Treatment of Flue Gas from an Infectious Waste Incinerator using the Ozone System

Wenich Vattanapuripakorn[1], Khomson Khannam[1], Sathapon Sonsupap[1], Umakorn Tongsantia[2], Jiradanai Sarasamkan[3], and Bopit Bubphachot[4*]

[1]*Department of Mechanical Engineering, Faculty of Engineering, Mahasarakam University, Mahasarakam 44150, Thailand*
[2]*Department of Public Health Administration, Faculty of Public Health, Khon Kaen University, Khon Kaen 40002, Thailand*
[3]*Department of Radiology, Faculty of Medicine, Khon Kaen University, Khon Kaen 40002, Thailand*
[4]*Heat Pipe and Thermal Tools Design Research Unit (HTDR), Faculty of Engineering, Mahasarakam University, Mahasarakam 44150, Thailand*

ARTICLE INFO

Received: 31 Dec 2020
Received in revised: 29 Apr 2021
Accepted: 8 Jun 2021
Published online: 20 Jul 2021
DOI: 10.32526/ennrj/19/2020282

Keywords:
Infectious waste/ Ozone/ Treatment/ Air pollution /Rotary kiln/ Atmosphere/ Oxidation

*** Corresponding author:**
E-mail: bopit.b@msu.ac.th

ABSTRACT

Recently, levels of air pollution caused by exhaust gases from infectious waste combustion have been rising at a startling rate. Pollutant gases such as carbon monoxide (CO) and nitrogen dioxide (NO_2) have numerous health implications when unsafe amounts are released into the atmosphere. Thus, Pollution Control Systems (PCS) and Gas Cleaner Systems (GCS) play an important role in industries and the monitoring of incinerators. This research evaluated the GCS of rotary kilns in medical facilities located in the Northeast of Thailand. Data was collected from various sites, analyzed, and examined. Furthermore, Ozone (O_3) technology was applied to the rotary kiln allowing for the collection of new information on the pollution treatment systems. O_3 technology was installed along with the Wet Scrubber System (WSS) catalyzing the oxidation of O_3 and pollutant gases. In addition, a chiller was added to control and stabilize the temperature of the water. After the water temperature was controlled, the concentration of O_3 increased resulting in an efficient pollution treatment system. Levels of pollutant gas emission were found to be beneath control standards of both Thailand and those of the U.S. EPA. TSP content was reduced significantly from 22.0 mg/m^3 to 3.4 mg/m^3 (97%), CO content from 13.6 mg/m^3 to 1.7 mg/m^3 (96%), and NO_2 content fell from 16.3 (mg/m^3) to 2.0 mg/m^3 (99%). It is clear that the rotary kiln and Ozone technology should be used together in order to create a new and far more effective method of pollution treatment in small and mid-sized cities of Thailand.

1. INTRODUCTION

At present, solid waste management in Thailand is already considered a serious problem and continues to grow. According to the data in a 2018 report on solid waste and hazardous waste, the amount of solid waste was about 27.8 million tons, an increase of 1.64% compared to 2017. Due to the rapid expansion of urban communities, the shift from an agricultural society to an urban society, population increase, a significant rise in tourism, and increased consumption, the country is generating solid waste at levels never seen before. Municipal waste of roughly 9.58 million tons (34.0%) was separated at the source and reused, an increase of 13.0% from the previous year. Most of it was utilized as recyclable waste and organic waste. Disposal methods also play an important role as a total of 10.88 million tons (39.0%) was disposed of properly, whereas the remainder totaling approximately 7.36 million tons of waste (27.0%) was disposed of incorrectly (PCD, 2018). According to the Thailand state of pollution report 2012-2016, the amount of infectious waste is more than likely set to increase continuously. According to the report, a steady upward trend in the amount of infectious waste produced can clearly be seen with 43,800 50,481 52,147 53,868 and 55,656 tons per year, respectively. Infectious waste is classified by its source of origin, namely, public hospitals (56.79%), private hospitals

Citation: Vattanapuripakorn W, Khannam K, Sonsupap S, Tongsantia U, Sarasamkan J, Bubphachot B. Treatment of flue gas from an infectious waste incinerator using the ozone system. Environ. Nat. Resour. J. 2021;19(5):348-357. (https://doi.org/10.32526/ennrj/19/2020282)

(17.0%), clinics (19.2%), sub-district health promotion hospitals (6.375%), animal hospitals (0.6%), and hazardous laboratories (0.01%) (PCD, 2017). The staggering amount of waste produced requires a number of different management methods such as landfills, incineration, recycling, sustainability practices, biological reprocessing, energy recovery, avoidance and reduction, waste handling and transport, technologies, etc. (Bacinschi et al., 2010). The incineration method is the most popular because it requires the least amount of space and it can eliminate large amounts of waste which can be processed into energy. However, a major drawback is the high air pollution it generates (Innocent et al., 2013). The combustion of fossil fuels, solid wastes, and biomass emits large amounts of pollutants, including sulfur dioxide (SO_2), nitrogen dioxide (NO_2), organic pollutants, heavy metals, and particulate matter (PM). Substance emissions released from incineration include carbon monoxide (CO), hydrogen chloride (HCl), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and metal vapor (National Research Council, 2000). Smoke, dust, noxious fumes, and acid rain are all byproducts of the incineration method as well. This can pose a serious risk to quality and length of life as well as environmental ecology (Ma et al., 2012; Perera, 2017). The greatest risk air pollution poses is on breathing and the increased likelihood of respiratory problems. NO_2 inflames the lining of the lungs and reduces immunity to lung infections. This can cause health effects such as wheezing, coughing, colds, flu, and bronchitis with complications leading inevitably to more severe cases of diseases such as pneumonia and cancer. Children with asthma and older people with heart disease are most at risk.

This review focuses on the work in fuel pollutant treatments through low temperature ozone oxidation, especially CO, NO_2, organic pollutants, and industrial applications for the simultaneous removal of SO_2 and NO_2 with ozone. To date, most industrial research publications continue to contribute to the simultaneous elimination of SO_2 and NO_x, which has been written about extensively. This work is primarily concerned with more serious applications of ozone gas generators with wet scrubbing technology in industries. (Wang and Zhong, 2016), such as carbon black drying kiln furnaces (Ma et al., 2016), marine emissions (Xi et al., 2019; Zhou et al., 2016), glass melting furnaces (Yamamoto et al., 2016), and pulverized coal boilers (Si et al., 2019).

According to the analysis of the amount of pollutants emitted from the chimney of the infectious waste incineration system after the addition of the O_3 system, the addition of one additional oxygen atom resulted in new molecules with conditions which were stable to high energy and hard to damage due to factors such as temperature, heat, pressure, and reaction with substances with lower energy leading to rapid oxidation. O_3 has been found to have an oxidation potential of up to 2.07 electron Volts (eV). According to the principles of electrical energy, the corona discharge phenomena (CD ozone) is a method for allowing pure and dry oxygen gas to pass through thousands of volts of an electrical field (50-100 Hz), at medium frequency (100-1,000 Hz) and high frequency (1,000 Hz or more) at the discharge gap caused by the production of electricity at the dielectric surface that is a factor causing the ozone concentration (Hartmann et al., 2009). This electric field causes the oxygen in the air to split into oxygen atoms (O^-) that are stable and combine with other oxygen molecules. O_3 is released in a high concentration, from 1-10% by weight, which can be used to treat water and air effectively. The machine sizes range from small to large (milligrams to kilograms per hour level); machines have very low operating and maintenance costs, and they can be used forever. It is not necessary to replace old machines like those which use other deodorizing chemicals, which is a distinctive feature of ozone. (except for storage under low temperatures or ice) (U.S. EPA, 1999a). The decay of ozone depends on temperature and humidity, it has a high concentration and a pungent smell, is comparable to a gas, has the potential to perform bactericidal disinfection in both water and air, and it is a very potent oxidizing agent. Therefore, it can react with organic and inorganic substances. The mechanisms of pollutant treatment from the O_3 generator that causes oxygen to react with pollutants in the system before being released into the environment are quite highly effective. (U.S. EPA, 2011), Knowledge of rotary kiln technology and the application of O_3 technology for flue gas treatment is essential for design, construction, and optimization of flue gas treatment systems on an industrial scale. (Wang et al., 2010). Another important element is the residence time that ozone can be treated in. It is suggested that the optimum residence time of 1.25 seconds for NO_2 production should be extended to 8 seconds for N_2O_5 generation. In previous studies it has been stated that NO oxidation to NO_2 can be achieved within 0.1 seconds, while

N_2O_5 generation requires 3-5 seconds at optimum temperature, using a plasma system catalytic method. (Wei et al., 2007; Lin et al., 2016). As mentioned above, NO can be converted to NO_2 and N_2O_5, with O_3 and ozone catalysis promoting efficiency and oxidation rate. It is an important step in the conversion of NO_x to nitrates, (Ding et al., 2016a; Ding et al., 2016b; Zhao et al., 2016; Guo et al., 2016; Han et al., 2018; Liu et al., 2019). Ozone oxidation and absorption in a water-filled scrubber recorded concurrent elimination efficiency levels of 90%, 93%, and 100%, respectively, with a molar O_3/NO ratio of 0.6 and (NH_2), CO/NaOH adsorption. N_2O_5 has a much higher solubility which allows it to be absorbed without any need for additives. At the same time, oxidation in treatment areas for wet pollution can also be the best choice for industries (Lin et al., 2020). The positive effects of ozone input and the promotion effect of ozone additive control on the catalytic efficiency were significant. Several changes were found in the conversion process of ozone-induced organic pollutants with the PCDD/Fs destruction efficiency of 45% compared to V-Mn/Ti-CNT at 150°C while this value increased to 91% with low concentrations (50 ppm) for the optimal use of ozone concentrations for pollution treatment (Wang et al., 2018). The SO_2 and NO_x removal efficiencies of ozone attained levels ranging from 85% to 90%, in particular, the removal of NO_2 due to the reaction with O_3 (Shao et al., 2019; U.S. EPA, 1999b). The dissolution of NO_x and mercury will increase with suspension status and organic pollutants can be decomposed into non-toxic small molecules by oxidation. O_3 is a strong oxidizing agent of gases and can cause early oxidation reactions at low temperatures and uses adsorption to eliminate NO_2 by complete oxidation. In addition, O_3 takes part in an oxidation reaction with CO_2 gas by decomposing carbon monoxide, according to $O_3 + CO \rightarrow CO_2 + O_2$ and eliminates carbon monoxide poisoning. (Young and Jordan, 1995). In summary, there are countless advantages of employing this technique though it is hardly necessary to completely abandon or overhaul the current pollution treatment systems. Only a heat exchanger and low temperature oxidation chiller are needed to assist in the control of the temperature allowing for ozone gas emissions at 20-25°C, a feature that increases the safety and flexibility of the system. Most importantly, it can be combined with other technologies to achieve lower emissions and near-zero emissions. This can be achieved by adjusting the ozone injection mixed with cold water to reach the highest ozone concentration possible. Including the use of oxygen gas to help create ozone concentrations, voltage adjustments are also required to determine the most effective ozone concentration of the ozone generator and flow field optimization, the strictest NO_x, emission standards for these approaches still face challenges to meet stringent requirements to reduce environmental pollution in both air and water treatment systems. This ozone oxidation technique can be a good alternative, either as a supplement or a standalone arrangement for the treatment of different exhaust gases or adaptation of technology to incinerators for hospitals. Overall, this approach has the following advantages: high efficiency at low temperatures; Simple regeneration of the process without affecting the front operation, and is suitable for all varieties of complex exhaust gas environments. (Lin et al., 2020; U.S. EPA, 2019; Sung et al., 2013; Yuan et al., 2016).

In this paper, the researcher studied the effects of the modified treatment of flue gas from infectious waste incinerators using an ozone system. The waste incinerator was modified by applying Ozone technology in order to be both more efficient and effective. The incinerator was designed in accordance with the U.S. EPA standards. A three step combustion function was added to the incinerator and LP gas was used as fuel in the combustion of the waste while the temperature was controlled so as to not fall below 800°C (chamber 1), 1,200°C (chamber 2), and 1,400°C (chamber 3). This temperature was high enough to combust metal waste and destroy the structure of dioxins/furans (PCDDs/PCDFs). The O_3 system was installed at the WSS where O_3 and water were mixed. This mixture injected pollutants before being released into the atmosphere. Also, the setting of the voltage system played an important role in this process since highly concentrated O_3, which was used to treat pollutant gases, was generated here. The oxygen generator was added to stabilize the concentrated O_3 generation. The efficiency of O_3 on the treatment depended on the concentration of O_3 and the temperature. Furthermore, time is another key factor that must be controlled as it allows O_3 to oxidize pollutant gases to the fullest extent. Temperature inside the scrubber room had to be maintained at the correct temperature range while the chiller kept the water temperature at 20-25°C to allow O_3 to treat pollutant gases most effectively. A chemical study of O_3 was analyzed to generate the O_3 treatment that affected the efficiency of pollutant gases which were NO_2 and CO. It was revealed that the oxidation between O_3 and low temperature exhaust gas significantly diluted the concentration of NO_2 and CO. The result suggested that the rotary kiln with O_3 application was more efficient than the one with no O_3 technology installed. Furthermore, the level of pollutant gas emissions decreased significantly when measured by the U.S. EPA and Thailand standards. The treatment method resulted in nearly zero pollutants being released. Therefore, the application of O_3 treatment methods of infectious waste incinerators needs further study as it is not only practical for industries, but also carries wide ranging implications for the global environment and human health.

2. METHODOLOGY

2.1 Infectious waste resources

The study utilized a total of 178 kg of infectious waste which came from hospitals, clinics, and medical establishments and was produced by medical services from a variety of treatments, dentistry, pharmaceuticals, laboratory diagnosis, and immunization as well as research studies conducted on humans in which there was contamination through contact with pathogens from patients or patient products. There was a clear collection process with general waste in which physical and chemical properties data were analyzed before waste was put into the incinerator. The samples of infectious waste analyzed in this research were of considerable importance because each kind of waste affected the burn and emitted different pollutants. The composition of the waste needed to be analyzed physically and chemically. Data such as weight, moisture, and density were collected. After that, each kind of waste was packed into 25×30×60 cm containers and the weight of each type of waste was recorded. The bags were completely sealed when burned and all that remained was ash after the combustion process was completed.

2.2 The infectious waste incinerator system

There are various air pollution control technologies related to maintaining safe levels of SO_2, NO_x, CO, organic pollutants, and mercury. Treatment site location and type of pollution are the two biggest factors when designing technology according to the flue behavior. A rotary kiln is designed in accordance with U.S. EPA standards. It combusts hazardous waste at least 850°C. Inside the kiln, there is a long tube placed in a horizontal line. This tube rotates while the machine is operating and is coated in fire-proof material so the machine can perform a long run combustion so that the hazardous waste is completely combusted. The function of a discharge breaching is to isolate the bottom ash caused by the combustion before the remaining ash is imported into the secondary combustion chamber. The secondary combustion chamber combusts the exhaust gases, which were left from the first combustion chamber, at a temperature not below 1,200-1,400°C (Jiang et al., 2019). At this high temperature, various types of steel, glass splinters and stainless steel are burned. A three-step kiln is designed to improve the combustion as it provides a more complete process leaving nothing remaining. The rotary kiln incinerator used in this experiment was developed using combustion furnace technology in Japan. An analysis of research advances for rotary incinerators found that the basic research for rotary incinerators tends to be mature. The latest research in rotary kilns is interdisciplinary and focused on technology integration with ozone generators. From a new perspective, this research further focuses on the comparative analysis of air emissions before and after ozone treatment of gas emissions, (Jiang et al., 2019) and was designed to achieve the highest possible efficiency for incineration systems used to dispose of infectious waste. Several recent improvements to the incinerator system in this study included improvements to the front gate of the primary chamber, where the combustion temperature is 800-1,200-1,400°C. Air-filling waste is heated and volatilized in the primary chamber. An aeration fan is used to inject and move air into the combustion chamber, which was designed to have an air flow through the front and back pipes, equalizing the air flow from both sides. The secondary chamber is used for the second round of exhaust gas combustion to eliminate gas pollution (dioxins and furans). Generally, the element mercury accounts for 20-50% in coal-burning fuel gas and 10-20% from conventional incinerators (Carpi, 1997). The cyclone separator functions as a dust collector; it typically employs centrifugal force, a form of inertia, to force the air containing dirt and dust through a vertical cylinder with a cone-shaped bottom. The aeration fan uses a high-pressure 0.5 horsepower pump to increase the pressure of the remaining gases after combustion and thus move them from the cyclone separator toward the wet scraper. The oxidized mercury is highly soluble in water and is reactive and can be absorbed in a wet scrubber. Therefore, an efficient pre-oxidation method can convert insoluble NO and Hg to highly soluble NO_2, N_2O_5, and Hg^{+2}, then simultaneous elimination can occur in the post-absorption apparatus together with SO_2 (Zhao et al., 2015). Gas scrubbing involves dust and small particles that pass through the cyclone separator. The gas treatment chamber hosts a high oxidation reaction. The cool water tank stores the cool water required for injection from a nozzle during gas scrubbing. A small portion of the warm water is subsequently released into the warm water tank. The warm water tank stores warm water heated by the absorbed pollutants from the exhaust gases produced via combustion. The debris is dropped to the bottom of the tank and subsequently disposed of. Thereafter, clean water is fed into a chilling machine. The chilling machine produces cold water that is stored in the coolant tank before it is sprayed into the scrubbing tank. Once the water absorbs the heat, leading to an increase in its temperature, it is circulated back to the chiller to be cooled again (Figure 1).

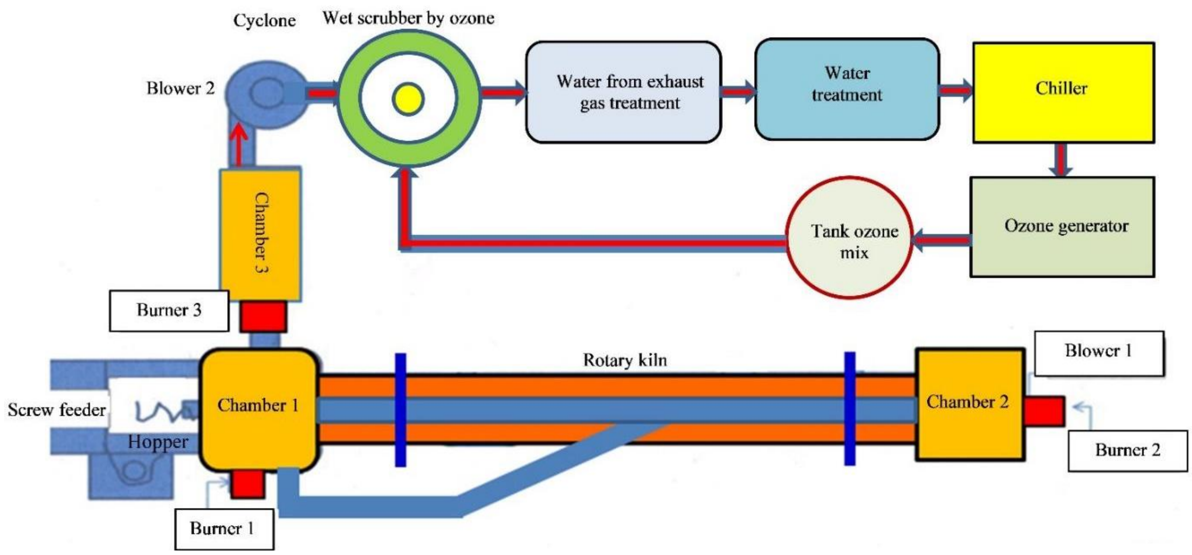


Figure 1. Infectious waste incinerator and ozone generator system

2.3 Air pollutants sampling and measurement

Sampling of the released exhaust gases at the end of the incinerator vent was performed at 2.2 m above the top end of the chimney. This process was based on the Air Quality of U.S. EPA (1999b) standard of gas emission sampling which recommends the collection of samples at a height equal to ten times the diameter of the chimney (0.22 m). The principle of emission suction from stationary sources was used to collect and analyze air quality samples for particulates.

For the sample collection in this study, the isokinetic (dry basis) sampling method was adopted; this method employs a filter cured at 105°C at the same wind velocity present during measuring, to prevent the refraction of moving particles and maintain an acceptable isometric kinetic range of ±10%. The methods used for air sampling and analyses are listed in Table 1. The results of fuel gas analysis were compared with the Thailand regulatory system and the U.S. EPA (1999b) standard.

Table 1. Methods of air pollution sampling and analysis

Parameters	Analysis method	Standard Value U.S. EPA (1999b)
Mercury (Hg)	Isokinetic, Cold Vapor - ASS	0.05 mg/m^3
Lead (Pb)	Isokinetic, ICP-AES	1.50 mg/m^3
Cadmium	Isokinetic, ICP-AES	0.50 mg/m^3
Hydrogen fluoride (HF)	Ion Chromatography	16.40 mg/m^3
Particulate (TSP)	Isokinetic, Gravimetric	320.00 mg/m^3
Sulfur dioxide (SO_2)	Barium Thorin Titrimetric	79.00 mg/m^3
Oxides of nitrogen (NO_x as NO_2)	Chemical Absorption, Colorimetric	470.00 mg/m^3
Carbon monoxide (CO)	Bag, Non-Dispersive Infrared	45.80 mg/m^3
Hydrogen chloride (HCl)	Ion Chromatography	119.00 mg/m^3

2.4 Ozone generator for fuel gas treatment

The O_3 generator (Figure 2) used in this experiment was developed and designed to achieve the highest possible efficiency for treatment systems used to dispose of infectious waste. The several recent improvements to the treatment system in this study are described below (Table 2).

Table 2. Infectious waste treatment system by ozone generator

Parameters	Value
Temperature chamber wet scrubber	20-25°C
Oxygen consumption rate	10 L/min
Ozone concentration	100-160 g/Nm^3
Effect of residence time	3-8 sec
Flow rate mixing	65 L/min
AC voltage	5-10 kV
Oxidation duration time	0.5-5 min

(a) The O_3 generator tube corona discharge is responsible for producing O_3. There were many sizes depending on the needs of use. Its sizes range from small to large (milligrams to kilograms per hour). It uses high voltage electricity to supply power to the ozone tube. A transformer was applied to increase the voltage to achieve high efficiency and low loss of power. This was achieved by switching the power supply and by changing the voltage from 220 V, 50 Hz to 1-10 kV, 1-10 kHz.

(b) The O_3 machine was responsible for producing O_3 (Zumozone brand, model: OZ100G/H, serial number: OZ 160726616, max capacity: 100 g/h, O_3 concentration: 100-160 g/Nm^3, type of O_3 cell cooling: water 220 V, 50 Hz).

(c) The oxygen generator is responsible for producing more than 90% oxygen to be supplied to the ozone machine (oxygen concentration: 90±3%; power consumption: 550-Watt Max; oxygen flow rate: 10 L/min; Built-in oil-free air compressor: 220 V/50 Hz).

(d) The O_3 mixing unit is responsible for mixing O_3 with water (flow rate mixing: 65 L/min; mixing unit two-tube pump, centrifugal pump 1 HP: 220 V, 50 Hz).

(e) Venturi injectors are a highly efficient means of mixing liquids or gasses into a stream of water. They work on the principle of differential pressure. Water enters the venturi at a higher pressure rate than it exits with. The difference in the entry and exit pressures creates a vacuum at the suction port on the side of the venturi. The bigger the difference in pressure, the greater the force of the vacuum, and therefore the efficiency of the mixing.

(f) Wet scrubbing traps dust and small particles that pass through the cyclone separator. The gas then flows through from a side of the tank above water into the cooling pad in the opposite direction. Water is kept at a temperature of 20-25°C and sprayed from the top towards the steering wheel that directs the flow to the activated charcoal which absorbs toxic gases and odors such as methyl sulfide.

(g) The gas treatment chamber with a high oxidation reaction eliminates most types of microbes, especially the most dangerous. Bacteria, odors, chemical compounds, and toxic gases are also eliminated using the treatment in this chamber before the gases are released to the atmosphere.

(h) The cool water tank stores the cool water required for injection from a nozzle during gas scrubbing. The water gate adjusts and mixes water containing heat and toxic gas before this water enters the cool water pump. A small portion of the warm water is subsequently released into the warm water tank.

(i) The water tank stores warm water that is heated by the absorbed pollutants from the exhaust gases produced via combustion. The debris is dropped to the bottom of the tank and subsequently disposed of clean water is fed into a chilling machine.

(j) The chilling machine has a capacity of 60,000 BTU/HR (condensing unit "CARRIER" R410; Water tank 550 L; SUS304 supply). The water pump circulates water through the system. The water pump (temperature control Dixell; water temperature inlet was 12°C; water temperature outlet was 7°C) produces cold water that is stored in the coolant tank before it is sprayed into the scrubbing tank. Once the water absorbs the heat leading to an increase in its temperature, it is circulated back to the chiller to be cooled again.

2.4.1 The method of ozone generator system

Oxygen generator generates pure oxygen and Ozone generator generates pure ozone. After pure ozone and pure oxygen are mixed, the injector pump suctions these gases through the pipe and water is injected into the pump. Then, the gases and water are mixed by the Venturi injector system. The mixing unit is compressed by the injector pump to the storage tank before it is used at the wet scrubber room as shown in Figure 2.

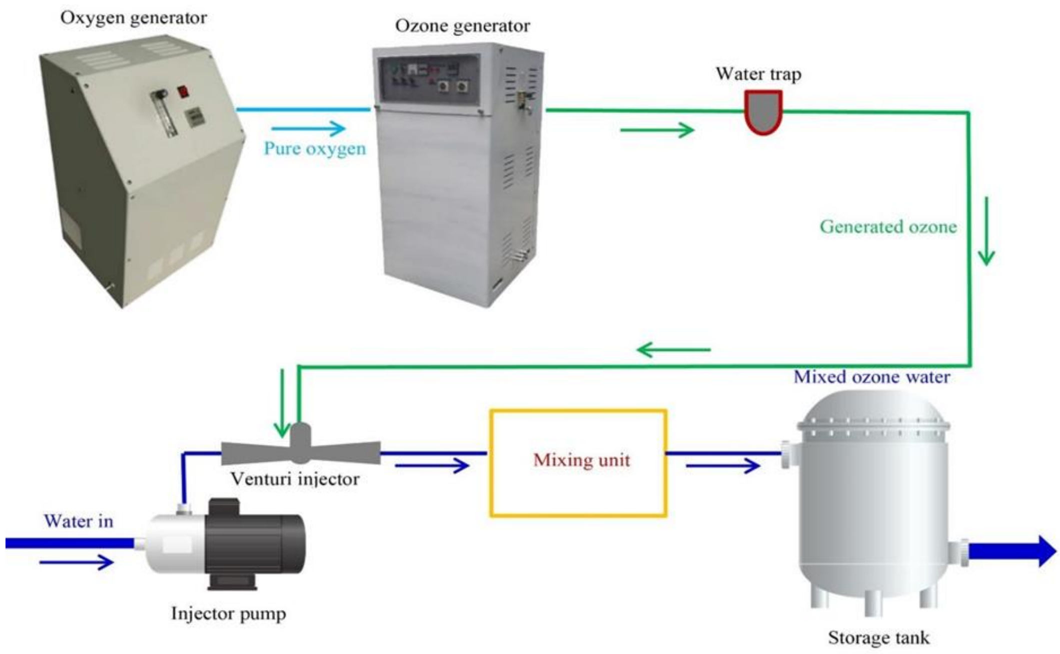


Figure 2. Ozone generator systems

3. RESULTS AND DISCUSSION

3.1 Physical and chemical properties of waste

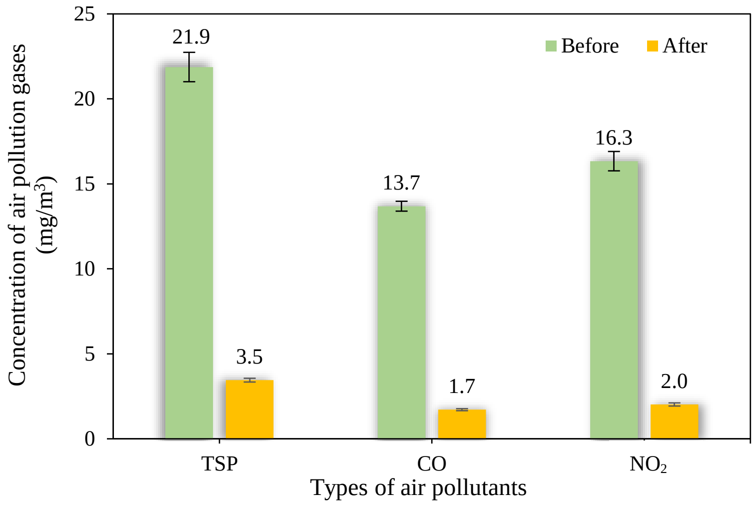
The components were analyzed by drying and weighing after drying. The highest level of plastic waste was 58.64%, followed by other various types of metal and textiles waste (21.38%), and rubber and glass splinter waste (11.45%). In addition, it was found that plastic waste pollution is one fifth of all infectious waste. (Olanrewaju, 2019). The proximate analysis of infectious waste showed that the moisture content was 42.69%, volatile matter content was 39.75%, ash content was 11.70%, and this infectious waste had a density equal to 173.45%. The most common chemical composition found was carbon (59.48%), followed by oxygen (31.30%), hydrogen (8.75%), and the remaining gas was nitrogen. This is consistent with the ratio of elements that can be found in both general waste and infectious waste. The chemical composition in the hospital waste was studied, and it was found that the highest carbon content was 34% and the oxygen content was 14%. The elemental composition analysis of hospital infectious waste revealed that the compositions of infectious waste were carbon content (34%) and oxygen content (15%) (Li and Jenq, 1993). Solid municipal waste was analyzed as well, and it was reported that the elemental compositions of the waste were carbon content (60%), hydrogen content (7.2%), oxygen content (22%), and nitrogen content (4.6%).

3.2 Comparative results of air pollution gases before and after using the ozone system in a rotary waste incinerator

The results of the gas values obtained from the comparison of the emission of air pollutants before and after using the ozone system in a rotary waste incinerator can be seen in the following list in descending order of amounts: dust, sulfur dioxide gas, carbon monoxide, nitrogen dioxide, hydrogen chloride gas, and opacity. The results revealed that air pollution gases before using the ozone system were as follows: TSP content was 22.0 (mg/m^3), CO content was 13.6 (mg/m^3), and NO_2 content was 16.3 (mg/m^3). After the O_3 system had been applied to the Wet Scrubber System of the rotary kiln, it was obvious that pollutant gas levels decreased significantly as follows; the level of TSP content was 3.4 (mg/m^3) (84%), the level of CO content was 1.7 (mg/m^3) (87%), and the level of NO_2 content was 2.0 (mg/m^3) (87%). It was found to be more efficient than those which had not applied O_3 technology as shown in Figure 3.

3.3 Comparison of air pollutant levels in the ozone system with U.S. EPA standards

The incineration process taking place inside the incinerator has been specially designed to match the characteristics of the waste, namely the high humidity rate and to be considerate of the variable heat value. Combustion has to be well controlled to prevent the



Remark: 15% Oxygen Content

Figure 3. The comparison of air pollution gases before and after using the ozone system in a rotary waste incinerator

release of harmful pollution into the environment in the form of s toxic gases, soot, and odors. The gases generated by combustion must be free of soot and particles as regulated by law before they are released into the atmosphere. O_3 technology was applied to the rotary kiln greatly improving its efficiency as highly concentrated O_3 worked optimally at the appropriate temperature (Lin et al., 2020). Additionally, O_3 treated and reduced SO_2 and NO_2 as well (Wang et al., 2018; Shao et al., 2019). Table 3 demonstrates the comparison of pollutant gas levels before and after using the ozone system in a rotary waste incinerator. It was found that the level of TSP content was 3.40 (mg/m³), the level of CO content was 1.7 (mg/m³), and the level of NO_2 content was 2.0 (mg/m³). Even though pollutant gases were still detected, they were far below the U.S. EPA standards. The Pollution Control Department of Thailand follows U.S. EPA standards set as the guideline for Thailand's own set of standards. The established standard is that the TPS content level is 120 (mg/m³), CO content level is 46 (mg/m³), and NO_2 content level is 339 (mg/m³). The comparison of pollutant gases after using the O_3 system under the U.S. EPA standard system demonstrated a significant reduction in pollutant gases as follows: TSP content was 3.4 (mg/m³) (97%), CO content was 1.7 (mg/m³) (96%), and NO_2 content was 2.0 (mg/m³) (99%). According to pollutant gas emission controls and of the U.S. EPA standards, the regulations for the amount of solid waste combustion is between 1 to 50 tons per day as shown in Table 3.

Table 3. Fuel gas concentration

Parameters	Concentrations			Unit
	15% O_2	7% O_2	U.S. EPA[(1)]	
TSP	3.4	7.4	120	mg/m³
SO_2	1.3	1.3	30	ppm
NO_x as NO_2	1.0	1.0	180	ppm
CO	1.5	3.3	40	ppm
Hg	0.001	0.001	0.050	mg/m³
Cd	ND[(2)]	ND[(3)]	0.05	mg/m³
Pb	ND[(2)]	ND[(3)]	0.50	mg/m³
HF	0.013	0.034	20	ppm
HCl	<0.015	<0.015	25	ppm
Opacity	5.0	5.0	10.0	%

[(1)] The standards for controlling the emissions of pollutants released from an infectious waste incinerator in accordance with the methods prescribed by the United States Environmental Protection Agency (U.S. EPA), burning less than 50 tons/day
[(2)] MDL=Method Detection Limit (MDL of Lead=0.19 mg/m³), (MDL of Cadmium=0.02 mg/m³)/N=Not Detected
[(3)] Results of actual % O_2

3.4 Effect of ozone system addition on NO_2 and CO reduction in infectious waste incineration

The results clearly presented the stark contrast in numbers when employing the system before using the ozone system, NO_2 content was 16.300 (mg/m³) and CO content was 13.600 (mg/m³), and after using the ozone system, NO_2 content was 2.0 (mg/m³) and CO content was 1.7 (mg/m³). Similar results were obtained by Ding et al. (2016a) and Ding et al. (2016b) which stated that a chemical study of O_3 was carried out to reveal how the O_3 treatment affects the concentration of pollutant gases such as NO_2 and CO. It showed that the oxidation between O_3 and low temperature exhaust gas, NO_2 and CO, significantly diluted the concentration of NO_2 and CO. Furthermore, the results suggested that O_3 application for the treatment of pollutant gases in the wet scrubber room is practical for industries (Wang and Zhong, 2016).

4. CONCLUSION

The study found that levels of pollutant gases such as TSP, NO_2, and CO emitted from infectious waste incinerator chimneys were significantly reduced after O_3 technology was installed. The results revealed that air pollution gases before using an ozone system were as follows; TSP content was 22.0 (mg/m³), CO content was 13.6 (mg/m³), and NO_2 content was 16.3 (mg/m³). Then, after an O_3 system had been applied to the Wet Scrubber System of the rotary kiln, it was immediately apparent that the process caused air pollution gas levels to drop significantly as follows; the level of TSP content was 3.4 (mg/m³) (84%), the level of CO content was 1.7 (mg/m³) (87%), and the level of NO_2 content was 2.0 (mg/m³) (87%). Results obtained from the study show levels which are far below the U.S. EPA standards. The established standard states that the acceptable TPS content level is 120 mg/m³, CO content level is 46 mg/m³, and NO_2 content level is 339 mg/m³. The study showed the result of air pollution gases after using the O_3 system as follows; TSP content was 3.4 mg/m³ (97%), CO content was 1.7 mg/m³ (96%), and NO_2 content was 2.0 mg/m³ (99%). The results suggest that the rotary kiln with O_3 application was more efficient than the one without O_3 technology installed. Therefore, the application of an O_3 system on infectious waste incinerators warrants further study as it is practical for a wide variety of industries, will have a considerable impact on the global environment, and the health and quality of life for people everywhere.

Further study of flue gas pollutants removal by O_3 oxidation and studies on the quality of water used for ozone-reactive blending for the injection of flue gas treatment of pollution in the wet scrubber room is strongly urged in the race to find a solution to treat the wastewater with the ratio of consumption. The water quality can be further utilized before being released from the treatment system for future use in industrial, agricultural, and various other fields.

ACKNOWLEDGEMENTS

This research was provided with financial support and technical support by Energy Experts Thailand Co., Ltd.

REFERENCES

Bacinschi Z, Rizescu CZ, Stoian EV, Necula C. Waste management practices used in the attempt to protect the environment. Proceedings of the 3rd WSEAS International Conference on Engineering Mechanics, Structures, Engineering Geology; 2010 Oct 24-26; Wisconsin: USA; 2010.

Carpi A. Mercury from combustion sources: A review of the chemical species emitted and their transport in the atmosphere. Water, Air, and Soil Pollution 1997;983(4):241-54.

Ding J, Lin J, Xiao J, Zhang Y, Zhong Q, Zhang S, et al. Effect of fluoride doping for catalytic ozonation of low-temperature denitrification over cerium-titanium catalysts. Journal of Alloys and Compounds 2016a;665:411-7.

Ding J, Zhong Q, Cai H, Zhang S. Structural characterizations of fluoride doped CeTi nanoparticles and its differently promotional mechanisms on ozonation for low-temperature removal of NO_x (x=1, 2). Chemical Engineering Journal 2016b;286:549-59.

Guo L, Zhong Q, Ding J, Ou M, Lv Z, Song F. Low-temperature NO_X (x=1, 2) removal with OH radicals from catalytic ozonation over α-FeOOH. Ozone: Science and Engineering 2016;385:382-94.

Han C, Zhang S, Guo L, Zeng Y, Li X, Shi Z, et al. Enhanced catalytic ozonation of NO over black-TiO_2 catalyst under inadequate ozone (O_3/NO molar ratio=0.6). Chemical Engineering Research and Design 2018;136:219-29.

Hartmann W, Roemheld M, Rohde KD, Spiess FJ. Large area pulsed corona discharge in water for disinfection and pollution control. IEEE Transactions on Dielectrics and Electrical Insulation 2009;164:1061-5.

Innocent AJ, Chamhuri S, Hassain MD. Incineration and its implications: The need for a sustainable waste management system in Malaysia. International Journal of Environmental Science 2013;4(3):367-78.

Jiang X, Li Y, Yan J. Hazardous waste incineration in a rotary kiln: A review. Waste Disposal and Sustainable Energy 2019; 1(3):3-37.

Li CS, Jenq FT. Physical and chemical composition of hospital waste. Infection Control and Hospital Epidemiology 1993;143:145-50.

Lin F, Wang Z, Ma Q, He Y, Whiddon R, Zhu Y, et al. N_2O_5 formation mechanism during the ozone-based low-temperature oxidation deNOX process. Energy and Fuels 2016;306:5101-7.

Lin F, Wang Z, Zhang Z, He Y, Zhu Y, Shao J, et al. Flue gas treatment with ozone oxidation: An overview on NO_x, organic pollutants, and mercury. Chemical Engineering Journal 2020;382:123030.

Liu B, Xu X, Liu L, Dai W, Jiang H, Yang F. Catalytic ozonation of NO with low concentration ozone over recycled SAPO-34 supported iron oxide. Industrial and Engineering Chemistry Research 2019;584:1525-34.

Ma Q, Wang Z, Lin F, Kuang M, Whiddon R, He Y, et al. Characteristics of O_3 oxidation for simultaneous desulfurization and denigration with limestone-gypsum wet scrubbing: Application in a carbon black drying kiln furnace. Energy and Fuels 2016;303:2302-8.

Ma J, Xu X, Zhao C, Yan P. A review of atmospheric chemistry research in China: Photochemical smog, haze pollution, and gas-aerosol interactions. Advances in Atmospheric Sciences 2012;295:1006-26.

National Research Council. Waste Incineration and Public Health. Washington, DC., USA: National Academies Press; 2000.

Olanrewaju O. Quantification and characterization of medical waste in public health care facilities within Akure Metropolis, Ondo State, Nigeria. EPH-International Journal of Agriculture and Environmental Research 2019;55:15-30.

Perera FP. Multiple threats to child health from fossil fuel combustion: Impacts of air pollution and climate change. Environmental Health Perspectives 2017;125:141-8.

Pollution Control Department (PCD). Thailand Statement of Pollution Report 2017. 1st ed. Bangkok, Thailand: Wongsawang Publishing and Printing; 2017.

Pollution control department (PCD). Thailand Statement of Pollution Report 2018. 1st ed. Bangkok, Thailand: Wongsawang Publishing and Printing; 2018.

Shao J, Xu C, Wang Z, Zhang J, Wang R, He Y, et al. NO_x reduction in a 130 t/h biomass-fired circulating fluid bed boiler using coupled ozonation and wet absorption technology. Industrial and Engineering Chemistry Research 2019; 5839:18134-40.

Si T, Wang C, Yan X, Zhang Y, Ren Y, Hu J, et al. Simultaneous removal of SO_2 and NO_x by a new combined spray-and-scattered-bubble technology based on preozonation: From lab scale to pilot scale. Applied Energy 2019;242:1528-38.

Sung TL, Teii S, Liu CM, Hsiao RC, Chen PC, Wu YH, et al. Effect of pulse power characteristics and gas flow rate on ozone production in a cylindrical dielectric barrier discharge ozonizer. Vacuum 2013;90:65-9.

United States Environmental Protection Agency (U.S. EPA). Wastewater Technology Fact Sheet: Ozone Disinfection. EPA/832-F-99-063. Washington, D.C., USA: EPA; 1999a.

United States Environmental Protection Agency (U.S. EPA). Nitrogen Oxides (NO_x): Why and How They are Controlled. EPA-456/F-99-006. Washington, D.C., USA: EPA; 1999b.

United States Environmental Protection Agency (U.S. EPA). Water Treatment Manual: Disinfection. Wexford, Ireland: Johnstown Castle Co.; 2011.

United States Environmental Protection Agency (U.S. EPA). Air pollutant emissions trends data [Internet]. 2019 [cited 2019 May 10]. Available from: https://.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data.

Wang Z, Li B, Ehn A, Sun Z, Li Z, Bood J, et al. Investigation of flue-gas treatment with O_3 injection using NO and NO_2 planar laser-induced fluorescence. Fuel 2010;899:2346-52.

Wang Q, Tang M, Peng Y, Du C, Lu S. Ozone assisted oxidation of gaseous PCDD/Fs over CNTs-containing composite catalysts at low temperature. Chemosphere 2018;199:502-9.

Wang J, Zhong W. Simultaneous desulfurization and denitrification of sintering flue gas via composite absorbent. Chinese Journal of Chemical Engineering 2016;248:1104-11.

Wei L, Zhou J, Wang Z, Cen K. Kinetic modeling of homogeneous low-temperature multi-pollutant oxidation by ozone. Ozone: Science and Engineering 2007;293:207-14.

Xi H, Zhou S, Zhou J. New experimental results of NO removal from simulated marine engine exhaust gases by $Na_2S_2O_8$/urea solutions. Chemical Engineering Journal 2019;362:12-20.

Yamamoto Y, Yamamoto H, Takada D, Kuroki T, Fujishima H, Okubo M. Simultaneous removal of NO_x and SO_x from flue gas of a glass melting furnace using a combined ozone injection and semi-dry chemical process. Ozone: Science and Engineering 2016;383:211-8.

Young C, Jordan T. Cyanide remediation: Current and past technologies. Proceedings of the 10th Annual Conference on Hazardous Waste Research; 1995 May 23-24; Kansas State University, Manhattan: USA; 1995.

Yuan D, Wang Z, Ding C, He Y, Whiddon R, Cen K. Ozone production in parallel multichannel dielectric barrier discharge from oxygen and air: The influence of gas pressure. Journal of Physics D: Applied Physics 2016;49:455203.

Zhao L, Li C, Zhang X, Zeng G, Zhang J. A review on oxidation of elemental mercury from coal-fired flue gas with selective catalytic reduction catalysts. Catalysis Science and Technology 2015;57:3459-72.

Zhao W, Zhang S, Ding J, Deng Z, Guo L, Zhong Q. Enhanced catalytic ozonation for NO_x removal with $CuFe_2O_4$ nanoparticles and mechanism analysis. Journal of Molecular Catalysis A: Chemical 2016;424:153-61.

Zhou S, Zhou J, Feng Y, Zhu Y. Marine emission pollution abatement using ozone oxidation by a wet scrubbing method. Industrial and Engineering Chemistry Research 2016; 5520:5825-31.