Performance test of prototype of mini compact crucible furnace

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Abstract. Mini compact crucible furnace prototype is aimed at reducing dimensions and weight without sacrificing capacity. The performance test was conducted in order to found its weaknesses. The performance parameters tested were crucible, support, and exhaust pipe as economizer. The crucible dimensions are \((\Omega 170 \times 250)\) mm and \((\Omega 110 \times 210)\) mm while the support’s high are 80 mm and 40 mm. The test was done in two conditions which are with and without economizer. The performance is defined by the temperature change rate in melting 3 kg of aluminium. A digital infrared thermometer was used to measure temperature changes. The result shows that position of economizer is too low so the residual gas combustion could not smoothly thrown out and it flow back and collide with the combusted gas from high pressure stove below. Reducing the heating chamber could enhance the furnace efficiency but economizer should be in proper position and support should be in optimum height. Redesign of heat insulator should be done related to the smash by combusted gas from high pressure stove.

1. Introduction

Competence in casting process is important for vocational high school (VHS) students’ in understanding the manufacturing process. This refer to VHS expertise spectrum in regulation number 06/D.DD5/KK/2018 dated 7 June 2018 declared by Directorate General of Primary and Secondary Education of Indonesian Education and Culture Ministry [1]. In order to reduce the inexpert labour [2], casting practice is necessary to be conducted at VHS.

A model of an aluminium casting laboratory has been developed [3]. Aluminium is a metal which has low melting point of 660 °C, easy to pour and widely available so that aluminium considerable used for casting practice at VHS. The primary equipment for this this model is a crucible furnace to melt the aluminium. The crucible furnace developed for the model is a gas fuelled crucible furnace with spiral finned crucible [4]. However, this crucible furnace is less appropriate for casting practice at VHS since the construction and operation is complicated. Moreover, the dimension and weight are too large and heavy, and also inefficient in gas consumption. Several gas fuelled furnace to melt aluminium has been developed [5-8], but it is not appropriate for casting practice.

In the previous work, a crucible furnace called a compact crucible furnace has been developed for casting practice at VHS [9]. A high pressure gas stove as the heat source is placed below the furnace, so that it has simple and compact construction. The compact crucible furnace has a bottom hole located right below the crucible pot. The compact dimension of 450x450x900 mm need less room. The compact crucible furnace has been implementing for casting practice at VHS [9-10].
However, the compact crucible furnace is considered too heavy and it is not easily moved. In order to solve this problem, a prototype of mini compact crucible is built [11]. This prototype has smaller dimension and lighter weight although use same high pressure gas stove as shown in figure 1. It has dimension of (330x330x750) mm and 46 kg of total weight. Reducing weight was also achieved by using combination of ceramic blanket and castable as the heat insulator. The performance test is necessary in finding the weaknesses of the mini crucible compact prototype. This test is important to collecting information that required for further development of the mini compact crucible furnace in order to perfecting it.

![Figure 1. Comparison between compact crucible furnace (left) and mini compact crucible furnace (right)](image)

2. Method
The mini compact crucible furnace which was tested has heating chamber dimension of $\varnothing$ 225 mm x 350 mm [11]. The setting of the high pressure stove was made in same setup. The dimension of two variations of crucible pot is shown in table 1. It was made from steel pipe. Performance is determined by rate of temperature changes during melting process. The temperature measuring point on the aluminium surface inside the crucible as illustrated in figure 2. Supports used in this test have height of 80 mm (high) and 40 mm (low). The low support used is shown in figure 3. Same as the compact crucible furnace, the prototype of mini compact crucible furnace also use economizer which is an exhaust that extended and deflected. The effect of economizer was also be examined. Performance test variations are shown in table 2.

![Figure 2. Illustration of measuring point on big (left) and small (right) crucible.](image)

| Crucible | Outside diameter (mm) | Wall thickness (mm) | Height (mm) |
|----------|-----------------------|--------------------|-------------|
| Big      | 170                   | 8                  | 255         |
| Small    | 115                   | 6                  | 210         |
Table 2. Coding of performance test variations

| Code | Crucible | Support | Economizer         |
|------|----------|---------|--------------------|
| A    | Small    | High    | Without economizer |
| B    | Small    | Low     | Without economizer |
| C    | Small    | High    | With economizer    |
| D    | Small    | Low     | With economizer    |
| E    | Big      | High    | Without economizer |
| F    | Big      | Low     | Without economizer |
| G    | Big      | High    | With economizer    |
| H    | Big      | Low     | With economizer    |

The procedure of performance test are: (1) Melt 3 kg of aluminium in the crucible and cooled it until solidify; (2) Placed in the support; (3) Warm up the heating chamber up to 100-140 °C; (4) Put in the crucible that has been prepared in the first step; (5) Turn on the high pressure stove and heat up for 40 minutes; (6) Measure the temperature rate changes at the measuring point every 5 minutes using digital infrared thermometer Krisbow KW06-409 and record. (7) Repeat the step 2 to 6 for other variation of crucible pot, support height and with and without economizer.

3. Result and Discussion
The outside diameter of mini compact crucible prototype is 325 mm. Total thickness of heat insulating is 100 mm, so the heating chamber diameter is only 225 mm. Furthermore, the heating chamber has only 350 mm of height. The small dimension of heating chamber is shown in figure 4. It is purposed for reducing weight and enhancing the heat efficiency. However, this small dimension would limit the furnace capability.
Figure 5 shows the temperature changes rate at support height constant. It can be seen that big crucible gives temperature rate changes higher for high and low support and also with and without economizer. The using of big crucible pot leads to a narrow space between the crucible pot and the inside wall. This limited space so requires less time to raise temperature. The high support generate better temperature rate because the heat flow could easily flow form stove into the heating chamber [12]. Furthermore, big crucible has shorter distance from aluminium surface to crucible bottom as can be seen in figure 2. Therefore, heat from stove is delivered faster to aluminium surface. Temperature rates for low support in figure 5b are almost similar. This is correspond with heat flow back [12].

![Figure 5](image1.png)

**Figure 5.** Temperature changes rate at support height constant: (a) high; (b) low

Figure 6 shows differences between big and small crucible using low support and without economizer. Position of axis of exhaust hole is 260 mm from base of heating chamber. The total height of big crucible and low support is 295 mm while 250 mm for small crucible and low support. So that, the height of big crucible is exceed the position of exhaust hole. It is clear that gas combustion waste did not come out when big crucible applied. Figure 7 illustrates the heat flow from the stove when big crucible used. Collision of turn back gas combustion waste and heat flow from stove causes turbulence and imperfecting combustion of gas. This results in longer time to achieve melting temperature of aluminium compare to compact crucible furnace [9]. However, for big crucible, absence of economizer resulting better temperature rate as shown in figure 5b because gas combustion waste is easier go out. The economizer is aimed at retarding in heat losing but it also preventing removal of gas combustion waste.

![Figure 6](image2.png)

**Figure 6.** Test using low support and without economizer: (a) small crucible; (b) big crucible
Figure 7. Illustration of heat flow in heating chamber when big crucible applied

The turn back fire on bottom side of furnace appears when both big and small crucible applied. The fire back when big crucible and low support used as shown in figure 6b prove that position of exhaust is too low. In fact, the turn fire back is observed in every condition of test. This getting bigger when economizer is presence as shown in figure 8. This problem is still remain. This could be due to the crucible design, inlet shape or exhaust pipe position.

Figure 8. Performance test using low support and economizer: (a) small crucible; (b) big crucible

Figure 9. Temperature rate changes at crucible dimension constant: (a) small; (b) big
Figure 9 presenting temperature changes rate at crucible dimension constant. It is observed that the temperature rate changes almost similar for variation of support height and economizer existence. It can be stated that crucible dimension gives insignificant effect on variations of support height and the economizer existence, especially for the first 30 minutes. However, further observation shows that the slope angle of curve in figure 9b is bigger than in figure 9a. It is describing influence of crucible dimension according to the effect of distance from crucible base to aluminium surface as shown in figure 2. Moreover, this also corresponds with narrow space when big crucible applied which indicate by higher temperature achievement in figure 9b.

Figure 10 showing changes of temperature rate on the existence of economizer. Generally, temperature rate without economizer seems better. Figure 10b shows that big crucible have temperature rate better. This more related with short distance from crucible base to aluminium surface, which causes heat to be transmigrated faster. This also observed in figure 5. The small crucible resulting better heat flow inside the heating chamber since the total crucible height is not exceed, but the temperature achievement distance from crucible base to aluminium surface is dominant in achieving higher temperature. Further analysis shows that the curve slope angle in figure 10a is bigger than those in figure 10b. It means that the use of economizer affects the rate of temperature increase. However, after 20 minutes, this effect is decrease due to retardation on removal of gas combustion waste. Figure 10b indicates big crucible could achieve higher temperature in 40 minutes. This condition associated with narrow space and shorter distance from crucible base to aluminium surface.

**Figure 10.** Temperature rate changes on the existence of economizer: (a) with economizer; (b) without economizer

**Figure 11.** Damage on inside wall of prototype of mini compact crucible furnace: (a) damage position; (b) damage on position A; (c) damage on position B
Observation on furnace condition is conducted after performance test. Figure 11 showing damage of heat insulating on inside wall of furnace. The furnace heat insulating was combination of ceramic blanket and castable (heat resistance cement) [11]. The type of castable used was TNC-17 produced by PT Benteng Api Refractorindo. This type of castable is able to withstand heat up to 1600 °C. Unfortunately, it has slightly rough grain, thus it broke when hit by bursts of gas combustion. In can be seen in figure 11b that damage occurred on furnace base is quite severe. The castable grain was detached and heat insulating of base wall becomes has no strength. Furthermore, in figure 11c was also observed damage occurred on bottom side of inside wall of furnace. Although the bottom side of inside wall was eroded, it still have strength thus it does not broke. This condition can be avoided by using another type of castable which has smoother grain, for example TNC 170LC. Another solution is doing redesign the heat insulating concept without increasing furnace weight.

Figure 12 shows an evidence that heat flow smash the inside of furnace lid and turn back down then collide with gas combusted from below. Heat insulator under furnace lid was eroded but the castable grain was not released. On further examination was found a smooth crack due to the temperature differences between centre side and edge side. However, the heat insulating under furnace lid is not collapse since it is strengthened by webbing of steel bar.

4. Research Limitation
The big and small crucible has different height could give bias in data. However, the aim of this performance test is to find the weaknesses of prototype of mini compact crucible furnace thus differences of crucible height can be ignored. The effect of too low of economizer position could be examined further according to the fire back on the furnace bottom. However, the fire back is also related to the support height refers to the previous research [12].

5. Conclusion
The result shows that position of economizer is too low so the residual gas combustion could not smoothly thrown out and it flow back and collide with the combusted gas from high pressure stove below. Reducing the heating chamber could enhance the furnace efficiency but the economizer should be in proper position and support should be in optimum height. Redesign of heat insulator should be done related to the smash by combusted gas from high pressure stove.

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