Redesigning mini compact crucible furnace to improve its performance

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Abstract. Redesigning mini compact crucible furnace to improve heat insulation durability and to obtain the best exhaust pipe position is needed to achieve compatibility for aluminium casting practice. Performance test of the redesigned mini compact crucible furnace was conducted by variation of crucible, support and economizer. The rate of temperature increase, the aluminium melting rate, and gas consumption for melting aluminium specify the furnace performance. The temperature change was determined by digital infrared thermometer. Heat insulator on the inner side wall of mini compact crucible furnace were redesigned by using stainless steel plate cylinder combining with ceramic blanket D.96. Total weight of the furnace decreases by 28%. This insulator combination was able to accelerate the temperature increase, maintain the heating chamber temperature, and reduce the gas consumption. The furnace was able to melt 3 kg of aluminium in 35 minutes by consuming around 1.2 kg of liquefied petroleum gas. The economiser functioned well, was able to accelerate the temperature increase, and maintain the heating chamber temperature.

1. Introduction

One of the problems faced by ASEAN countries is the unskilled workforce [1]. In Indonesia, many efforts have been done to overcome this situation, especially to build the competence of vocational high school students and prepare them to be a ready to work. One of the important competence is that in casting process. Casting process is a basic process in product manufacturing that is included in the expertise spectrum of vocational high school [2].

Aluminium is a suitable metal for casting practice in vocational schools because of its low melting temperature of 660 °C, low specific weight of 2.7 g/cm³, good abilities in casting, and easiness to be recycled. Moreover, the use of aluminium for casting practice in vocational schools gives obvious experiences to students since it is widely applied in the engineering field. In automotive and mechanical technology, aluminium components are often applied in the form of casting products.

Melting furnace is a primary equipment in the product manufacturing that involves casting process. Crucible furnace is a kind of furnace that widely used in learning of casting practices due to its simple construction and easiness to manufacture. The laboratory-scale crucible furnace has been widely developed [3-6]. The crucible furnace for casting practice learning could use diesel [3] or liquefied petroleum gas fuel [4-6] as energy sources. Both fuels are appropriate because they make crucible furnace easier to operate. Crucible furnace for practice learning is demanded to be compact, easy to move, operate, and maintain. Unique feature of crucible furnace is the heating chamber with two holes [7]. One on the bottom to put in heat resulted by fuel combustion, and the other, on the top to discharge combustion residue. A crucible pot as a metal container is placed inside the heating chamber. A heat
insulator attached on inner wall to maintain temperature in the heating chamber and to avoid heat loss. Ceramic-based refractory can be used as a heat insulator [8, 9, 10]. Various superior refractories for heat insulator in crucible furnace had been analysed [11]. However, those refractories which are used in solid form makes the furnace weight heavier.

In prior development, a mini compact crucible furnace was aimed to reduce weight [12]. This furnace had dimension of 330 x 330 x 750 mm and total weight of 46 kg. It had heat insulator that combining ceramic blanket and castable type TNC-17. However, performance test result showed a damage on castable due to erosion by bursts from gas combustion [13]. Therefore, redesign is needed to improve the furnace compatibility for aluminium casting practice.

2. Method

Figure 1 shows redesign concept of mini compact crucible furnace that has been previously developed [12]. Heat insulator in the top cover lid and bottom of the furnace was redesigned by combining ceramic blanket D.96 with castable TNC - 170C, whereas, at the heating chamber, ceramic blanket D.96 was used combine with stainless steel plate. Stainless steel plate was formed to be a cylinder as shown by Figure 2 so that this furnace had heating chamber dimension of Ø 250 mm x 340 mm.

![Figure 1. Redesign concept of mini compact crucible furnace](image1)

![Figure 2. A cylinder from stainless steel plate](image2)
Performance test was conducted by the same condition as that applied to previous mini compact crucible furnace [13]. The bigger crucible pot had dimension of ∅ 170 mm x 225 mm and wall thickness of 8 mm, whereas, the smaller crucible pot had dimension of ∅ 115 mm x 210 mm and wall thickness of 6 mm. The support height were 80 mm and 40 mm for higher and lower support respectively. Infrared digital thermometer Krisbow KW06-409 was used to measure the temperature at the aluminium surface and 4 points outside the furnace as shown by Figure 3. Code of performance test variations is presented at Table 1 [13]. An economiser attached at the furnace was an extended and turned pipe [14].

![Figure 3. Temperature measurement points at outside wall of furnace](image)

**Table 1.** Code of performance test variations [13]

| 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     |

Performance test including steps as the following: (1) melt 3 kg of aluminium and let it to be solidified in the crucible pot; (2) locating the support inside the heating chamber; (3) heat up the heating chamber up to around 100 - 110 °C; (4) insert the crucible pot which was prepared at the first step; (5) turn the high pressure stove on; (6) measure and record the temperature change every 5 minutes; (7) repeat step 2 to step 6 for different tests.

3. Results and Discussion

The insulator of mini compact crucible furnace was redesigned by combining ceramic blanket D96 of 50 mm thickness and stainless steel plate which was rolled and tacked weld to be a cylinder as shown by Figure 4. Stainless steel plate used was austenitic stainless steel 304 of 1.2 mm thickness which is often used for high temperature application. The castable TNC-170C which has fine granules was used as insulator at the bottom of the furnace. Meanwhile, Figure 5 showing ceramic blanket attached on the inner furnace wall. The stainless steel cylinder, was detachable so that it was easy to be maintained and replaceable without damaging the ceramic blanket. As shown by Figure 6, it formed heating chamber with dimension of ∅ 250 mm x 340 mm, and the exhaust pipe has been moved upper, 10 mm below the top side of the furnace. The redesign of mini compact crucible furnace has reduced the total weight of the furnace to be 33 kg and the furnace weight to be 16 kg. It means that the furnace assembly and the furnace part became 28 % and 45 % lighter, respectively.
Figure 4. Stainless steel cylinder

Figure 5. Ceramic blanket inner wall of furnace

Figure 6. Heating chamber

Figure 7 shows the effect of the support height to the temperature change. It is obviously seen that during first 15 minute higher support give higher temperature rise. The same result is achieved after 35 minutes where higher support provide better space for fire to flow from high pressure stove so that prevent the back flow of the fire [15]. Overall, the redesign gave better results than previous design [12, 13]. Without the economiser resulted in better performance than with economiser, even though, the position of exhaust pipe had been moved upper. The economiser is actually aimed to reduce the heat loss but could be a hindrance in releasing the exhaust gas [13].

Figure 8 shows that bigger crucible pot gave better rate in temperature increase. Due to the same weight of melted aluminium, the higher crucible pot, the shorter the aluminium height and the more heat transferred from the bottom of the furnace to the top surface of aluminium [13]. However, fire back flow tended to take place at the bigger crucible pot as shown by Figure 9, especially in the bigger crucible pot with shorter support and economiser. Fire from high pressure stove experienced back flow caused to the low rate of temperature increase as shown by Figure 8b.

Figure 7. The effect of support height to the rate of temperature change: (a) higher support; (b) lower support

Figure 8. The effect of support height to the rate of temperature change: (a) higher support; (b) lower support

Figure 9. Fire back flow caused to the low rate of temperature increase as shown by Figure 8b.
Figure 8. The effect of crucible pot dimension to the rate of temperature change: (a) small crucible pot; (b) big crucible pot.

Figure 9. Fire back flow at performance test of big crucible pot, high crucible support, and using economizer.

Figure 10 shows that melting process with economiser showed better rate of temperature increase. The upper moving of exhaust pipe gave insignificant effect. The limited height of the mini compact crucible furnace made the space dimension above the crucible pot also limited. Even though the exhaust pipe had been moved upper maximally, the limited space above the crucible pot caused the exhaust gas hardly release especially when using economiser. This increased carbon dioxide that lead to imperfect combustion. This phenomena was clearly observed at the higher-bigger crucible pot. Possibly, the exhaust pipe could be located on the lid so that the exhaust gas would directly move upward. However the smaller diameter of the furnace would be an obstacle.

Figure 10. The effect of economizer to the rate of temperature change: (a) with economizer; (b) without economizer.
In overall, the redesigned furnace gave 5 minutes faster rate of temperature increase. It needed 35 minutes to reach the aluminium melting temperature with average gas consumption of 1.2 kg. Stainless steel accelerate the temperature increase by store the heat during the melting process. However, the support needs to be further developed to get optimal fire flow. Furthermore, the effect free space dimension between crucible pot and exhaust pipe need to be deeply analysed.

Figure 11 shows the temperature measurement result on the outer wall of the furnace during 3 kg melting with smaller crucible pot, shorter support without economiser. On the cover lid and furnace handle, the temperature was around 110-120 °C after 40 minutes melting process. It indicates that heat insulator design maintained well the temperature of heating chamber. Economiser attachment affected to the temperature increase in the exhaust pipe and the adjacent zones. It store heat longer so that the temperature would gradually increase in the exhaust pipe as shown by Figure 11a. This indicated that economiser maintained the heat well in the heating chamber.

![Figure 11](image)

**Figure 11.** Outer wall temperature using small crucible pot and low support (a) with economizer; (b) without economizer

4. Research Limitation

The difference between bigger and smaller crucible pot is uncontrolled research variable that could result in data bias. Those would not be a problem because the main purpose of the performance study was to know the durability and capability of this mini compact crucible furnace. However, fire back flow phenomena related to crucible pot diameter need to be deeply analysed.

5. Conclusion

Heat insulator on the inner wall of mini compact crucible furnace was redesigned by using stainless steel cylinder combined with ceramic blanket D96. The redesign of mini compact crucible furnace has reduced the total weight of the furnace to be 33 kg (28 %). The redesigned furnace gave faster rate of temperature increase and maintain heating chamber temperature. It needed 35 minutes to reach the aluminium melting temperature with average gas consumption of 1.2 kg. The economiser functioned properly and was able to accelerate temperature increase as well as to store heat longer in the heating chamber. Support design and crucible pot diameter need to be analysed deeply related to heat loss during melting process.

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