FEASIBILITY STUDY OF OZONE GENERATOR BASED ON HIGH VOLTAGE ELECTRODE METHOD

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ABSTRACT

Currently, various technologies are being developed which aim to improve the oxidation process so that its pollutant byproducts can be reduced. One of them is the development of the use of ozone as an alternative oxidizer which in the organic chemistry perspective has more free electrons so it is more reactive than oxygen. Ozone can be produced through several methods, such as the electrolysis method, the incandescent electrode method and the high voltage electrode method. This study aims to measure the feasibility of an ozone-producing reactor based on the high-voltage electrode method to produce photon strips initiating the formation of oxygen radicals. As the main indicators of the feasibility is the efficiency and level of performance of the reactor in producing ozone. As a comparison, the reactor is based on the previously made incandescent electrode method. Based on data from experimental results in the laboratory it can be shown that the high voltage method reactor is quite feasible. It can be proven in the discussion and analysis using linear regression and Minitab software that this method provides an increase in efficiency of 0.5% (0.714% to 1.214%) and an increase in performance of 1.8 ppm / min (2.57 ppm / min to 4, 37 ppm / minute ozone gas can be produced from 2.4 L / min of atmospheric air flowed into the reactor tube).

Keywords: *Laboratory Experiment, Application, ASTM D-2912, Linear Regression and Minitab Software, Product Feasibility.*

1. INTRODUCTION.

Today there have been found various forms of new technology, both in the form of refinements of old technology and forms of technology that are truly new. Various technological innovations carried out in the industrial world. For example, incomplete combustion flue gas management technologies, such as CO and HC. Hydrocarbon combustion involves oxidation by oxygen. Some literature states that ozone is more reactive than oxygen as an oxidizer. For example, oxidation of potassium iodide. At room temperature oxygen slowly reacts with potassium iodide, but ozone forms iodine more quickly.

Research on ozone reactors based on incandescent electrodes and their use as oxidizing agents has proven to be more efficient and performance has improved, but it has not been significant. More innovation is needed, such as the use of other methods to produce ozone.

Based on the background and problems, the purpose of this research is to conduct a feasibility study of reactors based on other than incandescent electrode methods, namely

reactors based on high voltage methods. Avoiding the complexity of the problem, this paper is limited to:

1. Analyze the effect of high voltage electrodes on reactor performance.

2. Thermodynamic aspects are used as a reference, but not discussed.

3. Results of the study only apply to the specifications of the method being carried out.

The research method used in principle is in accordance with previous scientific methods, as follows:

1. Manufacture of ozone reactors.

2. Research and testing of ozone reactors using spectropometric methods.

3. Data analysis and conclusion making using Linear Regression and data processing with Minitab.

2. MATERIALS/ METHODOLOGY

2.1. Ozone Characteristics

Ozone (O_3) is a compound composed of three oxygen atoms, the molecule is symmetric at an angle of 117^{o}C. The chemical bonds are single bonds and double bonds where a pair of oxygen atoms form a double bond and the rest of the electrons are used to bind to other oxygen atoms, consequently the last oxygen atom is surrounded by free electrons which makes this ozone molecule very reactive because it resonates.

Like oxygen, ozone is also an oxidizing compound so that its reactivity can be evaluated in terms of its ability to oxidize a substance. The level of ozone reactivity can be demonstrated by comparing it with oxygen in oxidation reactions. For example the reaction to the potassium iodide solution below,

$$6\,KI_{(aq)} + O_{3(g)} \xrightarrow{20^oC} 3\,K_2O_{(aq)} + 3\,I_{2(g)}$$

$$4\,KI_{(aq)} + O_{2(g)} \xrightarrow{20^oC} 2\,K_2O_{(aq)} + 2\,I_{2(g)}$$

In a relatively short time ozone can oxidize potassium iodide to form iodine by changing the color of the solution from yellowish to reddish. Whereas oxygen can oxidize KI to show the same symptoms takes a long time, even days.

The reactivity levels of ozone from the energy spectra are as follows:

$$O_{2(g)} + 4H^+ (10^{-7}M) + 4e = 2\,H_2O_{(aq)} \qquad E^o = +0{,}815\ Volt$$

$$O_{3(g)} + 2H^+ (10^{-7}M) + 2e = O_{2(g)} + H_2O_{(aq)} \qquad E^o = +1{,}65\ Volt$$

Potential energy shows in ordinary aqua solutions having a difference of 0.835 volts. So from the two evidences above it can be said that ozone is far more reactive than ordinary oxygen.

Ozone in the natural gas phase is colorless, pungent. At a temperature of -111^{o}C it melts in blue. and solidify at a temperature of -192^{o}C to turn blackish blue. In this condition ozone has toxic properties over KCN or NaCN, stricture and carbon monoxide. Ozone toxins in plants cause slowing of growth at 30 ppb levels. At levels of 150 ppb to 300 ppb, humans experience throat irritation and asthma attacks.

2.2. The mechanism of the formation of ozone in nature

Ozone is abundant in the stratosphere, which is 30 km from the earth, which is a

cloudless and stable layer because there is no vertical air circulation. In the ultraviolet light Stratosphere, the wavelengths are short and high-energy are optimally absorbed by free oxygen to form oxygen radicals. Reactive oxygen radicals join the remaining O_2 molecule, forming O_3. In the lower, cloudy and unstable layers of the atmosphere, ozone is formed by the presence of free voltage from differences in charge accumulated and polished from moist clouds that generate high electrical energy. So in principle ozone is made by giving high energy to oxygen. The reactions that occur are

$$O_{2(g)} \xrightarrow{UV(220-230nm)} 2\,O\bullet$$

$$O\bullet + O_{2(g)} + M_{(g)} \xrightarrow{radiasi} O_{3(g)} + M_{(g)}$$

M is a third particle such as nitrogen or other molecules in the atmosphere. The third molecule is not a condition for the formation of O_3 but because the process in the wild this third molecule also absorbs some of the radiation energy that is useful to increase the life of unstable O_3.

Radical oxygen in nature is very unstable, to prove its existence can be done in the laboratory in the following ways:

a. Chemical method

This method is based on the characteristics of highly reactive radical molecules, which provide a reactant to be reacted with these radicals to form a more stable product, then carry out isolation and identification.

b. Spectroscopic method

This method utilizes the change in electronic energy levels in radicals when reacting with a reactant compound, in the same way with the previous method then identified by the spectroscopic method.

c. Sophisticated methods

Sophisticated methods for identifying radical molecules present in a solution are the SER (Spin Electron Resonance) method and the CIDNP (Chemically Induced Dynamic Nuclear Polarization) method. The final method of CIDNP is a method that utilizes the effect of chemicals (in this case, the chemicals being tested) on the dynamics of core polarization.

2.3. Ozone Making in Laboratory

Adopting the ozone formation process in nature, modifications can be made in the laboratory by the following methods:

2.3.1. Electrolysis Method

This method uses a reactor that works by electrolysis. The electrodes are fluorocarbons, while the electrolyte solution used is HBF_4, H_3PO_4. The products of this process are water vapor, oxygen and ozone. Efficiency obtained by 35% with a temperature condition of 10°C with 48% weight / volume HBF_4 at 400mA cm-2. This method needs aeration in the anode because it can explode, resulting in an efficiency of 15%]. The reaction is

$$2H_2O_{(aq)} - 4e^- \longrightarrow O_{2(g)} + 4H^+_{(aq)} \qquad E^o = 1{,}23\ V$$

$$O_{2(g)} + H_2O_{(aq)} - 2e^- \longrightarrow O_{3(g)} + 2H^+_{(aq)} \qquad E^o = 2{,}07\ V$$

2.3.2. Incandescent Electrode Method

This method uses electric sparks, the reactor is in the form of tubes and electrode circuits with a voltage of ± 7.5 kV. The working

principle of this method is based on the formation of ozone in nature by lightning, which utilizes electric sparks to form oxygen radicals that will react with oxygen compounds to form ozone.

The energy generated depends on the frequency of fire formation, and is directly proportional to the formation of oxygen radicals and the levels of ozone that are formed. CDI (Capacitor Discharge Ignition) as a frequency regulator. The transformer to increase the voltage from 220 V to 400 V back and forth is then changed by leveling into a direct current that passes through the coil or series of diodes and the condenser forms a 7.5 kV system. The flow of the gradual grader becomes the initiator of the ozone formation process.

In incandescent electrode-based ozone generators obtained efficiency of 0.714%. The value is obtained by flowing air containing 21% oxygen into the reactor at a speed of 2.4 L/minute, then the oxygen absorbed every minute is 0.504 L. That amount is equivalent to 360 mg/ L or 360 ppm.

2.3.3. High Voltage Electrode Method

This method uses high voltage to convert oxygen to ozone-forming free radicals. The high potential difference between the two electrodes makes the electrons detach from the surface of the cathode with a certain energy. This electron discharge is called a photon. The energy is formulated by Planck as follows:

$$E = n\,h\,v = n\,h\,c\,/\,\lambda \quad (1)$$

Information :

E = energy

h = Planck constant (6.624 x 10-34 j.dt)

v = photon frequency

c = speed of light

λ = photon wavelength

n = mole of photons

Energy (E) hits electrons in O_2 double bonds and is able to break the double bonds to form free radicals that are reactive to O_2 to form O_3.

The most important parts of this high voltage method are the high voltage generator circuit, the electrodes and the reactor tube. High voltage generator circuits that are often used are as below

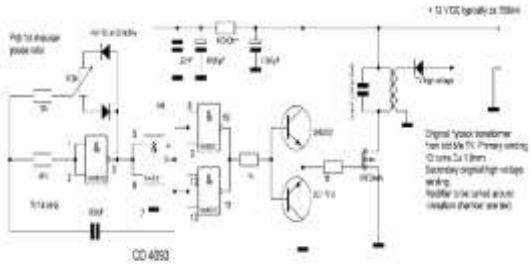

Figure 2.1. High voltage generator circuit

The combination of electronic components such as diodes, transistors, oscillators and voltage multiplier transformers or in the form of a coil. With a voltage of 20 kV electrodes of any type of metal will produce electron discharges.

The electrode is a very important part in producing the photons needed to break the O_2 double bond. The different types of electrodes will provide a difference in the price of heat conductivity and the difference in the price of heat conductivity gives a difference in the ability to move and release electrons. Metals that have high heat conductivity usually have a large atomic number, because the greater the atomic number,

the more inclined the atom tends to mobilize its outer electrons and the greater the heat conductivity of course the smaller the obstacle. According to the above understanding, it can be seen the effect of the size of the resistance of a type of electrode on the amount of energy to mobilize or release electrons. So examples of metals that meet the above requirements are copper, aluminum, tungsten.

The amount of photon energy that arises from a metal electrode can be determined by equations (2) and (3),

$$V = i R \quad (2)$$

$$E = V i t = (V2 / R) t \quad (3)$$

Information :

V = potential difference, in volts (V)

i = current in amperes (A)

R = resistance in ohms

E = electrical energy in units of watt seconds

t = time, duration of current flowing

The next important part is the reactor tube. In principle, the tube has room for collisions between bonding electrons and photons and meets the design requirements in the optimization of ozone production. Including controlled room temperature and pressure so that the volume of air containing oxygen involved in the ozonation process can be known with certainty, this is needed to determine efficiency.

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The reactor tube must be made of good insulating material, because in it there are high-voltage electrodes which can endanger the life of the tool user. Examples of good insulators are polymers such as PVC or ceramics.

The preparation of electrodes in the reactor is directly related to the optimization of the reaction. The position between the cathode and anode is directly related to the quantity of photons emitted. The electrode cross-sectional area also influences the quantity of photon discharge, the greater the cathode surface area, the greater the quantity of photons emitted. Then the cylindrical tube-shaped cathode was chosen because it had a wider surface than the rectangular bias. The cylindrical stick anode will cover the entire reactor tube so the percentage of collisions between photons and oxygen passing through the tube will be high. Like the design drawings below

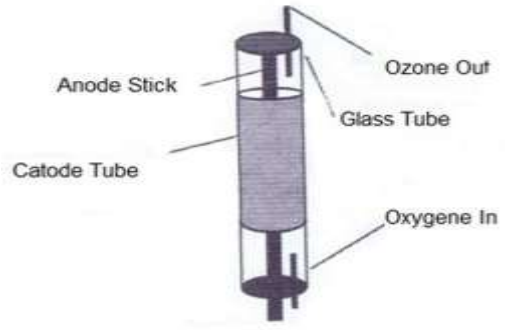

Figure 2.2. Reactor tube Model

2.4. Ozone Forming Energy

Oxygen turns into ozone, needs energy of + 285 kJ/mol. Petrucci revealed the following stages:

$$O_2 + hv \longrightarrow O + O$$
$$O_2 + O \longrightarrow O_3 + E$$

The energy needed to separate O atoms from O_2, break O=O double bonds and form 2 radicals is greater than hv (O_2 bond dissociation energy), which is 494 kJ/mol. Thus, a high voltage generator in an ozone producing reactor must be able to emit 1 mole of photons with a total energy of at least 494 kJ / mol, or 1 photon particle with an energy of $0.821.10^{-18}$ Joules. Following equation (1), it can be assumed to satisfy the energy above the minimum λ that a photon particle must have at 242.30 nm.

2.5. Stoichiometry of Oxygen and Ozone Radical Formation Reactions

This is the stoichiometry of the O=O double bond termination reaction to form the O radical, by irradiating the O_2 molecule with a photon with a wavelength of 242.3 nm.

In this calculation, the principle is to equate the number of moles of O_2 with the number of moles of photons. To determine the number of moles of oxygen passing, you can see the ideal gas equation below:

$$P V = n R T \quad (4)$$

Information :

P = gas pressure, in the atmosphere (atm)

V = gas volume (reactor tube volume), in liters (L)

n = gas mole

R = ideal gas constant = 0.082057 atm / mol.K

T = gas temperature in the reactor tube, in Kelvin (K)

Meanwhile, to determine the number of moles of photons can be determined by the Planck equation as in equation (1) above. Equations (1) and (4) can be substituted, so that the following equation is obtained:

$$P V / R T = E / hv \quad (5)$$

then by combining equation (3) with equation (5) the equation below is obtained,

$$P V / R T = vit / hv \quad (6)$$

Thus if the values of P, V, T are known then we can adjust the variables v, I and t to be able to determine the same mole price of oxygen and photons, because the λ is known, which is 242.3 nm.

Theoretically, if a photon mole is equivalent to a mole of oxygen then 100% O_2 will split into free radicals, then the calculation of the efficiency of the reactor will be optimal if the number of moles of photons is 1/3 of a mole of oxygen, assuming each radical is precisely paired with one O_2 molecule to form O_3.

2.6. Spectrophotometry Theory

Spectrophotometry is an analytical method based on the interaction of electromagnetic waves on the material being analyzed. This method is used for analysis of chemicals that have relatively low concentrations. The instrument used is called a spectrophotometer. A standard spectrophotometer consists of a spectrometer to produce light with a selected wavelength (monochromatic) and a photometer which is a device for measuring the intensity of the selected light.

An electromagnetic wave has an energy called a photon energy, and the magnitude of the photon energy can be determined through

equation (1). Photons with certain energy can be collided with the material will cause the transfer of atomic energy levels from the material. Each type of atom has different energy levels so that the transfer of energy levels that occur also varies. From the difference in the transfer of energy levels obtained differences in the spectrum of electromagnetic waves that are transmitted and absorbed or reflected and polished by matter. This is the main basis for identification. This law is known as the Lambert-Beer law.

2.6.1. Lambert-Beer Law

Briefly by Lambert-Beer, it is explained that if a beam of light passes through a homogeneous medium, then part of the incoming ray (Po) is absorbed as much as Pa and reflected as much as Pr (then the value is assumed to be 0 because the magnitude is below 4%) and continued as Pt, which can be formed in the equation below,

$$Po = Pa + Pt \quad (7)$$

After being given input by Bougar the equation was developed into an equation which became the working principle of the UV (Ultra Violet) spectrophotometer and looked, as follows:

$$T = 10^{-abc} \quad (8)$$

$$LogT = Log (Pt/Po) = -abc \quad (9)$$

$$Log(1/T) = log(Po/Pt) = abc \quad (10)$$

$$A = abc \quad (11)$$

Where T is Transmittance, A is Absorbance and a is the absorptivity constant and b is the optical distance and c is the concentration of the substance being analyzed.

2.6.2. Legality of Lambert-Beer-Bougar Law

There are several conditions which are the conditions for the entry into force of the Lambert-Beer-Bougar law, namely:

i. The light used must be monochromatic. If this is not fulfilled, more than one A (absorbance) value will appear from several wavelengths of light.

ii. The substance analyzed is a solution with a relatively low concentration. At high concentrations this law may become invalid, because in some colorless salts at high concentrations it has the opposite absorbance effect of this law. In suspension this law also does not apply.

iii. Solutions from substances that emit fluorescent fluorescence do not always follow this law. Similarly, solutions that undergo chemical reactions (polymerization, hydrolysis, association, dissociation).

The legal validity of Lambert-Beer-Bougar can be known by calibration, and is carried out before measurement. A system can be said to follow this law if the graph between absorbance of concentration is in the form of a linear curve (straight line) through the point (0,0). Some ways to do the calibration, including the continuous variation method.

The calibration process using the continuous variation method in principle is as follows, the main reactants in the analysis process are grouped into two groups of solutions, first as a sample solution (containing substances to be analyzed) continuously varying in volume and second is a solvent whose volume is adjusted so that the amount of both have the

same volume. From the mixtures having varying compositions each absorbance was determined with a spectrophotometer, then analyzed for validity (this method is detailed in chapter 3).

2.7. Analysis with a spectrophotometer

The spectrophotometer used is a UV 120 D. The workings of this spectrophotometer are in principle the same as the other previous models. The principle of this analysis is based on the reaction of ozone with KI solution, in this case the KI solution as an absorbent, where ozone gas can be optimally absorbed by this solution at neutral pH. The neutral state (pH = ± 7) is formed by providing a buffer solution of KH_2PO_4 and $Na_2HPO_4.12H_2O$.

2 KI (aq) + O_3 (g) + H_2O (aq) = I_2 (aq) + O_2 (g) + 2 KOH (aq)

The O_3 level in the solution is determined based on the formation of I_2 in the solution to which the spectrophotometer responds (in the reaction equation, the O_3 coefficient is equivalent to the I_2 coefficient so that the O_3 mole is also equivalent to the I2 mole), in which I_2 absorbs the complementary color of the emitted color which is brownish yellow.

2.8. RESEARCH METHODOLOGY

2.8.1. Equipment used

The tools used in this study are: Pumpkin measuring; Glass funnel; Volume pipette; Balance; Watch glass; Cuvette; UV-VIS spectrophotometer; Stirrer; Erlenmeyer; Stopwatch; Air pressure controller; Thermometer; Midget Tube; Test tube.

2.8.2. Material used

The ingredients used in this study are: Air (21% Oxygen); Aluminium plate; Aluminum wire (3 mm diameter); Cylindrical tubes (made of glass or PVC insulators (Polyvinil Chlorida) with diameters equivalent to twice the distance between the electrodes (3,6)); copper cable; KH_2PO4 is solid; $Na_2HPO4.12.H_2O$; Solid KP; Distilled water; A standard solution of iodine 0.05 N.

2.8.3. Analysis Method

The method used is based on the analysis method of ASTM (American Society for Testing Methods) number D-2912. The methods referred to above in detail are as follows:

1. Making Absorbent Solution. It was successively dissolved 6.8 g KH_2PO_4 17.9 gr $Na_2HPO_4.12H_2O$ and 5 gr KI with 500 mL distilled water.

2. Making of Iodine Solution ($I_{2\ (aq)}$) 0.0025 N. Taken with a 5 mL pipette 0.05 N iodine solution put into a 100 mL measuring flask and then added distilled water to the mark limit. Furthermore, this solution is called a standard work solution.

3. Determination of Maximum Wavelength (λ maximum). Prepared two cuvettes. Squeeze the absorbent solution and put the cuvette to the mark, then this solution is made into a blank solution. A pipette of 0.0025 N iodine solution was put into the other cuvette. Both cuvettes are prepared in a spectrophotometer (spectrophotometer is ready to use) to determine the maximum absorbance (maximum), and the wavelength is recorded at the time of the

maximum absorbance. In the next steps the measurement is always used with these wavelengths.

4. Determination of the Calibration Curve. Prepare 0.0; 1,0; 2.0; 3.0; 4.0; 5.0 mL of 0.0025 N iodine solution each into a 25 mL measuring flask, then diluted to the mark with a flavoring solution and stirred evenly, then the solution is referred to as a sample solution. The sample solutions are transferred into the cuvette to determine its absorbance using a spectrophotometer at the maximum wavelength, (the blank used is an absorbent). A calibration curve is made between each concentration of I_2 from various variations of the sample solution in sequence with its absorbance to be determined from the slope, and symbolized by K. The desired calibration curve is plotted with the values of A (absorbance) as the ordinate (y-axis)) and the prices of C (concentration) are abscissa (x-axis), which can more clearly be seen a table that includes the data forming the curve, namely table 2.1.

Table 2.1. Retrieval of data to form a calibration curve

Standard Solution SS	Absorbent Solution AS	Sample Solution SS+AS	Absorbance	Calibration Concentration
mL	mL	mL	A	I_2 (ppm)
0	25	25	A1	C1
1	24	25	A2	C2
2	23	25	A3	C3
3	22	25	A4	C4
4	21	25	A5	C5
5	20	25	A6	C6

$$C = \frac{\text{SS Concentration x SS Volume x MW I2}}{\text{Sample Volume x n}} \text{ x } 1000 \qquad (12)$$

where, the initial concentration of LK is 0.0025 N and x is (1, 2, 3, 4, 5, 6) and n is the valence number.

5. Determination of Ozone Levels. Ozone levels are determined using equation (13):

$$\text{Level of } O_3 = \text{Iodine Concentration x } \frac{\text{MW Ozone}}{\text{MW Iodine}} \qquad (13)$$

where, C_t is the concentration of I_2 (in ppm) at various variations of t in step 5, and is determined by the equation $A_t = kC_t$. At is the absorbance (measured at maximum wavelength) measured at various variations at t in step 5, where K is the slope determined from the calibration curve equation. BM is the molecular weight of the compound in question.

6. Reactor Testing. Testing is done by observing changes in ozone levels over time (t) (explained in the 4th treatment) and t varies to 1; 1,5; 2; 2.5; and 3 minutes and the inlet air velocity is made constant (2.4 L / min). A table which includes variations in the price of t and ozone levels obtained in various variations of t, can be seen in table 3.2 for more details.

Table 2.2. Retrieval of data ozone levels to t

t	Absorbance	Level Ozone
Minutes	A	ppm
1	A1	C1
1,5	A2	C2
2	A3	C3
2,5	A4	C4
3	A5	C5

Curves are made from the data in table 3.2, where ozone levels are ordinate and time is

absent. The curve is an interpretation of the state of the reactor tested. The test used is a linear test (linear regression theory) that works with Minitab software. The parameters are H_0 (linear curve) and H_1 (non-linear curve), and the determination is based on the magnitude of the error probability (P) value of the fault tolerance (∞). If the P value is less than the value ∞ (in the laboratory equipment test ∞ is 0.05) then Ho is accepted and the reactor can be considered suitable for use as equipment.

3. RESULTS AND DISCUSSION

Research into the use of high-voltage electrodes to produce ozone gas provides results that will be discussed in this chapter. The results obtained include reactor model.

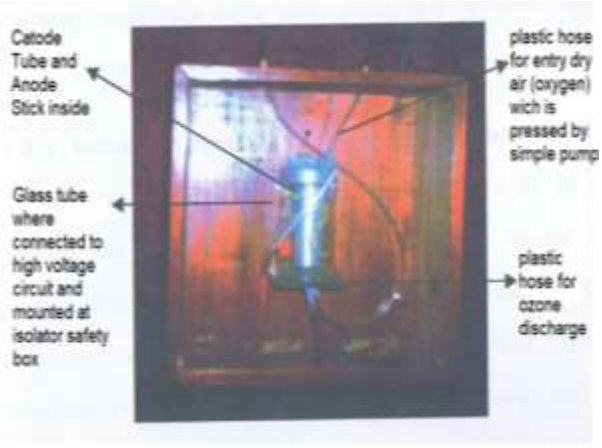

Figure 3.1. Reactor model

Other results are the data from the spectrophotometric analysis of sample solutions or samples.

3.1. Reactor Tubes

The reactor model created in this study is as shown in Figure 3.1. There are electrodes such that collisions between photons and oxygen molecules can be optimized and stoichiometric calculations can be fulfilled.

The main components in the reactor are two electrodes, namely anode and cathode. In accordance with its function as a photon generator, the electrode material chosen must meet the requirements as described in the previous chapter. The type of metal that includes meeting these requirements is aluminum, which in addition to cheap is also easily obtained in the market. Aluminum also has good resistance to the corrosive nature of oxygen. The walls of the reactor tubes are made of tightly porous glass so that the possibility of oxygen or ozone leaks in the glass pores can be ignored. This glass tube has a fairly good resistance to heat, which is able to withstand heat to boiling water temperature.

3.2. Calibration

The calibration process has been explained in previous, and the data obtained are in table 2.1. The slope of the curve formed by the plot between iodine (ppm) and absorbance levels is 0.0108 (known using the linear regression method through the point (0.0)). The equation of the regression curve is found in equation (14) and the image of the calibration curve presented in figure 3.2 below,

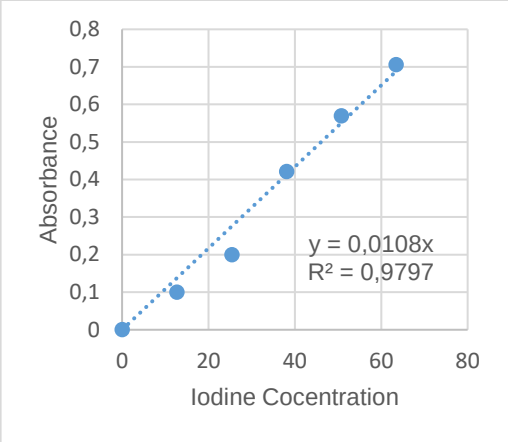

Figure 3.2. Calibration Curve

$$A = 0.0108\ C \qquad (14)$$

where A (absorbance) as ordinate (y axis) and C (concentration (ppm) of I_2) as abscissa (x axis). An example of a calculation in determining the calibration concentration (C_C) I_2 at volume I_2 (volume of standard working solution) of 1 mL is as follows:

$$Cc = \frac{\text{C Iodine x SS Volume x MW Iodine}}{\text{Sample Volume x n Iodine}} \text{ x } 1000 \text{ ppm}$$

$$Cc = \frac{0{,}0025 \text{ N x } 1 \text{ mL x } 253{,}840 \text{ gr/mol}}{25 \text{ mL}} \text{ x } 1000 \text{ ppm}$$

Cc = 12,692 ppm

and for calculations on various volumes of standard solutions as a whole can be seen in the data in table 3.1.

Table 3.1. Various levels of I_2 (ppm) in the calibration process (calibration of standard working solution I_2).

Standard Solution (SS)	Absorbent Solution (AS)	SS + AS (Sample Solution)	Spectro-Absorbance	Calibration
mL	mL	mL	A	$I_{2\,i}$ in (ppm)
0	25	25	0	0
1	24	25	0,1	12,692
2	23	25	0,2	25,384
3	22	25	0,421	38,076
4	21	25	0,57	50,768
5	20	25	0,706	63,46

3.2.1. Linear Test

The test is carried out according to the analysis method described in chapter 2.8.3. The time and absorbance data used and the ozone levels obtained by equation (13) are in table 3.2.

Table 3.2. Test data for the feasibility of a high voltage electrode reactor

Time	Mean of Absorbance A	Level Ozone	maximum wavelength
Minutes		ppm	nm
1	0,103	2,136	352
1,5	0,267	5,538	
2	0,425	8,814	
2,5	0,585	12,133	
3	0,727	15,079	

Total of Ozone Level = 43,7 ppm

Mean of absorbance is the average value of absorbance at each predetermined time interval, which can be more clearly seen in figure 3.3 below

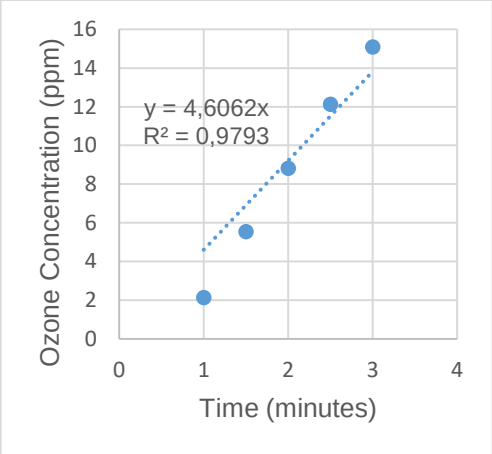

Figure 3.3. Interpretation Curve of ozone reactor

The calculation of determining ozone levels in table 3.2 for example is as follows (in this case at t = 1 minute and then A = 0.103 is obtained):

C1 minute = A1 minute / Calibration

= 0.103 / 0.0108

= 9.537 ppm

According to the reaction between KI and ozone contained in chapter 3, the coefficient of O_3 is equivalent to the coefficient of I_2, then the mole of O_3 is equivalent to the mole of I_2. So, the concentration of ozone is as follows:

ozone levels (ppm) = Ct x (MW O_3 / MW I_2)

= C1 minute x (48 gr.mol^{-1} / 253.84 gr.mol^{-1})

= 9.537 ppm x 0.224

= 2,136 ppm

Calculation of ozone levels for the other t can be seen in Appendix 4. As a basis for analysis (interpretation) of the reactor state, a regression curve is made, where time (t) is absent and ozone levels (ppm) as the ordinate. The test parameters include a pair of conflicting statements (expressed as Ho (linear curve) and H_1 (non-linear curve)), and the comparison parameter is the error tolerance value which is denoted as ∞ . The parameter ∞ have a certain price that is proportional to the desired level of accuracy (in exact terms the price ∞ used is generally 5%, except in medicine, which is equal to 1%). Analysis is done by using Minitab software to determine the probability level of error (P). And P value is compared with value ∞, if P value is smaller than Ho can be accepted and H_1 is rejected, and if P is greater than ∞, H_1 is accepted and Ho is rejected. The level of relationship (correlation coefficient) between the data obtained can also be known through Minitab, and this can be shown in a regression curve, this correlation level is denoted by R-square (R-sq) or R^2, but it can also be known level the possibility of data entered in the system can be received and this is denoted R-square-adjective (R-sq-adj) or Radj. R^2 and Radj are determined at the beginning of the analysis process before proceeding to the next stage.

Based on data obtained from experiments (table 3.1) and data on ozone levels (ppm) and time data (minutes) a regression curve (linear regression) can be seen in figure 3.3, and R^2 of 90.42% is obtained. The price of R^2 is large enough so that further analysis of the data that will be carried out with Minitab is worth continuing. The Minitab process can be more clearly seen in stage details below

Regression Analysis

Regression Equation = **ppm = 0.27 + 3.21 minute**

Prediction	Coeff	Stdev	t-Ratio	p
Constant	0.266	1.721	0.15	0.887
Minute	32.116	0.8113	3.96	0.029

s = 1.283 R-aq = 83.9% R-aq(adj) = 78.6%

Analysis of Variance

Source	DF	SS	MS	F	p
Regressior	1	25.786	25.786	15.67	0.029
Error	3	4.936	1.645		
Total	4	30.722			

Figure 3.4. Minitab software printed

The curve above (figure 3.3) is processed by this minitab software, and from the curves obtained the following regression equation:

O_3 (ppm)-level = 4.61 t (15)

and the price of P is 0,029.

The test parameters determined in this analysis are as follows,

Ho = linear curve

H_1 = non-linear curve

and the comparison parameter (∞) is 0.05. The P value of 0,000 compared to the ∞ value (0.05), turns out to be smaller (0,000 <0.05), so that the Ho that contains the statement that the curve is linear is acceptable.

The purpose of the linear test is to determine the feasibility of reactor based on the formation of a regression curve from the acquisition of data about the ozone levels formed in a certain time that varies according to continuous increase. It turns out that in this chapter it can be proven that the curves formed are linear, so the reactor equipment tested can be considered feasible (The shape of the reactor's state of interpretation curve can be seen in figure 3.3).

3.4. Reactor Performance

The performance of the reactor (PR) in question is the ability of the reactor to produce ozone gas each time unit. The performance of this reactor is known by calculating the average ozone concentration per unit time. Ozone performance is obtained by dividing the total amount of ozone content (ppm) by the total amount of time (minutes). Total ozone levels can be seen in table 3.2. For more details, the calculation is as follows:

$$P.R. = \frac{\text{Total amount of O3 levels}}{\text{Total amount of times}} \quad (16)$$

$$= \frac{2{,}136+5{,}538+8{,}814+12{,}133+15{,}079}{(1+1{,}5+2+2{,}5+3)}$$

$$= \frac{43{,}7 \text{ ppm}}{10 \text{ menit}}$$

= 4,37 ppm/minutes

So it can be concluded temporarily that the reactor that has been made by utilizing high voltage as an initiator can produce ozone from dry air an average of 4.37 ppm every minute (it is assumed that dry air contains 21% oxygen and is flowed into the reactor at speed 2, 4 L / min).

3.5. Reactor Efficiency

The efficiency of this high voltage electrode reactor equipment and incandescent electrode reactor (which was explained in previous chapter) can also be known by assuming that the oxygen converted to ozone comes from dry air, and is contained by 21% (this assumption is based on some quite popular literature). Various gases contained by dry air (the other 79%) other than oxygen did not affect the feasibility of this

experiment because the test method used was based on a method that was only sensitive to the effects of ozone to the absorbent solution used in this experiment (ASTM D-2912).

The efficiency of both reactors is formulated as follows:

$$\frac{\text{O3 Concentration Out}}{\text{O2 Concentration In}} \text{x100\% = \% efficiency} \quad (17)$$

Incoming oxygen levels as much as 21% of 2.4 L / min, then the oxygen absorbed per minute is 0.504 L. That amount is equal to 360 mg / L or 360 ppm.

Then the efficiency of the previously made incandescent electrode reactor is as follows:

$$\frac{2,57\,ppm}{360\,ppm} \text{ x } 100\,\% - 0,714\,\%$$

whereas, the efficiency of the high voltage electrode reactor made in this study is as follows:

$$\frac{4,37\,ppm}{360\,ppm} \text{ x } 100\,\% - 1,214\,\%$$

So the efficiency of high voltage electrode reactor is better when compared to incandescent electrode reactor.

3.6. The Effect of Continuous Photon Discharge on Reactor Performance, Efficiency and Eligibility

The intended photon discharge is an electron discharge from the cathode to the anode that occurs in the reactor tube. In Chapter 2, it has been explained that to achieve optimal results (performance and efficiency), the number of moles of photon that is stripped is 1/3 of the mole of oxygen that passes.

The reactor tube model used (Figure 3.1) has placed electrode pairs in such a way that every mole of oxygen passed will be crushed by a photon discharge with an appropriate number of moles, but the performance and efficiency shown remain low (4.37 ppm / min performance and efficiency 1,214%).

The low performance and efficiency are estimated due to the symptom discontinuity of photon discharges when the reactor is operated. Symptoms that can be observed by ordinary eyes are the emergence of purple and red rays that are not continuous (can be observed from the reactor tube made of transparent glass). Symptoms of discontinuity are clearly visible, so that in one minute several times occur outages (in one minute does not always occur full photon stripping). So, in one minute there are a few moles of passing oxygen which are not crushed by photon discharges, thereby reducing the performance and efficiency of the reactor.

The feasibility of the reactor does not depend directly on performance or efficiency, because this is determined statistically (in this case with linear regression combined with minitab software, and has been described in chapter 3.2.1) after a thorough analysis of all data obtained, it turns out that these photon stripping discontinuity symptoms have no direct effect on the suitability of the reactor. This can be proven in chapter 3.2.1 where Ho (linear curve) can be accepted.

4. CONCLUSION

Based on data obtained from experiments and after discussion, several conclusions can be drawn, as follows:

First, the ozone producing reactor (reactor) based on the high voltage electrodes tested was found to be feasible based on Linear and Minitab Regression testing. Where the Comparative Parameter (∞) is 0.05 and the Probability Rate of Error (P) is 0,029, because P < ∞ then the Acceptable Test Parameter is Ho (Linear Curve). So that the acquisition of data from experiments is considered feasible as well as the test ozone reactor (Reactor) equipment can be said to be feasible.

Second, the performance of the ozone-producing reactor tested showed an increase of 1.8 ppm in every minute compared to the performance of a previously made incandescent reactor (used as a comparison in this study), where a high voltage electrode-based reactor had a performance of 4.37 ppm per minute and the incandescent electrode reactor has a performance of 2.57 ppm per minute.

Third, the efficiency of high voltage electrode reactor is better than incandescent electrode reactor, and an efficiency increase of 0.5%, where the efficiency of high voltage electrode reactor is 1.214% while incandescent electrode reactor is 0.714%.

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