The Effectiveness of Incinerator at the Integrated Waste Treatment Plant in the Campus of Engineering Faculty - Hasanuddin University

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Abstract. Waste is an endless environmental problem. The amount of waste production has increased due to the increasing population. Besides being produced in a city, waste generation is also produced by universities or campuses. One of them is the Gowa campus, the campus of Faculty of Engineering, Hasanuddin University. Current waste management is carried out by holding, collecting and burning in open areas without further management. It can cause environmental pollution and health problems. The objectives of this study were to determine the amount of campus waste generation, to analyze the needs of incinerators in campus, to determine incinerator tools, and to determine the advantages, disadvantages, efficiency and effectiveness of the incinerators in Gowa Campus. The results showed that the amount of waste generated at the Gowa campus was 0.25 liters/person/day and 0.12 kg/person/day. This incinerator requirements analysis uses the geometry method and the efficiency and effectiveness method. From the calculation, it is known that the use of incinerators for the next ten years is one unit. The disadvantage of using an incinerator is that the cost is very high. However, the advantage is that it can reduce waste generation and overcome environmental and health problems. The comparison between Double Chamber and Maxpell incinerator gave the results that the most effective and efficient is the Maxpell incinerator with an effectiveness of 97.5% and efficiency of 17.17%.

1. Introduction

One of the factors that cause the environment to be polluted is waste. Waste generation is directly proportional to the population, which is the increase in population, so the waste generation also increases. In addition to waste generation in a city, a place that also produces waste generation is a campus or university that has routine activities even on holidays. One campus that produces waste is the Gowa Campus, the campus of Engineering Faculty, Hasanuddin University located in Gowa Regency, South Sulawesi. Waste that is produced in the form of organic waste comes from the canteen or food stalls. Moreover, inorganic waste comes from teaching and learning activities and other activities. Waste generated from each building is then collected, transported, disposed of and burned in open fields without further handling. This poor management can cause environmental problems such as air pollution and health problems. One example of poor environmental management is the open dumping landfill which is indicated to have released dangerous gas. It should be immediately anticipated, and this
dangerous gas can claim the lives of people who are in the closest radius of the landfill. People who breathe in methane gas every day may be able to experience damage to organs and cells of the body or even die if they continue to breathe in methane gas. Also, methane gas can explode at any time. Based on previous research [1, 2, 3] shows that the concentration and emissions of methane from the Tamangapa landfill in Makassar city are in a very varied range, from 12 - 425 parts per million (ppm) for methane concentrations and 2.44-18 Gg/year for methane emissions.

Based on these problems, waste needs to be appropriately managed, namely by burning waste using incinerator technology. However, the problem in applying incinerator is emission in the form of particulate matter (PM), Sulfur Dioxide (SO\textsubscript{2}), Carbon Monoxide (CO), Carbon Dioxide (CO\textsubscript{2}), Hydrogen Chloride (HCl), dioxin, furan and heavy metals. Therefore, incinerator that can be used must be equipped with a control system to meet the limits of particulate emissions and exhaust gases so that the smoke coming out of the incinerator is neutral smoke/gas. To find out the incinerator used is useful or not, then we need a method to determine the value of the efficiency and effectiveness of using an incinerator. Efficiency is a calculation to find the value of accuracy in carrying out incinerators as well as the benefits derived from the management of incinerators, while effectiveness is the effect or the results obtained from the incinerator technology.

The objectives of this research are: (1) to find out the amount of waste generated, (2) to analyze the need for incinerators, (3) to find out which incinerator tools can be used, it is adjusted to the amount of waste generated, and (4) to determine the strengths, weaknesses, efficiency, and effectiveness of incinerators that will be used in the Gowa campus.

According to the Law of the Republic of Indonesia No. 18 of 2008, Chapter One Article 1, waste is defined as the remnants of daily human activities and/or solid natural processes. Sources of waste come from campuses, markets, households, highways and public places. The types of waste generated are organic, inorganic, domestic, building waste and others [4]. In general, the most common types of incinerators applied are rotary kiln, multiple hearth, and fluidised bed incinerators. However, these types of incinerators are often applied for combustion of toxic and hazardous waste. The types of incinerators that can be used to burn domestic waste and as research material are as follows: Maxpell and Double Chamber Incinerator.

Maxpell incinerator is incinerators that do not use fuel, have a hydro process system that absorbs poisons and odours and converts carbon particles into magnets that can be captured by the split cell before exiting through the chimney. Moreover, Double chamber incinerator is a type of incinerator that uses diesel fuel. This incinerator has two furnaces, with temperatures of 300-600 °C for the first furnace and 600-1000 °C for the second furnace. This incinerator is equipped with a water scrubber that serves to prevent air pollution by using water spray against gas coming out of the second combustion chamber before entering the chimney.

![Figure 1. Maxpell Incinerator [5]](image1)

![Figure 2. Double Chamber Incinerator [6]](image2)
2. Methods
The tools used in this study, in measuring the waste generation in Gowa Campus, were 60-litre garbage bag, 500-litre measuring box, meters, 50 kg scales, tarpaulins, stationery, and personal protective equipment (masks and gloves). The material used is waste generation from the Gowa campus. This study was conducted in four months consisting of preparation, experiment and report preparation. At the experiment stage, taking and measuring samples eight days. The experiment was carried out at the Gowa campus, Campus of Engineering Faculty, Hasanuddin University.

![Source: Google Earth](image1)

**Figure 3.** Study site (Gowa Campus - Hasanuddin University)

The experiment began by distributing waste bags to the cleaning service on duty at each building. Waste originating from the cleaning service is then brought to the point of collection. The waste is then put into a 500-litre measuring box and compacted by dropping the box three times with a height of 20 cm. Then, measuring the area of the box and the height of the waste to get the waste volume. Next, sort waste according to the type of waste, weigh and record the weight of the waste. Add up the total weight of the waste from each type of waste to get the overall weight of the waste [7].

![Figure 4. Measuring of waste generation in Gowa Campus](image2)
Data analysis was performed using the following equations: (1) waste volume = area of the base of the measuring box x height of waste, (2) waste density = waste mass (kg)/waste volume (m³). For the analysis of waste characteristics, sorting according to their characteristics and then calculated using the equation of percentage characteristics (%) = total mass of waste (kg)/characteristic mass (kg) x 100%. Next, calculate the waste generation per person per day = v₁ + v₂ + v₃ + vₙ/n (litre/person.day). Waste generation and the need of incinerator are directly proportional to the population, then the population and the rate of waste generation are projected using the Geometry method: \( P_n = P_0 + (1 + r)n \) and \( r = \frac{1}{t \ln P_t/P_0} \). Where, \( P_0 \) = population in the starting year, \( P_n \) = Population in n year, \( l \) = constant number, \( r \) = population growth rate, \( n \) = total number of years from start to year n, and \( t \) = time period.

Furthermore, the calculation of efficiency and effectiveness of the use of incinerators is: (1) efficiency = amount of input (cost)/amount of output (benefit) x 100% and (2) effectiveness = tangible result/target x 100%. To find out the efficiency and effectiveness of using an incinerator can be seen from the criteria of financial efficiency and the interpretation of the effectiveness value as follows:

### Table 1. Criteria of financial efficiency [8]

| Value of Efficiency Ratio | Interpretation of Efficiency Value |
|---------------------------|----------------------------------|
| > 100 %                   | Not Efficient                    |
| 90 % - 100 %              | Less Efficient                   |
| 80 % - 90 %               | Efficient                        |
| 60 % - 80 %               | Efficient Enough                 |
| < 60 %                    | Very Efficient                   |

### Table 2. Interpretation of effectiveness value (%) [8]

| Effectivity Value (%)   | Interpretation of Effectivity Value |
|-------------------------|------------------------------------|
| 80 – 100                | High                               |
| 60 – 79.9               | High enough                        |
| 40 - 59.9               | A little low                       |
| 20 – 39.9               | Low                                |
| 0.0 – 19.9              | Very low                           |

To analyze the costs and benefits of an activity, in this study is about the procurement of incinerators on the Gowa campus, several methods can be used [9]. Two of the methods are: (1) the Return Period method, used for valuing an investment project, based on the length of time the investment can be covered with cash inflows and (2) the Return of Investments method, used to return investment which is used to measure the percentage of benefits generated by the project compared to the costs incurred.

### 3. Results and Discussions

The total population in the Gowa campus is 4843 people, divided into 4479 students, 242 lecturers, 88 employees, and 34 cleaning services. The existing condition of waste management on the Gowa campus still adheres to the old paradigm of gathering, transporting, then dispose of it, as can be seen in Fig. 5. The waste collection that has been sorted is carried out in a container and transported at 07.00 AM and 4.00 PM. At the transportation stage, the waste is transported by the cleaning service officer, and then the waste is disposed of at the point of disposal then burned on open land without further management. This waste management model can pose a risk of air pollution and health problems.

Judging from the existing conditions of waste management at the Gowa campus, an integrated waste treatment plant is needed, as shown in Fig. 6. The integrated waste management paradigm is described based on Law No.18 of 2008 as follows: (1) waste sorting, (2) waste collection, (3) waste transportation, and (4) waste treatment.
3.1. Integrated Waste Management
Waste sorting can be divided into organic, non-organic, hazardous and toxic waste, recycling, and others. Waste bins/containers are useful for distinguishing types of waste from sources of waste, making it easier to transport and manage the waste. Waste collection is conducted by using a vehicle that is modified by using a bulkhead to separate the waste according to the sorting that occurs at the waste source. The capacity of the transport vehicle is adjusted to the capacity of the waste generated each day. The collection time is equalled twice a day which is carried out at 7 am and 4 pm.

3.2. Waste Generation and Characteristics in Gowa Campus
Measurement of waste generation is divided into two: waste (1) mass and (2) volume measurements. The following is the result of measuring the weight and volume of waste generated from each building (waste source).
### Table 3. Waste weight of Gowa campus

| No. | Name of Building | Waste Weight (kg) | Waste Average Per Day |
|-----|------------------|-------------------|-----------------------|
|     |                  | Wed   | Thu   | Fri   | Mon   | Tue   | Wed   | Thu   | Fri   |        |
| 1   | COT              | 2.46  | 2.78  | 2.16  | 2.50  | 2.06  | 2.14  | 1.92  | 1.76  | 2.22   |
| 2   | CSA              | 9.16  | 10.9  | 8.19  | 11.49 | 9.82  | 9.2   | 11.02 | 7.66  | 9.68   |
| 3   | Classroom        | 13.35 | 10.96 | 8.49  | 16.03 | 12.7  | 11.08 | 10.43 | 9.07  | 11.51  |
| 4   | Civil            | 14.86 | 10.86 | 8.45  | 17.8  | 20.62 | 15.75 | 10.22 | 7.07  | 13.20  |
| 5   | Architecture     | 2.66  | 3.8   | 2.31  | 2.46  | 3.63  | 2.85  | 2.12  | 1.6   | 2.68   |
| 6   | Mechanical       | 0.81  | 2.42  | 1.02  | 6.3   | 2.96  | 1.27  | 2.72  | 1.29  | 4.18   |
| 7   | Electrical       | 7.5   | 5.85  | 1.5   | 1.35  | 2.55  | 3.46  | 4.55  | 1.83  | 3.57   |
| 8   | Geology          | 1.93  | 1.92  | 1.35  | 2.25  | 2.28  | 2.73  | 2.95  | 2.35  | 2.22   |
| 9   | Naval            | 3.16  | 2.24  | 2.2   | 1.81  | 2.05  | 2.1   | 2.16  | 1.7   | 2.18   |
| 10  | Ramsis           | 11.85 | 9.6   | 11.37 | 18.26 | 13.54 | 13.74 | 14.36 | 11.11 | 12.98  |
|     | Total            | 67.74 | 61.33 | 47.04 | 80.25 | 72.21 | 64.32 | 62.45 | 45.44 | 64.42  |

### Table 4. Waste volume of Gowa campus

| No. | Name of Building | Waste Volume (l) | Waste Average Per Day |
|-----|------------------|------------------|-----------------------|
|     |                  | Wed   | Thu   | Fri   | Mon   | Tue   | Wed   | Thu   | Fri   |        |
| 1   | COT              | 62.57 | 84.34 | 58.98 | 72.77 | 57.33 | 55.13 | 48.79 | 47.41 | 60.91  |
| 2   | CSA              | 157.11 | 161.24 | 147.74 | 171.99 | 154.07 | 124.86 | 170.06 | 131.75 | 152.35 |
| 3   | Classroom        | 224.08 | 189.63 | 180.53 | 235.38 | 215.54 | 210.85 | 189.08 | 186.05 | 203.89 |
| 4   | Civil            | 201.21 | 172.82 | 134.78 | 308.70 | 319.17 | 261.29 | 167.03 | 120.17 | 210.65 |
| 5   | Architecture     | 85.44  | 126.24 | 74.14  | 104.19 | 119.07 | 78.55  | 74.42  | 62.57  | 90.58  |
| 6   | Mechanical       | 13.00  | 83.00  | 19.00  | 172.00 | 61.00  | 10.00  | 96.00  | 17.00  | 58.92  |
| 7   | Electrical       | 88.20  | 66.15  | 49.61  | 64.22  | 74.42  | 61.74  | 57.88  | 65.60  | 65.98  |
| 8   | Geology          | 52.37  | 54.57  | 51.54  | 60.91  | 60.64  | 72.77  | 75.80  | 63.39  | 61.50  |
| 9   | Naval            | 90.96  | 67.53  | 62.29  | 64.77  | 68.91  | 68.08  | 60.09  | 63.12  | 68.22  |
| 10  | Ramsis           | 248.06 | 159.86 | 238.97 | 349.49 | 271.49 | 278.93 | 100.60 | 229.87 | 234.66 |
|     | Total            | 1223.22 | 1165.07 | 1017.88 | 1604.14 | 1401.28 | 1222.15 | 1040.21 | 987.29 | 1207.65 |

### Table 5. Waste composition characteristics of Gowa campus

| No. | Day  | Waste Weight Based on Composition from All Buildings (kg) |
|-----|------|----------------------------------------------------------|
|     |      | PET | Non PET | Paper | Tissue | Cardboard | Styrofoam | Metal | Organic |
| 1   | Wed  | 14.21 | 10.06 | 6.76 | 4.54 | 6.89 | 1.62 | 0.77 | 22.48 |
| 2   | Thu  | 13.76 | 10.34 | 6.68 | 4.69 | 7.68 | 1.98 | 0.35 | 15.85 |
| 3   | Fri  | 10.63 | 7.58  | 4.91 | 3.58 | 5.22 | 1.47 | 0.10 | 13.55 |
| 4   | Mon  | 18.14 | 10.53 | 9.18 | 6.93 | 10.27 | 3.00 | 1.15 | 21.05 |
| 5   | Tue  | 14.47 | 11.27 | 9.30 | 7.20 | 7.94 | 2.23 | 0.45 | 19.35 |
| 6   | Wed  | 13.19 | 12.80 | 8.33 | 4.00 | 6.29 | 1.85 | 0.62 | 17.24 |
| 7   | Thu  | 13.27 | 13.82 | 5.21 | 4.06 | 6.46 | 2.32 | 0.77 | 16.54 |
| 8   | Fri  | 9.46  | 6.71  | 4.97 | 3.70 | 3.99 | 1.60 | 0.21 | 14.80 |
|     | Total| 107.13 | 83.11 | 55.34 | 38.7 | 54.74 | 16.07 | 4.42 | 140.86 |
|     | Percentage (%) | 21 % | 17 % | 11 % | 8 % | 11 % | 3 % | 1 % | 28 % |
Based on Tables 3 and 4, the results of waste generation per individual unit in Gowa campus is 0.013 kg/person/day and 0.25 litre/person/day. The data above is very important in determining the required land area of Integrated Waste Treatment Plant of Gowa Campus and the facilities contained therein, including incinerator. The tables also show the weight and volume of waste generation on the Gowa campus. From the whole building and the total population, the generation of waste generated every day is 64.42 kg/day and 1207.65 L/day. It can be seen the amount of waste that is burned every day with improper combustion techniques. It can cause significant problems for health and environmental pollution. Regarding these problems, incinerator technology is needed on Gowa Campus to reduce the amount of waste generated.

### 3.3. Projected Population and Waste Collection Rate in Gowa Campus

The results of the calculation of the projected population and waste generation on the Gowa campus are shown in Table 6.

#### Table 6. Total population and waste generation projection

| No | Year | Total Population | Population Growth (r) | Waste Generation (L/person/day) | Waste Generation Rate (m³/hari) | Total Waste Generation (m³) |
|----|------|------------------|-----------------------|---------------------------------|---------------------------------|-----------------------------|
| 1  | 2018 | 4,843            |                       |                                 | 1.21                            | 441.92                      |
| 2  | 2019 | 4,905            |                       |                                 | 1.23                            | 447.58                      |
| 3  | 2020 | 4,967            |                       |                                 | 1.24                            | 453.24                      |
| 4  | 2021 | 5,031            | 0.0128                | 0.25                            | 1.26                            | 459.08                      |
| 5  | 2022 | 5,095            |                       |                                 | 1.27                            | 464.92                      |
| 6  | 2023 | 5,161            |                       |                                 | 1.29                            | 470.94                      |
| 7  | 2024 | 5,227            |                       |                                 | 1.31                            | 476.96                      |
| 8  | 2025 | 5,294            |                       |                                 | 1.32                            | 483.08                      |
| 9  | 2026 | 5,361            |                       |                                 | 1.34                            | 489.19                      |
| 10 | 2027 | 5,430            |                       |                                 | 1.36                            | 495.49                      |
The results of the projected population of the Gowa campus in 2027 were 5,430 people with the generated waste of 0.25 litre/person/day. Therefore, the waste generation on Gowa campus in 2027 is 5,430 people x 0.25 liters/person/day = 1.36 m$^3$/day, then the total waste production in 2027 is 1.36 m$^3$/day x 365 days = 495.49 m$^3$.

3.4. Analysis of the Needs and Effectiveness of Incinerators in Gowa Campus

Study and consideration in the selection of incinerator technology is a study to determine the effectiveness and efficiency of a waste burning technology. The main criteria considered for technology selection are the number of tools in reducing waste, the capacity for combustion, and the final results released by the incinerator. Errors in the selection of waste combustion technology can cause the failure of the entire waste treatment system that leads to health problems and environmental damage. Of the many companies making incinerator technology, two types of technology were taken for this study, namely the Double Chamber and Maxpell incinerator technology. Both of these machines were chosen to see how much effectiveness in reducing waste. The comparison of the specifications of these two technologies, it can be determined the amount of waste reduced from the residual ash of combustion and the time of operation carried out. Comparison of the effectiveness of the two incinerator technologies is as follows:

| Comparison                | Double Chamber Technology | Maxpell Technology |
|---------------------------|---------------------------|-------------------|
| Combustion Capacity      | 0.075 m$^3$/hour          | 0.085 m$^3$/hour  |
| Combustion Time           | 16 hour/day (8 times combustion process) | 16 hour/day (8 times combustion process) |
| Combustion System         | Double Chamber            | Gasification      |
| Combustion Temperature    | > 900˚C                   | 600 - 1000˚C      |
| Smoke Neutralizer         | Wet Scruber               | Smoke Scruber     |
| Fuel Usage                | Diesel Fuel               | No Fuel           |
| Electricity               | 6.5 kWh                   | No Electricity    |
| Combustion Ash            | 10 %                      | 5 %               |
| Area Needs                | 3 m x 3 m                 | 3.5 m x 3.5 m     |

The results of the comparison of incinerator technology in the form of the effective value of Double Chamber and Maxpell incinerator technology can be seen in Figure 8. This figure shows the effectiveness value of the Double Chamber incinerator is 90% and 95% for Maxpell incinerator. Thus the technology that has a high value of effectiveness in reducing waste is the Maxpell incinerator. This effectiveness is because the burning of waste is conducted only three times a week, not every day, in order to minimise damage to incinerators and further reduce the impact on air pollution.

Maxpell incinerator has greater effectiveness in reducing waste generation and is environmentally friendly because this incinerator does not use fuel compared to Double Chamber incinerators. Moreover, this incinerator has air pollution control devices (Hydro process) so that the air coming out of the chimney is safe for the environment.
Based on the results of projected waste generation, specifications, and calculation of the combustion rate of the Maxpell incinerator, the incinerator requirements in Gowa Campus can be analyzed, as shown in Table 8.

| No. | Year | Waste Generation Rate (m³/hari) | Total of Waste Generation (m³) | The Incinerator Needs (unit) |
|-----|------|---------------------------------|--------------------------------|-------------------------------|
| 1   | 2018 | 1.21                            | 441.92                         | 1                             |
| 2   | 2019 | 1.23                            | 447.58                         | 1                             |
| 3   | 2020 | 1.24                            | 453.24                         | 1                             |
| 4   | 2021 | 1.26                            | 459.08                         | 1                             |
| 5   | 2022 | 1.27                            | 464.92                         | 1                             |
| 6   | 2023 | 1.29                            | 470.94                         | 1                             |
| 7   | 2024 | 1.31                            | 476.96                         | 1                             |
| 8   | 2025 | 1.32                            | 483.08                         | 1                             |
| 9   | 2026 | 1.34                            | 489.19                         | 1                             |
| 10  | 2027 | 1.36                            | 495.49                         | 1                             |

Based on the results of the calculation of the need for incinerators in the above table, it can be seen that the number of incinerators needed until 2027 is only one unit. Incinerator needs are known from the calculation of the rate of combustion. The volume of waste is divided by the time of combustion so that the resulting waste is burned for one hour is 0.075 m³/hour with a total waste generation of 1.207 m³/day. It can be assumed that the combustion capacity used is 0.085 m³/hour or proportional to the amount of waste generated 1.36 m³/day.

3.5. Analysis of Incinerator Efficiency in Gowa Campus

The two incinerators are then compared using the efficiency formula, the value of the retrieval period and the investment return method. The comparison can be seen in Figures 9, 10, and 11.
Based on figures 9, 10, and 11 and the table of efficiency criteria for financial performance, the value of the efficiency ratio for Double Chamber incinerator is in the efficient range of 69.68%, and Maxpell incinerator is in the highly efficient criteria of 17.17%. The return period value for Double Chamber incinerator is 40 months and 14 months for Maxpell incinerator. While the Return of Investment (ROI) value in the Double Chamber incinerator is 81.41% and 482.33% in the Maxpell incinerator. The benefits of using incinerators can be increased, such as processing waste into electrical energy and so on, because it has a more significant advantage compared to the sales of waste ash produced. However, because the operational costs of incinerators are significant, the campus needs to work closely with other parties to ease the costs of procuring and operating incinerators on campus.

4. Conclusions
Based on the objectives of this study which are based on the results of research and data analysis, the following conclusions are obtained:

1) The total solid waste generation in the Gowa campus is 1207.65 litres/day and 64.42 kg/day, with individual units: 0.25 liters/person/day and 0.12 kg/person/day. The composition of waste is dominated by non-organic waste by 72% and organic waste by 28%.

2) The pattern of waste management on the Gowa campus is to collect, transport, and dispose of it. Therefore, it is necessary to properly process waste management, which is sorting, collecting, transporting and managing. At the management stage, the technology needed to reduce waste other than compost and enumeration is the incinerator. The advantage is that it can reduce waste quickly and has air pollution control devices so that it can reduce the impact of environmental and air pollution.
3) Based on the projection results, the population and the rate of waste generation in the Gowa campus in 2027 are 5,430 people and 495.4 m$^3$. Waste that is burned for one hour is 0.075 m$^3$/hour. It can be assumed that the combustion capacity used is 0.085 m$^3$/hour or proportional to the amount of garbage generated 1.36 m$^3$/day.

4) From the results of the study, it is known that the lack of incinerators is that they have extensive procurement, operational and maintenance costs while the excess of incinerators is that it can reduce waste generation and can overcome environmental problems and health problems. From the results of the calculation of the effectiveness and efficiency of the right incinerator used on the Gowa campus is the Maxpell incinerator with an effectiveness of 95% and an efficiency of 17.17%.

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