	68	67	66	65	62
Temperature stack (c°)	160	126	167	225	221	220	205	185	170	158	152
CO₂ (ppm)	4.8	4.5	4.3	3.5	2.4	2	1.3	1	0.8	0.7	0.6
NO_x (ppm)	35	33	50	44	29	25	16	12	11	9	8
NO (ppm)	0	0	0	0	0	0	0	0	0	0	0
NO₂ (ppm)	36	35	50	44	29	25	16	12	11	9	8
SO₂ (ppm)	34	0	0	0	0	0	0	0	0	0	0

Table 3 Gases produced from combustion of (250g) mixed waste at different time and $T=920\text{ }^{\circ}\text{C}^{[10]}$

Time (min) Outputs	8	13	18	26	33	38	45	52	70	80	85	90	95
O ₂ (ppm)	19.4	19.2	19.3	19.4	19.5	19.6	19.4	19.3	18.6	19.2	19.4	18.2	18.8
CO(ppm)	210	191	192	178	182	188	188	209	212	154	168	56	139
Temperature stack (c°)	183	193	199	202	201	201	183	191	205	229	216	223	241
CO ₂ (ppm)	1.1	1.3	1.2	1.1	1	1	1.1	1.1	1.2	1.7	1	2.1	1.6
NO _x (ppm)	12	10	10	10	7	6	5	12	23	13	11	28	21
NO (ppm)	12	10	10	10	7	6	5	5	5	0	0	12	3
NO ₂ (ppm)	0	0	0	0	0	0	0	6	17	13	11	15	16
SO ₂ (ppm)	31	26	25	22	22	18	16	14	0	6	8	0	0

From the figure 3.1, the stack temperature of mixed waste, and lipovast increase with increasing the residence time because the reaction is exothermic. Then the temperature decrease at 40 min because the amount of waste reduced and approximately converted to gases during this time.

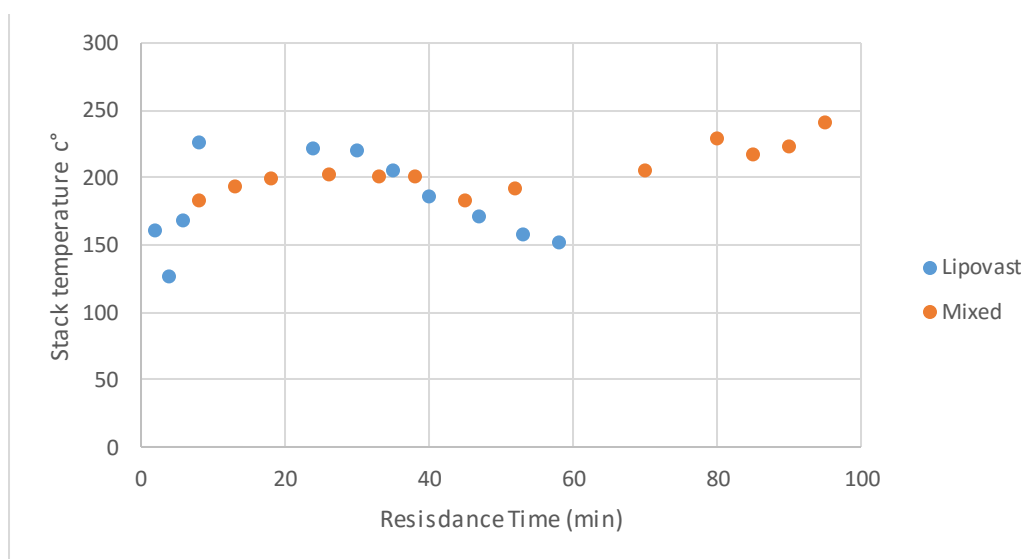


Figure 3.1 The relationship between residence time and the stack temperature of Lipovast and mixed ^[10]

As shown in figure 3.2 the concentration of CO decreased with increasing the residence time at the same temperature. CO converted to CO₂ as a result of complete combustion due to increasing the amount of O₂, and decreasing the amount of fuel as shown in figure 3.4. The concentration of CO in the mixed waste is higher than the Lipovast solid waste because it contains different composition. As shown in figure 3.3 in general the concentration of O₂ for solid waste increase with increasing the residence time because the mass reduction increase, but in mixed waste there is an experimental error. The concentration of gas produce depend on the composition of waste. In addition, as shown in figure 3.5 and figure 3.6, the concentration of NO_x and NO₂ decrease with increasing residence time.

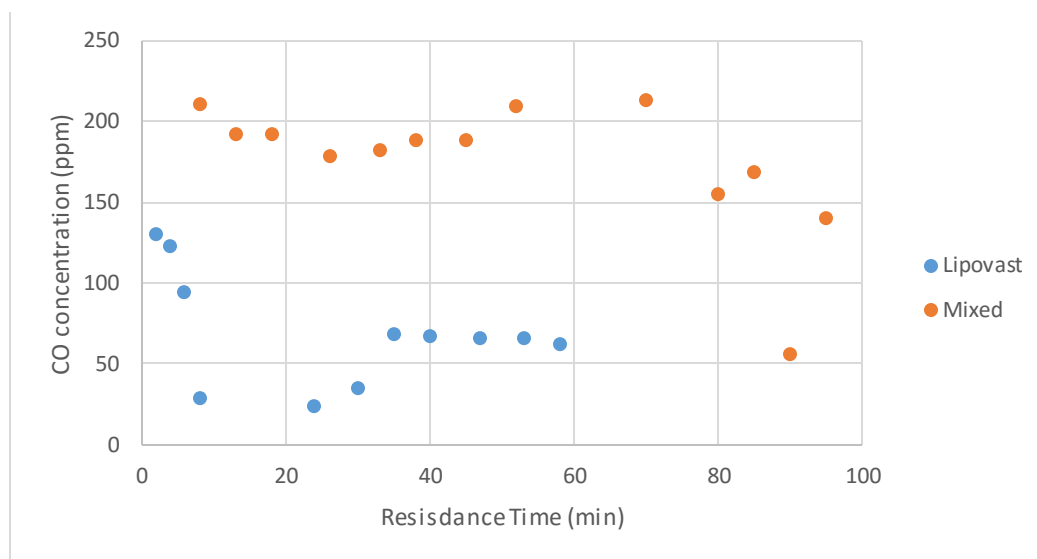


Figure 3.2 The relationship between residence time and the concentration of CO gas in ppm ^[10]

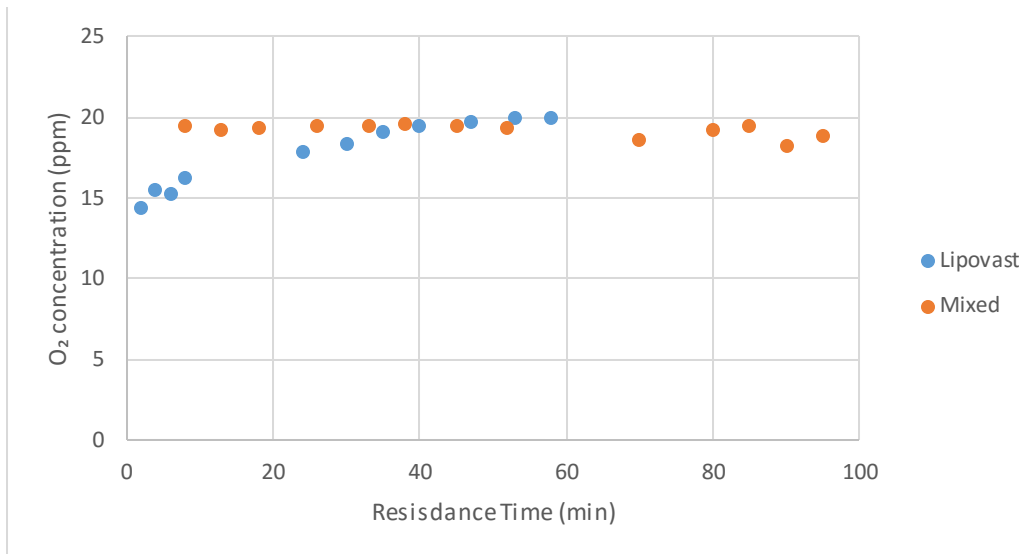


Figure 3.3 The relationship between residence time and the concentration of O₂ gas in ppm^[10]

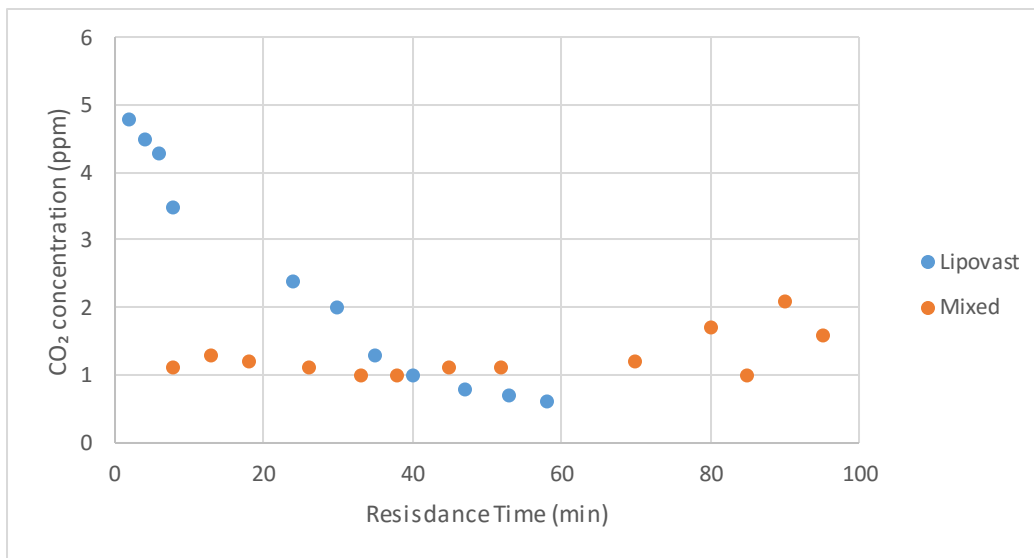


Figure 3.4 The relationship between residence time and the concentration of CO₂ gas in ppm^[10]

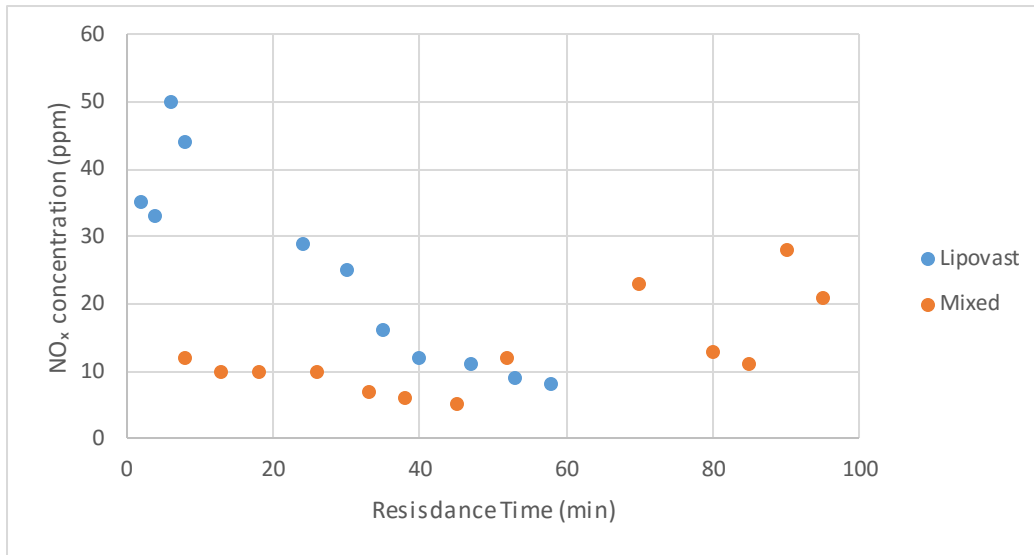


Figure 3.5 The relationship between residence time and the concentration of NO_x gas in ppm^[10]

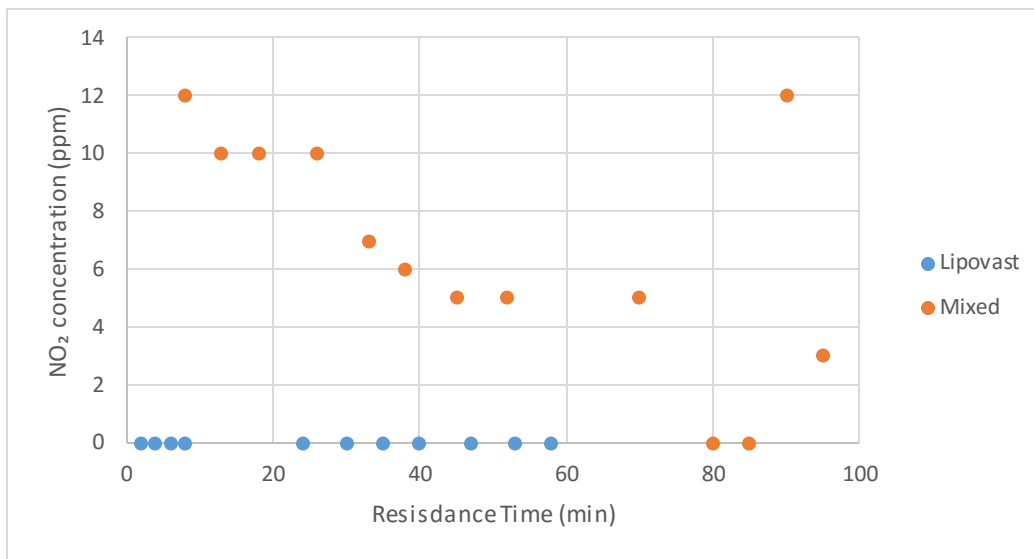


Figure 3.6 The relationship between residence time and the concentration of NO₂ gas in ppm^[10]

As shown in figure 3.7 and 3.8, the concentration of NO and SO₂ are approximately zero because lipovast waste does not contain sulfur composition and complete combustion for NO, but for mixed waste the concentration of SO₂ and NO decrease with increasing residence time.

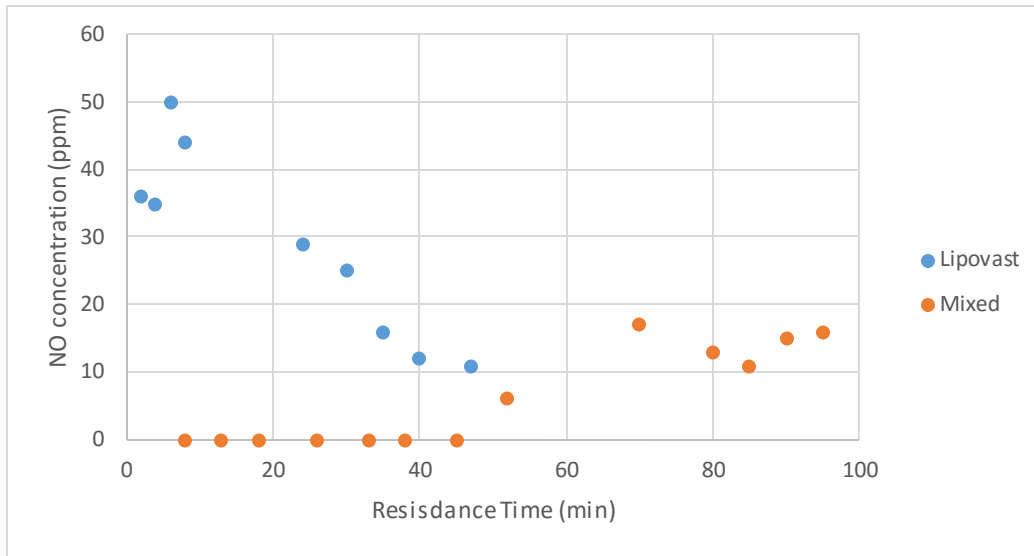


Figure 3.7 The relationship between residence time and the concentration of NO gas in ppm ^[10]

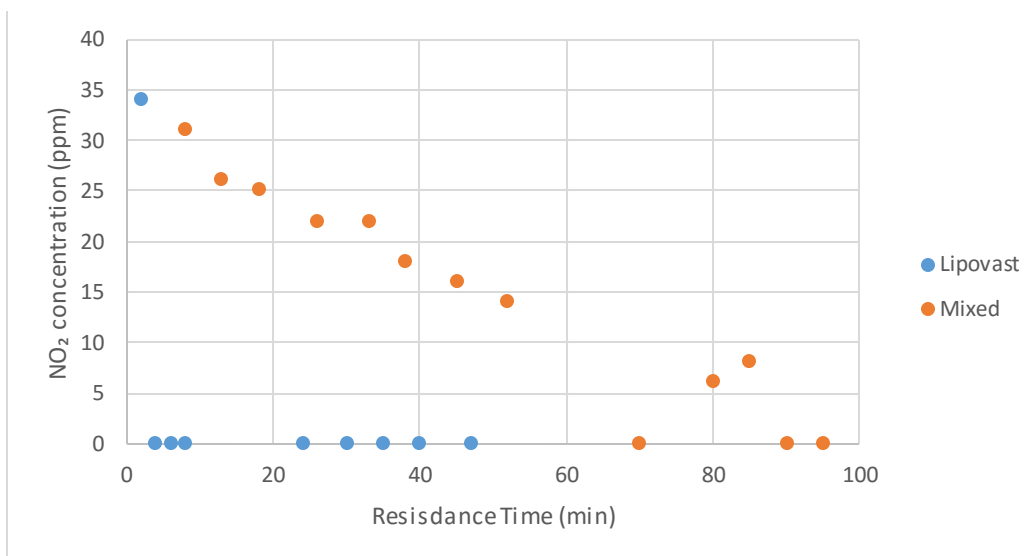


Figure 3.8 The relationship between residence time and the concentration of SO₂ gas in ppm ^[10]

Chapter 4: Methodology

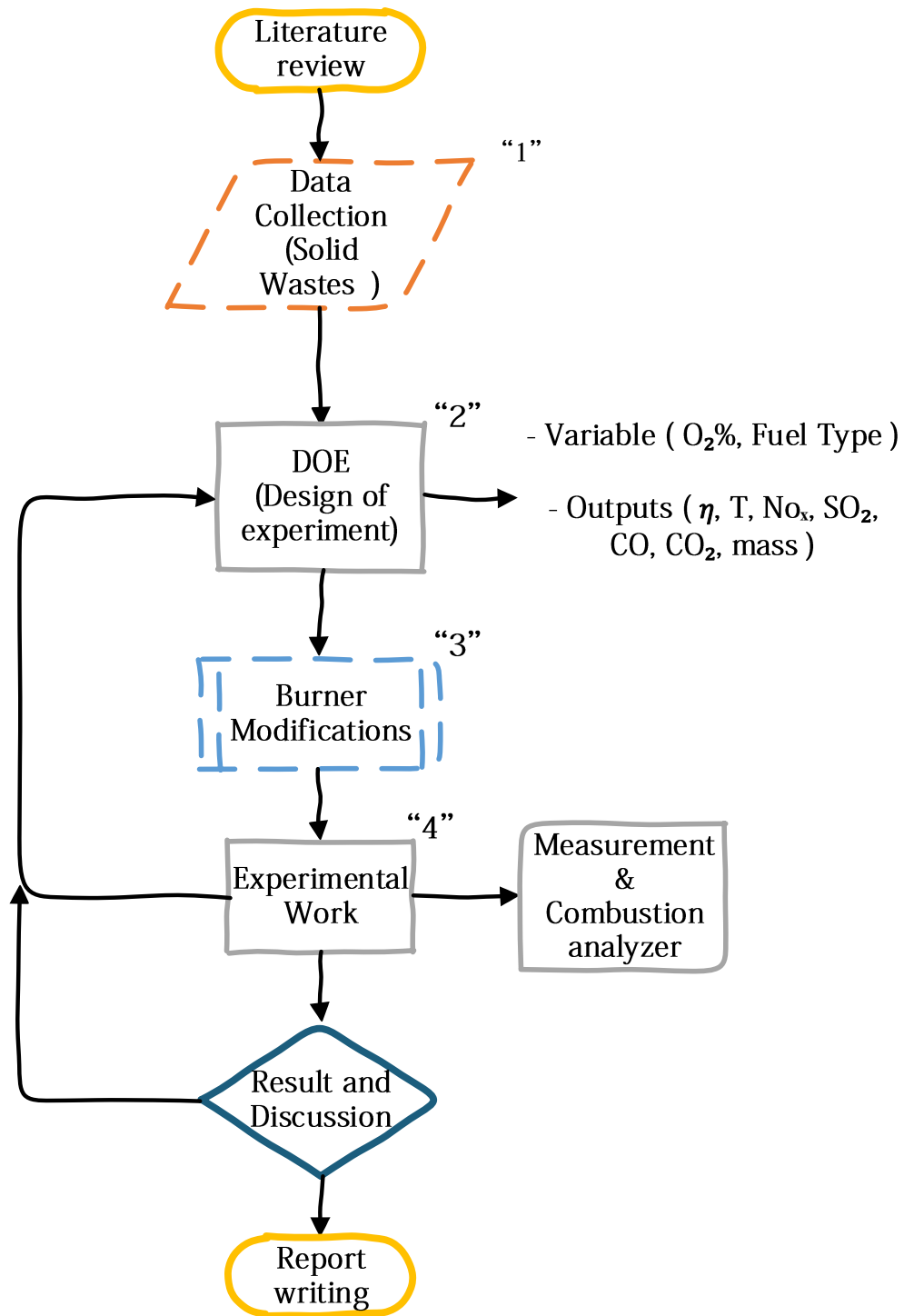


Figure 4.1 Experimental Methodology

4.1 Data collection (Solid wastes [Drugs], Emissions and Coal)

Data collection is a process of gathering and measuring information on targeted variables in an established systematic fashion, which then enables one to answer relevant questions and evaluate outcomes. Therefore, it is necessary to know the current condition and data related to the project.

According to Palestinian Central Bureau of Statistics, Emissions to Air report in 2011 shows the amounts of carbon dioxide emitted from the energy, agriculture and solid waste sectors were estimated at around 3.1 million tons, distributed as 2.7 million tons from the energy sector, 326 thousand tons from agriculture and the remaining 63 thousand tons from the solid waste sector (open burning of solid waste). In figure 4.2, shows the amount change of CO₂ during period 2001-2011.

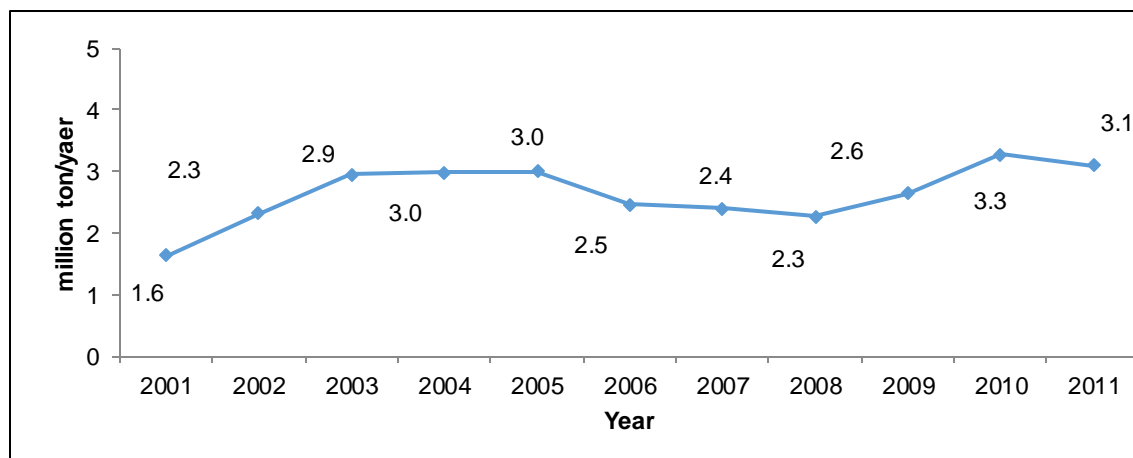


Figure 4.2 Amounts of CO₂ emitted in Palestine (2001-2011) ^[6]

In addition, amounts of NO_x emitted from the energy sector during 2011 were estimated at around 40,112 tons compared to 27,533 tons during 2001. In figure 4.3, shows the amount change of NO_x during period 2001-2011.

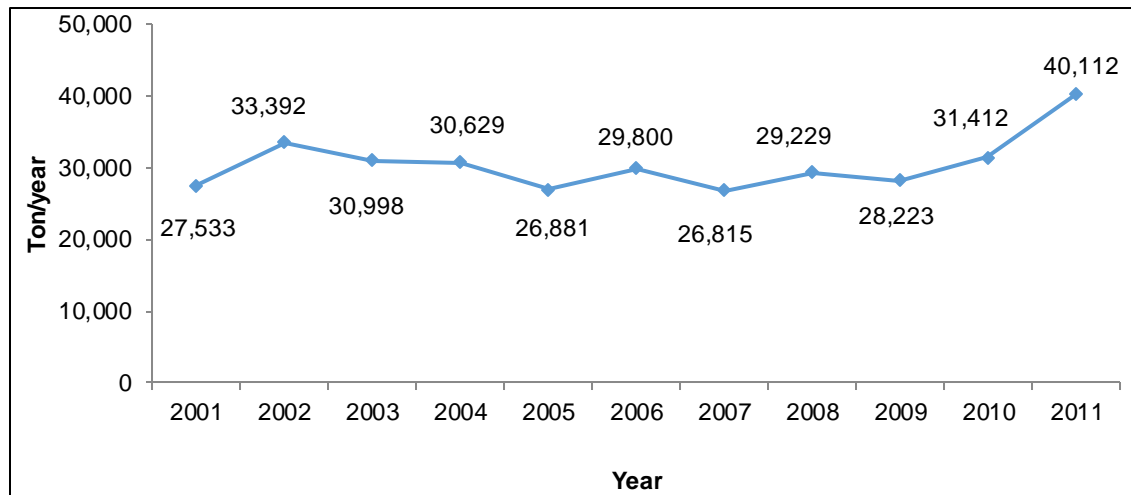


Figure 4.3 Amounts of NO_x Emitted in Palestine (2001-2011) ^[6]

Follow to emissions, the amounts of CO emitted from the energy sector during 2011 were estimated at around 283,190 tons compared to 193,486 tons during 2001. In figure 4.4, shows the amount change of CO during period 2001-2011.

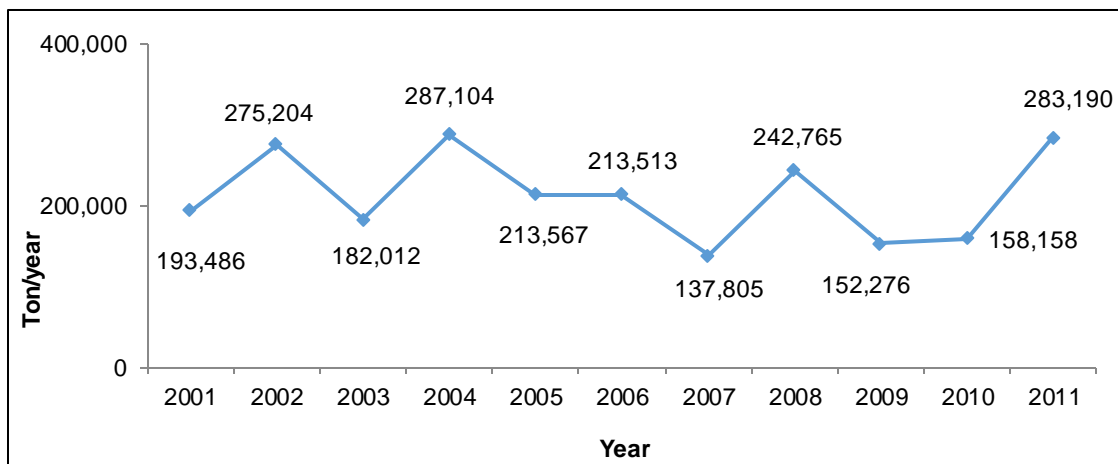


Figure 4.4 Amounts of CO emitted in Palestine (2001-2011) ^[6]

Moreover, data collection in year 2000 for Medical waste especially pharmaceutical waste in 2000. The percentage of chemical, pharmaceutical and non-radioactive wastes according to tables 4, equal 2.3% in West bank and 8.7% in Gaza Strip, from all the medical waste.

Table 4 Percentage Distribution of Medical Establishments by the Type of Separated Medical Waste and Region in year 2000 ^[8]

Type of Waste	المجموع Total	المنطقة Region		نوع النفايات
		قطاع غزة Gaza Strip	الضفة الغربية West Bank	
General Waste	30.4	22.2	33.9	النفايات العامة
Infectious Waste	20.6	20.3	20.8	النفايات المعدية
Chemical, Pharmaceutical and non radioactive Wastes	4.2	8.7	2.3	نفايات كيميائية وصيدلانية وغير مشعة
Radioactive Waste	1.5	2.6	1.0	النفايات المشعة
Sharp Waste	42.9	46.2	41.4	النفايات الحادة
Others	0.4	0.0	0.6	أخرى
Total	100	100	100	المجموع

Besides, Pharmaceutical wastes moreover chemical and non-radioactive disposal use land burial not by open burning or incineration. Table 5 confirm that, which the percentage of the pharmaceutical, chemical and non-radioactive waste 0% in both West Bank and Gaza Strip that use open burning.

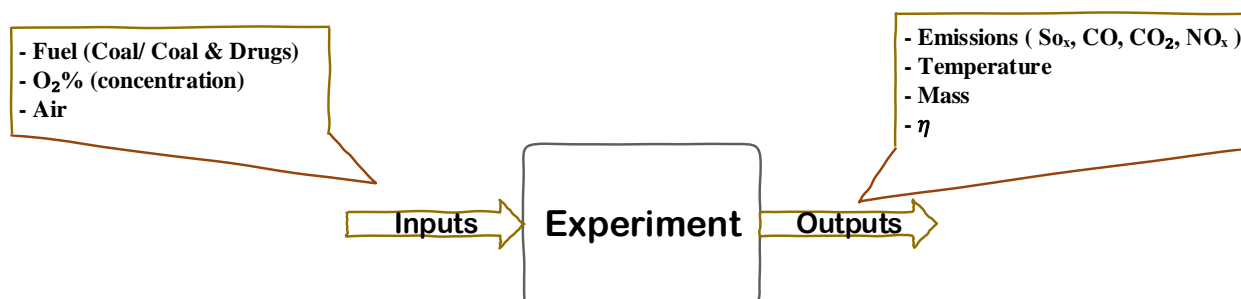
Also related to administrator in Birzeit Pharmaceutical Co (BPC). confirm until now a days using land burial which is responsibility of Ministry of Health.

Table 5 Percentage Distribution of Medical Establishment by Type of Medical Waste Treated with Open Burning Method and Region in year 2000 ^[8]

Type of Waste	المجموع Total	المنطقة Region		نوع النفايات
		قطاع غزة Gaza Strip	الضفة الغربية West Bank	
General Waste	56.0	24.5	100	النفايات العامة
Infectious Waste	18.3	31.4	0.0	النفايات المعدية
Chemical, Pharmaceutical and non radioactive Waste	0.0	0.0	0.0	نفايات كيميائية وصيدلانية وغير مشعة
Sharp Waste	25.7	44.1	0.0	النفايات الحادة
Total	100	100	100	المجموع

Charcoal production in Palestine consider very important in Jenin city especially in Yabad village. According to estimates by the Ministry of National Economy in Jenin and Society "Coal eco-friendly" in Yabad; number of workshops coal production in the Yabad area was about 80 Workshop, including 55-60 workshop in the town of Yabad and neighboring villages and 20 workshop behind the apartheid wall, and annual production is nearly 15 thousand tons. It produces each workshop about 20 tons of coal per month, and in the year between 200-250 tons of coal [9].

4.2 DOE (Design of experiment)



O₂ concentration from the input and all of components in output except the mass are going to be measured by using combustion analyzer at different O₂ concentrations in order to prove the effect of OEC in pollutants reduction and efficiency improvement.

There is no plant incinerating waste in Palestine. All types of waste (domestic, medical, and industrial) are mixed, and it is assumed that about 85 per cent are burned in open air.

Table 6 PCBS: Emissions to Air from waste incinerating, 2004 [7]

Component	(Kg/ton)
SO ₂	0.5
CO	42
NO _x	3.0

4.3 Burner modification

The burner that used was modified to obtain the concept of the experimental work by specific modifications which were adding an air diffuser inside the chamber has a function of uniform

air distribution; another thing is adding other entrance for pure oxygen generator and a mixing point (T connection) with a distance of 80 cm away from the connection point with the burner to ensure that the mixing between air and pure oxygen have done very well. At the top there is a smokestack which will use the combustion analyzer from ENERAC instruments, Model number 500, to get the data analysis from it. Figure 4.5 shows the Structure of the burner.



Figure 4.5 Burner Structure

4.4 Experimental Work

1. Equipments

- All the combustion process were done by using this burner show in figure 4.5, which characteristics were mentioned above in point 4.3 (**Burner modification**).
- The air flow was controlled by adjusting the same flow speed at all the experiments.



Figure 4.6 Air flow supply

- The oxygen cylinders which were used to provide the oxygen stream.



Figure 4.7 Oxygen cylinder

- The junction point for the air and oxygen streams, to insure proper mixing, the outlet stream was directly connected to the burner input.

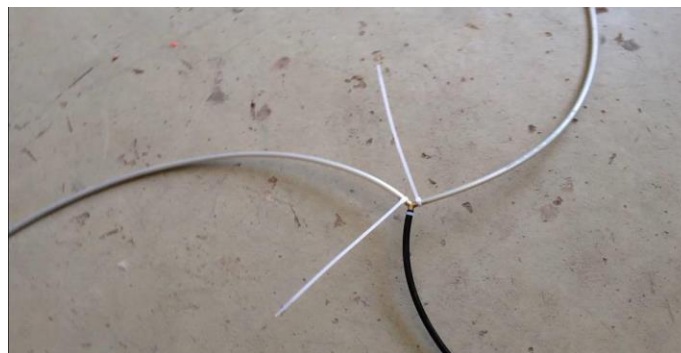


Figure 4.8 Junction point (air and oxygen)

- This bottle was used to determinate the concentration of O_2 , by putting the outlet stream from the junction point inside the bottle and measure $O_2\%$ using the combustion analyzer, this method was done to insure isolate the mixture from the ambient air.



Figure 4.9 Show how to confirm oxygen concentration

2. Fuels

- Charcoal was used as fuel with an amount of 500 g in every trial, 25% of this amount was used as a heat source. Because in the combustion not only the fuel and the oxidizer are important, some source of heat is also necessary to start combustion. Once combustion gets started, there is no need to continue providing the heat source.
- Expired drugs.



Figure 4.10 Expired drugs

3. Measuring devices

- The combustion analyzer (ENERRAC micro-emissions analyzer model 500) which is used to calculate emissions concentrations, total efficiency, the efficiency calculated by it is a modified equation that considers combustion efficiency and stack losses. And O₂ concentration.



Figure 4.11 Combustion analyzer device

- Infrared thermometer with laser pointer which was used to measure to maximum and instantaneous temperatures.



Figure 4.12 Thermometer laser device

Chapter 5: Result and Discussion

The experiment implemented using burner, and the results were measured by the combustion analyzer, each measured result was documented after suitable enough time of inserting the combustion analyzer probe into the exhaust stack emissions and the combustion chamber to ensure stability and steady measurements.

In this experimental work, 6 levels of intake air oxygen enrichment were used; these levels are 20% O₂ which is the ambient air composition, 21%, 22%, 23%, 24%, and one case more than 24%. No higher intake air oxygen concentrations were used in order to maintain the burner, because higher oxygen concentrations need some modifications to protect the burner from damage as a result of the expected higher output temperature. In addition, the combustion analyzer cannot read more than 24% for O₂.

The main variable in this experiment is O₂ concentration in the intake air and the experiment includes two stages the first one was burning charcoal alone, the second burning charcoal with expired drugs. In addition, the combustion analyzer used to measure the burner exhaust gas temperature, NO_x emissions, CO emissions and SO₂ emissions, CO₂ emissions, and efficiency.

The result which measured in 20% of O₂ (ambient air) was taken as a reference to compare with the rest of the results by increasing the O₂ concentration.

➤ 5.1 Charcoal

- **Effect of Oxygen Concentration on Exhaust Gas Temperature**

The exhaust gas temperature can be used as an indicator about the combustion process and how affected by higher intake air oxygen concentrations.

The output gas temperature increases almost linearly by increasing the intake air O₂ concentration, it happens as a result of the additional oxygen quantities enter the combustion process; these oxygen quantities improve the combustion process and produce higher thermal energy.

The results summarized in Table (7) it is shown that using more than 24% O₂ intake air enrichment produce 100.5 °C output gas temperature which is higher than the output gas temperature when using 20% O₂ intake air.

Table 7 Burner stack gas temperature when using different O₂ concentrations

	O₂ %	Temp(°C)	Stack Temp (°C)
Reference point →	20.6	382	33.89
	21	410	39.4
	22	490	64.12
	23	544	86.67
	24	712	90.24
	> 24	977	100.5

- **Effect of Oxygen Concentration on Exhaust NO_x Emissions**

As mentioned before, NO_x emissions is one of the most poisonous combustion products, it contributes in forming acid rain which is destructive to whatever it comes in contact with, including plants, trees, and manmade structures like buildings and bridges.

In this experimental work, results show that NO_x emissions increase by using higher intake air oxygen concentration, the combustion process improvement due to additional oxygen quantity contributes in increasing NO_x emissions thermal formation.

These results are shown in Table (8). It shown that increasing in NO_x concentration in the stack gas emissions when using 24% O₂ intake air enrichment is higher than these emissions 20% O₂ intake air.

Table 8 Burner stack gas NO_x formation when using different O₂ concentrations

	O ₂ %	Temp (°C)	NO _x (ppm)
Reference point →	20.6	382	0
	21	410	8
	22	490	10
	23	544	15
	24	712	23
	> 24	977	48

- **Effect of Oxygen Concentration on Exhaust CO Emissions**

Carbon monoxide is a toxic gas which is harmful for human and environment, and it contributes in forming smog. However, CO emissions can be used as an important indicator for combustion process completeness, higher CO emission means larger portion of the fuel does not burn completely.

In table (9), show experimental results that using higher intake air oxygen concentrations keep the CO over due to the incorrect position of O₂ entrance which was at the top of burner but in fact it must be from the bottom of the burner or even from multiple inlets to ensure that the distribution is very well and reach to a complete combustion.

Table 9 Burner stack gas CO concentration when using different O₂ concentrations


	O ₂ %	Temp (°C)	CO(ppm)
Reference point →	20.6	382	Over
	21	410	Over
	22	490	Over
	23	544	Over
	24	712	Over
	> 24	977	over

- **Effect of Oxygen Concentration on Exhaust O₂ Emissions**

To ensure as complete combustion as possible, it is necessary to operate under excess air conditions, which means higher intake air quantities containing more O₂ concentrations are given to the process to improve the combustion and ensure its completeness.

Experimental results show that using higher intake air oxygen concentration increases the O₂% in the exhaust gas. The result shown in table (10).

Table 10 Burner stack gas O₂ concentration when using different O₂ concentrations

Reference point


O ₂ %	Temp (°C)	O ₂ % on stack
20.6	382	12
21	410	16.3
22	490	16.7
23	544	17.1
24	712	17.5
> 24	977	24

- **Effect of Oxygen Concentration on Exhaust SO₂ Emissions**

SO₂ is a poisonous gas that can be very corrosive in the presence of water. It is more destructive to plants than humans and animals; it forms acid rain when it combines with water in the atmosphere which is so destructive to the environment.

The change in the production of SO₂ in a combustion system is very little as it shown in table (11) below.

Table 11 Burner stack gas SO₂ concentration when using different O₂ concentrations

	O ₂ %	Temp °C	SO ₂ (ppm)
Reference point →	20.6	382	157
	21	410	159
	22	490	161
	23	544	155
	24	712	152
	> 24	977	149

- **Effect of Oxygen Concentration on Combustion Efficiency**

Combustion efficiency can be defined as the ratio of output energy to input (stored) energy, in actual life, thermal efficiency is always below 100%, and it is determined by subtracting the heat content of the exhaust gases, expressed as a percentage of the fuel's heating value, from the total fuel-heat potential, or 100%, as shown in the formula below.

$$\% \text{ Combustion Efficiency} = 100\% \left(\frac{\text{stack heat losses}}{\text{fuel heating value}} \times 100 \right)$$

In this experimental work, the increasing in stack gas temperature is an indicator of the combustion process improvement and also improvement in combustion efficiency. Result shown in table (12). The optimum efficiency measured was 89.9% at 24% O₂ concentration.

Table 12 Combustion efficiency improvement indicators when using higher O₂ concentrations.

	O ₂ %	Temp (°C)	η %
Reference point →	20.6	382	68
	21	410	71
	22	490	79.8
	23	544	84
	24	712	89.8
	> 24	977	Over

- **Effect of Oxygen Concentration on excess air**

Although higher excess air level leads to better combustion characteristics, it has unavoidable disadvantages too; it carries a tangible amount of thermal energy by convection from combustion chamber and transfers it out to atmosphere as a waste energy with stack gases, to minimize this effect, the excess air level should be optimized at minimum points.

In this experimental work, higher oxygen quantities can be given to the combustion process without using higher excess air levels, instead of it, enriching the intake air with higher oxygen concentrations can produce more benefits and reduce the energy waste due to higher excess air levels. Table (13) shown the result.

Table 13 Combustion excess air when using higher O₂ concentrations

Reference point


O₂ %	Temp(°C)	Excess Air%
20.6	382	397
21	410	340
22	490	280
23	544	210
24	712	171
> 24	977	141

➤ **5.2 Charcoal with drugs:**

In this experiment the drugs added at each O₂ concentration level, but it was noticed that the drugs did not burn until the temperature becomes over 600 °C. Mass reduction reach 90% for the drugs and that was appeared after finishing the combustion.

Table 14 Effect of O₂ concentration on burner temperature

O ₂ (%)	Temp (°C)
21	392
22	440
23	505
24	724
> 24	985



Figure 5.1 Adding the drugs into the burner



Figure 5.2 Drugs stayed the same at low temperature



Figure 5.3 Drugs after reaching high temperature

Chapter 6: Conclusion and Recommendations

Waste disposal sector in Palestine is suffering from a lack of experience and the support of modern technologies. The Ministry of Health used the burial method by dumping in a landfill and this has a negative impact on soil and water. In the project a modified burner used to burn charcoal and expired drugs with charcoal using OEC (different O₂ concentrations). Experimental work confirms the success of OEC method for expired drugs disposal, which was achieved when reached high temperature (more than 600 °c). The highest temperature achieved was 985 °c at > 24% O₂ concentration. Some of unexpected results appeared like CO concentration, which have been over at all O₂ concentration. The reason return to non-uniform intake air distribution inside the burner. In addition, NO_x expected to reduce with using OEC, but for the same reason for CO concentration, NO_x concentration increased. Furthermore, SO₂ analysis stayed in the same range which did not change very much in whole experiment, which was expected before. Another goal achieved, reduction in drugs mass about 90% from the whole mass.

Recommendation:

- Designing the burner with intake air from the bottom to ensure distribution air inside to have complete combustion.
- Using Oxygen generator to get the best and easiest calibration for oxygen.
- Increase the height of the smoke stake to reduce the temperature of released gases.
- Improve the insulation system in the burner to reduce heat losses.
- Doing Ash analysis for ash samples then decide what to do with it.
- Build a system to recover the energy produced from combustion
- A cooperation with the Ministry Of Health in order to construct incineration plant.

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