Solidification/Stabilization of Hospital Waste Incineration Bottom Ash using Ordinary Portland Cement

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Abstract - Solidification/stabilization is an alternative treatment for hazardous and toxic waste materials. The research aims to study solidification/stabilization of bottom ash from hospital incinerator using Ordinary Portland Cement (OPC) and to evaluate the effect of a composition ratio of mortar mixture to heavy metal leaching which influenced by pH, stirring, and leaching time. The rough texture of bottom ash was crushed manually to 4 mm in size, and mortar fabrication was carried out based on the practical instructions for mixing mortar according to ASTM C 305, and mortar molds were prepared based on standard procedures of SNI 03-6825-2002. Leaching test for heavy metals from a mortar sample was carried out by immersing it in 500 mL of aquadest. Results showed that bottom ash from hospital waste incinerator could be mixed with cement as a binder in the solidification/stabilization process. The addition of bottom ash 25-75% of the weight of sand occurred in increased compressive strength. However, the addition of bottom ash greater than 50% by weight of fine aggregate would be reduced the compressive strength of mortar. The compressive strength of all mortar samples of this study met to the standard value (SNI 03-6882-2002). Furthermore, the results of the study showed that there was an influence of changes in pH conditions. These results were indicated by the presence of Cu metal content of 0.0109 mg/L at 50 rpm shaking with pH = 11 and Cu metal content of 0.0101 mg/L at 50 rpm shaking with pH = 7 on mortar baths.

1. Introduction
Waste from hospital facilities includes all waste generated from health installations, health facilities, research facilities, and laboratories. Nearly 90% of the waste produced by health facilities comes from administrative, domestic and maintenance activities, only about 10% is a hazardous and toxic waste, which can cause various health impacts and environmental impacts. Hospital waste from health facilities is categorized as hazardous material waste because it has infectious and dangerous. The waste can have a serious impact on the environment and requires special management ranging from being produced to disposal [1].

Hazardous waste processing is a process to reduce and eliminate hazardous properties and toxic properties that can be carried out thermally and non-thermal. Thermal processing can be carried out using autoclave, microwave, radio frequency irradiation equipment and incinerators. Almost all hospitals in Indonesia destroy their hazardous waste by using an incinerator. Incinerators use the
principle of incineration, which is a high-temperature dry oxidation process that can reduce organic waste and combustible waste into inorganic materials. Incineration is the most widely used method of eliminating Hospital waste. Combustion of Hospital waste consisting of organic and inorganic compounds can produce gas emissions, including steam, carbon dioxide, nitrogen oxides, and some toxic substances (e.g., metals and halogenic acids), and particulate matter as well as solid residues in the form of ash. Although this method can destroy Hospital waste in large volumes and in a short time, it has many weaknesses, especially concerning its impact on the environment. This method is a source of contaminants for soil and underground water because it produces toxic heavy metals, furan, and dioxin in the process [2].

The use of incinerators in treating Hospital waste can reduce the amount of waste generation by up to 90 percent and produce two types of ash, namely fly ash and bottom ash. Fly ash comes from chimney emissions containing particulate ash composed of heavy metals, dioxins, furans, organic compounds, and gases. The dust-catching unit in the incinerator captures the particulate. Heavy metals will accumulate because of the adsorption of fly ash through water evaporation and reduction of waste volume so that the concentration of heavy metals will reach a higher level [3]. The bottom ash derived from the combustion of incinerated Hospital waste contains heavy metal contaminants and polycyclic aromatic hydrocarbons (PAH). From previous studies, it is known that incinerator ash can be reused as building material (fine aggregate) and made into mortar or concrete and mortar mixtures, aggregates in the manufacture of asphalt and roads, can also be used as concrete or coastal barrier [4].

Solidification/stabilization is an alternative treatment for hazardous and toxic waste materials. In the process of solidification/stabilization occurs mixing of waste with the binder to reduce contamination wherein the chemical changes in the waste before being discharged to the environment [5]. Both processes have objectives that are in line in improving waste management so that they are generally discussed together. Solidification shows a waste encapsulation technique, making pollutants a solid and limiting the migration of contaminants by reducing the surface area that can facilitate the release of contaminants from the waste and wrap pollutants with materials with low permeability. Solidification is a mechanical process where there is mixing of contaminants with one or more reagents. The resulting solid is called a monolith. While stabilization is a process, where there is a chemical reaction between reagents and contaminants to reduce the release of pollutants into a more stable form.

The main objective of the Solidification/stabilization process is to form a solid that is strong and durable, and easy to handle and does not melt contaminants into the environment. The essence of the Solidification/stabilization process is reducing the mobility and solubility of heavy metals (pollutants) in waste. The solidification process causes contaminants to not interact with solidification reagents, because mechanically, contaminants are locked or trapped in solids formed during the solidification process. Stabilization is a technique designed to minimize the mobility or solubility of pollutants with or without changes in the physical properties of waste. The stabilization process usually involves adding material to hazardous waste and creating a more sanitary product.

Solidification/stabilization techniques using cement are mostly done because they have various advantages, including relatively low costs of preparation, stable in the long term, both physically and chemically, have good compressive strength, by various types of waste for a long time, resistant to biodegradation, reduces solubility and contaminant protection. This method also able to bind liquid waste to relatively low water permeability. The use of cement/fly ash as a binder reduces disarmament caused by the limited migration of heavy metal ions in various forms, such as C-S-H gel and adsorption. Similarly, the compressive strength that increases due to the addition of the proportion of cement/fly ash and the curing period is longer [4]. The research aims to study solidification/stabilization of bottom ash from hospital incinerator using OPC and to evaluate the effect of the composition ratio of mortar mixture to heavy metal leaching which influenced by pH, stirring, and leaching time. This research conducted based on Behnken Box Response (RSM) Box.
2. Materials and Methods

2.1 Materials
Bottom ash was obtained from a Hospital Waste Incineration Facility (HWIF) in Zainoel Abidin Hospital of Banda Aceh City. This HWIF had a single lined feeding system, which led the operational temperature of the combustion chambers between 1100 and 1200 °C. Cement used was Ordinary Portland Cement (OPC), which was obtained commercially from the Lafarge Cement Ltd. Chemicals such as HNO₃, NaOH were obtained commercially as the regent grade from the Waco Ltd.

2.2 Experiment design
The experimental design of RSM Box-Benhken using Design Expert Version 6.0.6 software carried out to obtain the optimization results of Cu, Pb, and Zn metal waste content and determine the effect of mixture ratio, pH, leaching time and shaking rate. The experimental design of Response Surface Methodology (RSM) Box-Benhken was tabulated in Table 1.

Table 1. RSM Box-Behnken design level with each parameter test

| Variables | Level       |
|-----------|-------------|
| Materials Ratio (X₁) | low | Middle | High |
| Leaching Time (X₂)    | 1   | 2      | 3    |
| Shaking rate (X₃)     | 7   | 21     | 35   |
| pH(X₄)                | 0   | 50     | 100  |

2.3 Research procedure
2.3.1 Heavy Metal Analysis
Manually crushed material (< 4mm) was leached using an extraction buffer of HNO₃ and sodium hydroxide (pH 4.93 ± 0.05) at a liquid/solid ratio of 40:1. The extraction (at 30 ± 2 °C) was performed by shaking the material on the hot plate for 30 min. Subsequently, the leachate samples were filtered through a 0.8 µm borosilicate glass fibre filter, and the resultant extract (filtrate) was analyzed for heavy metals using Atomic Absorption Spectrometer (AAS) Shimadzu 6300. The laboratory quality control procedures included sample duplicates.

OPC Mortar Preparation
The rough texture of bottom ash was crushed manually to 4 mm in size, and mortar fabrication was carried out based on mortar mixture in Table 2.

Table 2. The ratio of OPC mortar fabrication mixture

| Materials Ratio cement : (sand + bottom ash) | Requirements weight (Kg) |
|--------------------------------------------|-------------------------|
|                                            | Cement | Sand | Bottom Ash |
| 1 : 4 : 0                                  | 2.30   | 11.66 | -          |
| 1 : 1 : 3                                  | 2.30   | 2.91  | 3.36       |
| 1 : 2 : 2                                  | 2.30   | 5.83  | 2.24       |
| 1 : 3 : 1                                  | 2.30   | 8.74  | 1.12       |

Mixing mortar material was carried out by using a mechanical mixer based on the practical instructions for mixing mortar according to ASTM C 305. Mortar molds were prepared based on standard procedures of SNI 03-6825-2002 for testing the strength of cement mortar by using molds of cube-shaped specimens measuring 5 cm x 5 cm x 5 cm. 63 mortar samples were prepared for this experiment. Furthermore, mortars were cured for 28 days by wrapping the sample with a wet gunnysack, placed them in a humid place, and protected by the sun's light during the curing for 28 days.
2.3.2 Compressive strength test (SNI 03-0349-1989)
Mortar sample was placed on a pressure-testing machine and followed by a constant loading between 2 to 4 kg/m² per second. Loading was carried out until the test object destroyed; the maximum load that occurs during an examination of the test object was recorded. Calculation of compressive strength of mortar carried out by dividing maximum load at the time object was destroyed with the gross compressive area expressed in kg/cm².

2.3.3 Leaching test for heavy metals.
A mortar sample mortar was immersed in 500 mL of aquadest in each of 29 test containers. Water-based shaker speed and pH of the water were set according to the variables that have been established.

3. Result and Discussion
3.1 Heavy Metal Content in Bottom Ash
The concentration of heavy metals in bottom ash was analyzed based on spectrophotometric method, and the results were tabulated in Table 3. The results of the analysis showed that bottom ash samples contained Zinc (Zn), Lead (Pb), and Copper (Cu), while Mercury (Hg) and Cadmium (Cd) metals were not found on the bottom ash. These heavy metals found were common type found on the bottom ash from the combustion of hospital waste. Some previous researchers reported that bottom ash from the burning of hospital waste in the incinerator contained heavy metal contaminants and polycyclic aromatic hydrocarbons (PAHs). Analysis results with spectroscopy showed that bottom ash contains Zn, Ti, Ba, Cu, Pb, Mn, Cr, Ni, and Sn. Heavy metals are generally in the form of flakes (Ba, Cr, Ni, and Sn), Mn, Pb, and Zn in the formation of Fe-Mn oxides fraction. Also in the form of an organic-matter fraction, such as Fe, Cu, and Cr [6] [7] [8]. Heavy metals contained in the solid waste cannot be destroyed by incineration and were found to be dispersed through the chimney and accumulated on the bottom ash of the incinerator [4]. The incinerator cannot destroy these toxic materials and make them concentrated.

| No. | Parameter     | Concentration (mg/kg) |
|-----|---------------|-----------------------|
| 1.  | Mercury (Hg)  | ND                    |
| 2.  | Cadmium (Cd)  | ND                    |
| 3.  | Zinc (Zn)     | 11245.8               |
| 4.  | Lead (Pb)     | 53.18                 |
| 5.  | Copper (Cu)   | 12200.6               |

ND = not detected

3.2 Characteristics of Mortar from solidified bottom ash and cement
Mortar samples solidified from the mixture with the addition of bottom ash produced more compact compared to mortar samples without the addition of bottom ash. These results were supported by the measurement of the specific gravity of mortar illustrated in Figure 1. From Figure 1, it can be seen that the average specific gravity of mortar with the composition of cement: sand: bottom ash (1:4:0) was 2036.88 kg/m³. When compared to the specific gravity of mortar with the addition of bottom ash as a substitute for sand in the mixture, the specific gravity of mortar samples will be lighter.

Compressive strength is one of the primary performance of mortar and the ability of mortar to accept the compressive force of broad unity. The compressive strength values obtained from each sample will be different, because mortar is a heterogeneous material, whose compressive strength is influenced by the mixture proportion, shape and size, loading speed, and by environmental conditions at the time of testing. Mixing the bottom ash composition as much as 25%, 50%, and 75% of the
weight of sand, the compressive strength obtained varies for each sample. Mixing bottom ash as much as 25%, 50%, and 75% of the weight of sand obtained the compressive strength of each sample varies. On the addition of as much as 25% bottom ash (1:3:1), an average compressive strength of 18.71 MPa was obtained. Bottom ash addition of 50% (1:2:2) showed an average compressive strength of 14.09 MPa, and an addition of 75% bottom ash (1:1:3) resulted in the average compressive strength of 12.06 MPa. When compared with the average compressive test results of normal mortal samples (without the addition of bottom ash) that was 10.52 MPa, the addition of bottom ash 25 - 75% of the weight of sand occurred in increased compressive strength. However, the addition of bottom ash greater than 50% by weight of fine aggregate would be reduced the compressive strength of mortar.

Standard mortar specifications based on SNI 03-6882-2002 for type M, S, and N were 17.2 MPa, 12.5 MPa, and 5.2 MPa, respectively, so when compared to the standard, the compressive strength of all mortar samples of this study met to the standard value. The compressive strength of mortar will increase with the increasing age where at 28 days, pasta and mortar will obtain the desired strength. Also, bottom ash was known to contain about 47% CaO, characteristics that are similar to the components of cement, which are like pozzolan in nature [9]. Furthermore, [10] reported that cement-based solidarity exhibited a compressive strength of 0.55-16.12 MPa. The strength decreased as the percentage of cement loading was reduced; the compressive strength was 6.62–16.12 MPa for a mixture of 60% cement and 40% bottom ash.

![Figure 1](image.png)

**Figure 1.** Specific gravity and compressive strength of mortar from solidified bottom ash and cement

### 3.3 Leaching test for heavy metals in mortar samples

Design Expert Software (version 6.0.6) was used to design research statistics and to analyze research data. The suitability of model and determination of the optimum conditions for the response have been determined. In this study, the Behnken Box design was used because it has advantages where the design more efficient and less number of run trials. The Box-Behnken RSM was conducted to optimize and evaluate the effect of mortar mixture ratio, pH, shaking, and leaching time. Observation data with Box Behnken design for four response variables tabulated in Table 4.

The design resulted in the experimental design of 29 experimental runs with repetition at the center point of 5 runs at run 4, 20, 21, 23, and 26. The center point was repeated five times, namely the ratio of cement: sand: bottom ash (1: 2: 2), 21 days leaching time, water pH 7, and shaking rate 50 rpm. Data from observations in Table 4 shows the experimental response, namely the concentration of heavy metals (lead, zinc, and copper) in mortar samples soaking water. These results indicate that levels of heavy metal zinc and lead did not give a response (the value obtained is not detected). However, different from copper metal that obtained several values in low concentrations.
### Table 4. Summary of Box Behnken design observation data for response variables of leaching test

| Run | Ratio | Leaching Time (days) | Shaking (rpm) | pH | Pb | Zn | Cu |
|-----|-------|----------------------|---------------|----|----|----|----|
| 1   | 2     | 7                    | 0             | 7  | 0  | 0  | 0  |
| 2   | 1     | 21                   | 50            | 3  | 0  | 0  | 0.0039 |
| 3   | 2     | 35                   | 50            | 3  | 0  | 0  | 0  |
| 4   | 2     | 21                   | 50            | 7  | 0  | 0  | 0.0101 |
| 5   | 2     | 7                    | 100           | 7  | 0  | 0  | 0  |
| 6   | 1     | 21                   | 100           | 7  | 0  | 0  | 0.0032 |
| 7   | 3     | 21                   | 0             | 7  | 0  | 0  | 0  |
| 8   | 3     | 21                   | 50            | 11 | 0  | 0  | 0.0109 |
| 9   | 2     | 7                    | 50            | 11 | 0  | 0  | 0  |
| 10  | 1     | 7                    | 50            | 7  | 0  | 0  | 0  |
| 11  | 3     | 35                   | 50            | 7  | 0  | 0  | 0  |
| 12  | 1     | 35                   | 50            | 7  | 0  | 0  | 0  |
| 13  | 3     | 21                   | 100           | 7  | 0  | 0  | 0  |
| 14  | 1     | 21                   | 0             | 7  | 0  | 0  | 0  |
| 15  | 1     | 21                   | 50            | 11 | 0  | 0  | 0.0040 |
| 16  | 3     | 21                   | 50            | 3  | 0  | 0  | 0.0070 |
| 17  | 2     | 35                   | 0             | 7  | 0  | 0  | 0  |
| 18  | 2     | 35                   | 100           | 7  | 0  | 0  | 0  |
| 19  | 2     | 21                   | 100           | 3  | 0  | 0  | 0  |
| 20  | 2     | 21                   | 50            | 7  | 0  | 0  | 0.0139 |
| 21  | 2     | 21                   | 50            | 7  | 0  | 0  | 0  |
| 22  | 2     | 35                   | 50            | 11 | 0  | 0  | 0  |
| 23  | 2     | 21                   | 50            | 7  | 0  | 0  | 0  |
| 24  | 2     | 21                   | 0             | 3  | 0  | 0  | 0  |
| 25  | 2     | 21                   | 0             | 11 | 0  | 0  | 0  |
| 26  | 2     | 21                   | 50            | 7  | 0  | 0  | 0  |
| 27  | 2     | 7                    | 50            | 3  | 0  | 0  | 0  |
| 28  | 3     | 7                    | 50            | 7  | 0  | 0  | 0  |
| 29  | 2     | 21                   | 100           | 11 | 0  | 0  | 0  |

The results obtained in Table 4 were in line with the purpose of this study that to solidify and stabilize the bottom ash to prevent leachate contamination into the environment which was affected by acid-base factors. So far, from the results of this study occurred the effectiveness of solidification/stabilization of the bottom ash from a hospital waste incinerator. From previous studies, it has been known that the process of solidification/stabilization can withstand the rate of migration of heavy metals in the matrix. Cement as a binder material can bind heavy metals well because the binder can reduce the mobility and solubility of heavy metals (pollutants) in waste. The bonding mechanism that occurs in the solidification/stabilization process is ion exchange, precipitation, and other surface reactions. According to Zhang, et al. [3], the use of cement can reduce the rate of protection due to restrictions on the migration of heavy metals in various forms, such as C-S-H formation and adsorption. The addition of cement as a binder in the mixture produces calcium silicate hydrate gel formed on the surface of the solidified material, and the gel serves as a barrier between the solid waste and the surrounding water. This process is influenced by chemical reactions that depend on the pH of the water and the ratio of Ca/Si from cement and bottom ash [11].
Table 5. The concentration of Cu in leachate

| Ratio | Leaching Time (days) | Shaking rate (rpm) | pH  | Concentration Cu in leachate (mg/L) |
|-------|----------------------|-------------------|-----|------------------------------------|
| 1     | 21                   | 50                | 3   | 0.0039                             |
| 2     | 21                   | 50                | 7   | 0.0101                             |
| 1     | 21                   | 100               | 7   | 0.0032                             |
| 3     | 21                   | 50                | 11  | 0.0109                             |
| 1     | 21                   | 50                | 11  | 0.0040                             |
| 3     | 21                   | 50                | 3   | 0.0070                             |

Furthermore, the results of the study showed that there was an influence of changes in pH conditions. These results were indicated by the presence of Cu metal content of 0.0109 mg/L at 50 rpm shaking with pH = 11 and Cu metal content of 0.0101 mg/L at 50 rpm shaking with pH = 7 on mortar baths (Table 5). Sobiecka, et al. [12] reported that heavy metals from the solidification/stabilization process of fly ash such as Cu, Pb, Cd, and Zn tend to leach in solutions with pH below 4 and above 11. In contrast to Yakubu, et al. [11] who reported that metal ions will be in a stable condition when the pH of the solution was low, but will miss when the pH of the solution was neutral and alkaline.

3.4 Analysis of Variant (ANOVA)

ANOVA is the factorial of Box-Behnken design, which is useful for generating interactions between process variables and response variables. Components of ANOVA are used to calculate the F-ratio, which serves to determine the effectiveness of a model. The F-value obtained is greater, and the p-value is smaller indicates the suitability of the model obtained. If the Prob. F value is lower than 0.05, then the model is significant, and for Prob. F values above 0.05, the model is not significant. In this case, the process variable consisting of the mixture ratio, leaching time, shaking rate and pH showed no significant effect on the response variable, namely the leachate of heavy metals. The experimental results based on the Design Expert showed that the response component could not represent the experimental design so that for this experiment it cannot be optimized using the Box Behnken design.

4. Conclusion

This study leads to conclusions that bottom ash from hospital waste incinerator could be mixed with cement as a binder in the solidification/stabilization process. The addition of bottom ash 25-75% of the weight of sand occurred in increased compressive strength. However, the addition of bottom ash greater than 50% by weight of fine aggregate would be reduced the compressive strength of mortar. The compressive strength of all mortar samples of this study met to the standard value (SNI 03-6882-2002). Furthermore, the results of the study showed that there was an influence of changes in pH conditions. This was indicated by the presence of Cu metal content of 0.0109 mg/L at 50 rpm shaking with pH = 11 and Cu metal content of 0.0101 mg/L at 50 rpm shaking with pH = 7 on mortar baths.

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