Design Development of Portable (Mini) Multi-function Incinerator for Dry Medical Waste Handling.

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Abstract. Medical waste contains biohazard, such as dry medical waste from the Centre of Public Health Services (PUSKESMAS) should be burning out, especially in the pandemic of covid 19. One of the possible solution is burning the waste by using incinerator. Basic concept of incinerator is controlled high temperature combustion, thus it should be perfect condition to burnt out the hazardous waste. Heat energy that exposed while incinerator operated should having high potency to be used for other purposes such as water heater and carbonization process. This research aims to develop an incinerator which can be used not only as high temperature burner (as incinerator’s main function), but also for water heater system and carbonization process, in the same time. The incinerator designed as mini portable incinerator since it will be used in a center of public health services (PUSKESMAS). Both of hot water and charcoal produced while incinerator operation can be used for sanitation purposes in the PUSKESMAS itself. Combustion process temperatures, smoke quality, safety factor, and energy utilities are the parameters which were determined as incinerator performance. Some design improvement has been done to the original design by Pradipta and Agustina [1] in order to improve the incinerator performance. The latest design performance is showing that combustion temperature successfully increased up to 980 °C for combustion rate of 9 kg waste /hour. Utilization of heat energy produced by combustion process inside the chamber has been successfully produce 2-2.5 kg of good quality coconut shell charcoal and hot water of 83 °C at 6 lt/minute flow rate.

1. Introduction
Medical waste contains biohazard, such as injection tools, patologic, citotoxic, chemical and pharmatiucal goods and other dry medical waste, should be burning out to prevent people and environment. The Centre of Public Health Services (Puskesmas) which has obligation to conduct health services in each district area in Indonesia needs equipment to utilize their daily medical waste properly. One of equipments which can be used for those purpose is incinerator. Basic concept of incinerator is controlled high temperature combustion (higher than 800 °C). Additional advantage of incinerator usages is ‘free’ heat energy resource. Heat energy produced during the incineration process can be utilized for other purposes such as carbonization and water heater, which also should be useful for sanitation purposes in those Center of Public Health Services (Puskesmas) Unit.

A portable incinerator, combined with carbonization chamber and water heater system and has been designed by Pradipta and Agustina in 2011 [1]. Those original design has been developed by Pane and Agustina in 2013 [2] by improvement on feeding system and enlargement capacity (0.15 m3) in order to meet requirement of Puskesmas for their medical waste utilization, but the developed incinerator still needs more improvement since the highest temperature in the combustion chamber still lower than 800°C. Design
improvement by Nurcholis and Agustina in 2016 [2] by improving air inlet system in order to increase the combustion temperature also hasn’t met the expected performance yet (higher than 800 °C). This paper discussing about the latest design improvement of those portable (mini) multifunction incinerator and the performance result.

2. Method
The stages of this research were design & modification approach, fabrication, performance test and analysis, as shown in Figure 1. The mixture of patchwork waste and plastic bottles has been used as feeding material, since the using of real B3 waste on campus is not possible.

![Figure 1. The research stages](image)

The purpose of all modification is to improve the incinerator performance, mainly combustion temperature level. Due to the purpose, modification approaches have been done by improving air inlet system to let the combustion process could be occurred completely and perfect to produce highest temperature inside the combustion chamber. Minimum air needed for combustion can be calculate by using formula as follow (Perry and Chilton [3]):

\[
W_{\text{min}} = \frac{100}{21} \times [(1.96 \times C) + (5.85 \times H)]
\]

where :
\[
W_{\text{min}} = \text{Theoretical minimum air inlet (m}^3/\text{kg material)}
\]
\[
C = \text{Carbon content in material which will be combusted (\%)}
\]
\[
H = \text{Hydrogen content in material (\%)}
\]

An additional air inlet of 40% of theoretical air inlet has been given as excess air to get higher possibility of perfect combustion process. The heat energy produced by combustion process should be kept to stay more longer inside the combustion chamber to keep the incineration process running in high temperature then able to incinerate the garbage or dry medical waste completely. Utilization of the heat energy by keeping it for carbonization process in the dust (flew solid particle) collector chamber, will be help to keep combustion chamber in high temperature continuously. This process also helping to avoid or reduce negative impact of combustion flew gas (smoke), since the incinerator will be release smoke with lower temperature and less flew solid particle. For the same purpose, insulation of the wall was needed in order to keep the heat energy not transfered outside the system but help the combustion chamber running on high temperature while operated. This insulation also helps to get better safety factor because the operator will be prevented from the heat radiation. Water heater piping in one side of the combustion chamber wall could take role both of as an insulation and as waste energy utilization system. The previous multifunction incinerators can be seen in the Figure 2a, 2b, and 2c below.
Incinerator performances indicate by some parameters as follows:

a. Temperature produced by combustion process, and temperature distribution inside combustion chamber (°C)
b. Combustion rate (kg waste/hour)
c. Smoke quality (temperature, color, smelt, solid particle content)
d. Effectiveness of heat energy utilization (for water heater system and carbonization)

3. Results and discussion

3.1. Incinerator structure

The portable (mini) multi-function incinerator consist of some component as described in the Figure 3 below.

The main function of incinerator represented by combustion chamber performance. The chamber performance depends on the air inlet system which took an important role as combustion air supplier. The performance also supported by the feeding system and chimney design, so the process could be running continuously. Dust (flew solid particle) collector chamber is a space which was designed to keep smoke for a while before leaving out from the incinerator through the chimney, so the smoke temperature level will
be reduced and dust or other solid particle will be trapped inside the chamber. Utilization of the heat energy content in the smoke was optimized by biomass carbonization process to produce charcoal in this chamber. While water heater piping was designed as utilization of heat energy produced by combustion process. This part also took a role as insulation of the combustion chamber wall, meaning the exposed heat energy while the incinerator operation will be reduced. Figure 4 shows the latest improved incinerator.

![Figure 4. The latest air system modification](image)

As described above, each improvement which has been done was focus on increasing combustion temperature, with the target is higher than 800 °C. Table 1 below shows comparation of air inlet system on each previous incinerator and the latest modified incinerator.

| No | Type of incinerator          | Air supply design (air inlet system improvement)                                                                 |
|----|------------------------------|---------------------------------------------------------------------------------------------------------------|
| 1  | Pane and Agustina (2013)     | 20 air inlet holes of 2 cm diameter, were placed in one side of the combustion chamber walls.                   |
| 2  | Nurcholis and Agustina (2016)| 20 air inlet holes of 2 cm diameter, were placed in one side of the combustion chamber walls (same with previous design) and additional 1 hole as entry point of air supplied by blower. |
| 3  | The latest design (2020)     | 8 air inlet holes of 2.5 cm diameter, were placed in lower part of one side of combustion chamber walls, and 3 additional holes as entry point of air inlet supplied by blower |

3.2. Incinerator performance
As described above, incinerator performance was indicated by some parameters. Those parameters are temperature produced by combustion process and temperature distribution inside combustion chamber (°C), combustion rate (kg waste/hour), smoke quality (temperature, color, smelt, solid particle content), and the effectiveness of heat energy utilization (for carbonization and water heater system).

The result of performance test of the latest improved incinerator and the comparation of those performance with performance of the previous incinerators presented in the Table 2 below.
Table 2. Comparation of the performance test result among the incinerators.

| No | Parameter                          | Previous design (2013) | Previous design (2016) | The latest incinerator design (2020) |
|----|-----------------------------------|------------------------|------------------------|--------------------------------------|
| 1  | Capacity (kg)                     | 10 – 12,5              | 10 – 14                | 10 - 14                              |
| 2  | Operation time (minutes)          | 130 – 190              | 120 – 135              | 75 – 90                              |
| 3  | Combustion rate (kg waste/hour)   | 3,16 – 5,78            | 4,8 – 6,2              | 8 – 9,33                             |
| 4  | Air velocity (m/sec)              | 1,822                  | ambient : 0,24         | ambient : 0,93                        |
|    |                                   |                        | blower : 14            | blower : 7 – 13                      |
| 5  | Smoke color                        | clear                  | clear                  | Clear                                |
| 6  | Smoke smelting                     | yes                    | yes                    | Yes                                  |
| 7  | Particle content in the smoke      | none                   | none                   | None                                 |
| 8  | Temperature (°C):                 |                        |                        |                                      |
|    | a. Upper side of combust. chamber  | 294,6 – 453,7          | 427,9 – 688            | 537,8 – 903                          |
|    | b. Lower side of combust. chamber  | 322,5 – 689,6          | 422,7 – 780            | 505,8 – 980                          |
|    | c. Combustion chamber walls        | 136,8 – 284,5          | 123,4 – 199            | 155,3 – 295                          |
|    | d. Chimney                         | 133,5 – 326,1          | 121,1 – 361            | 357,3 – 686                          |
|    | e. Dust collect.chamber            | 152,7 – 432,4          | 242 – 661              | 422,5 – 758                          |
| 9  | Ash (as residu) (kg)               | 1 – 2                  | 0,754 – 1,3            | 1,1 – 1,8                            |

3.3. Temperature inside combustion chamber

Based on the data (Table 2), improvement of air inlet system by concentration air inlet in the lower part of the combustion chamber and addition of air inlet flow by using blower with 3 (three) outlet pipes, in order to produce more wider contact surface between material and oxygen (air flow), has been successfully increasing combustion temperature up to 980 °C. This temperature is the range of temperature should be reach by an incinerator (800 °C - 1050 °C) as described by Pitchel [4]. Temperature distribution inside the combustion chamber based on the data of 3 experiments are presented in Figure 5a and 5b. We can see that the best result was achieve by experiment no 3. Figure 6 shows temperature inside the chamber when the incinerator operated in experiment no 3. Based on the data shown in the Figure 6, we can see that temperature distribution inside the combustion chamber is relatively same both of upper side and lower side. It means that the air inlet flow having good distribution inside the chamber and successfully produce good combustion process in the whole area of the chamber. This condition also represented by final condition after incineration process which shows that all material successfully burnt out and left only ash as residue.
3.4. Combustion rate
Based on the data as shown in Table 2, improvement of air inlet flow rate also successfully on increasing combustion rate to 8 – 9.33 kg/hour. This number is almost twice compared to the previous design. As known well, the higher combustion rate will produce higher combustion temperature due to the more heat energy released by the energy conversion process.

3.5. Smoke quality and other safety factors
Data in the Table 2 also shows that the quality of the smoke was quite good, represented by the smoke color and smelt, and dust (flew solid particle) content in the smoke. The smoke which produced while incinerator operation was illustrated in Figure 7. Temperature of the combustion chamber walls were recorded in a range of 155 °C – 295 °C. This high temperature will be radiated to the around of incinerator unit, so it should be reduced to prevent operator and more save to the environment. Reducing heat radiation by install a 4 m pipe of 2.5 cm diameter in one side of the combustion chamber wall, also successful on taking a function as a water heater system to produce hot water of 83 °C at 6 lt/minute flow rate (Table 3), but it looks still needs more improvement such as using insulation around the combustion chamber wall to reduce heat radiation from the wall and also keep more heat energy inside the chamber to help the incinerator running in stable temperature. Another data which also represent incinerator performance is about residue. There was no combustion residue except ash (Figure 8), meaning that all of the material was successful burnt out.
3.6. Heat energy utilization

As described above, heat energy produced in the incineration process has been designed to be utilized for water heater system (by put a 4 m pipe of 2,5 cm diameter, in one side of the combustion chamber wall) and carbonization process (by putting coconut shell inside the dust collector chamber, to produce charcoal). Those utilization has been successfully producing heat water (up to 83 °C) with flow rate of 6 lt water/minute, and producing up to 2,5 kg high quality of coconut shell charcoal in 50 minutes of incinerator operation. Table 3 presents performance of the heat utilization system (both of water heater system and coconut shell carbonization).

Table 3. Utilization of heat energy

|   | Parameter                                                                 | Prev. design (2013) | Prev. design (2016) | Latest design (2020) |
|---|---------------------------------------------------------------------------|---------------------|---------------------|----------------------|
| **Water heater system**                                                 |                     |                     |                      |
| 1 | Water flow rate (lt/minute)                                              | 5                   | 11                  | 6                    |
| 2 | Water inlet temp. (°C)                                                   | 24 - 32             | 27 - 28             | 27 - 28              |
| 3 | Max Water outlet temp.(°C)                                                | 40 - 62             | 44 - 53             | 40 – 83              |
| 4 | Total useful energy For water heater (kW)                                | 4,5 – 5,5           | 13                  | 2,11 – 3,1           |
| **Carbonization process**                                               |                     |                     |                      |
| 1 | Temperature range inside dust collector chamber (°C)                      | 164,5 – 432,4       | 406 - 661           | 679 - 765            |
| 2 | Processing time (minutes)                                                | 180 - 190           | 125 - 135           | 45 – 50              |
| 3 | Weight of coconut shell (kg)                                             | 3                   | 6                   | 12                   |
| 4 | Weight of charcoal (kg)                                                  | 0,2 – 0,5           | 0,5 – 0,8           | 2 – 2,5              |
| 5 | Yield (%)                                                                 | 6,7 – 16,6          | 8,8 – 13,8          | 16,7 – 21            |
| 6 | Charcoal quality                                                          | Fairly good         | Good                | Good                 |

Based on the data, design improvement in order to increasing the heat energy utilization is still a big challenge, due to the facts that heat energy released from the incinerator still higher than energy needed for the previous utilization that has been done. For example, by using pipe which has higher heat capacity, capturing energy from the pipe (which has temperature around 155 – 218 °C) will be more efficient and able to produce more hot water. The high temperature of combustion gas when enter to the dust collector chamber (697 – 765 °C) was more than enough to convert only 12 kg coconut shell to produce around 2 – 2,5 kg charcoal, since the carbonization actually can be occurred with ideal condition.
in the temperature of around 400 – 500 °C. Higher temperature of carbonization will produce higher quality of carbon content in the charcoal. Enlargement of dust collector chamber will be a chance to produce more charcoal, and the other side also reducing smoke temperature throughout the chimney for better environmentally impact. In this study, charcoal quality evaluates by physical appearances only, there are blackness color, hardness, and the surface inside charcoal was shiny when it broken down (Figure 9).

Figure 9. Coconut shell charcoal produced by the incineration process.

4. Conclusion
Based on the data above, the latest improvement of “portable (mini) multifunction incinerator” has better performance compare to all of previous design, in both of the main function (incinerate material/solid waste) and utilization of heat energy which was released while the incineration process. The design improvement has been successful on increasing combustion temperature up to 980 °C for combustion rate of 9 kg waste /hour, to burnt out the material/waste completely into the ash. Thus, the incinerator already met the Centre of Public Health Services (Puskesmas) requirement to burning out all of the hazardous medical waste. The incinerator produce clear smoke and no flew solid particles, meaning that the incinerator produce minimum air pollution and relatively safe to be implemented.

Utilization of heat energy released by the process has been successful producing hot water up to 83 °C at 6 lt/minute flow rate, and produce 2-2.5 kg of good quality coconut shell charcoal. Both of the products can be used by the Centre of Public Health Services (Puskesmas) for their services and sanitary purposes, such as providing warm water for the patients, medical tools sterilization, and water waste treatment. Improvement design still a big challenge to get better heat energy utilization such as design of wall insulation to prevent operator from the over heat radiation, and in the same time also keeping heat energy inside the combustion chamber to help the combustion occurred in stable high temperature.

References
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