Optimizing performance of compact crucible furnace by optimizing position of crucible pot

AL Soemowidagdo¹, A Arifin²
¹,² Mechanical Engineering Education Department, Yogyakarta State University
E-mail: arianto_ls@uny.ac.id

Abstract. Innovations has been conducting recently in order to obtain suitable crucible furnace for casting practice at vocational high school. This research is aimed at optimizing performance of compact crucible furnace by optimizing the crucible pot position. The crucible pot have diameter of 170 mm and height of 250 mm. The height of pot supporting are vary of 20, 40, 60, 80, and 100 mm. The furnace performance is determined by the rate of temperature rise to melt 3 kg of aluminium. Temperature changes measured by infrared thermometer. The result indicate that pot support of 60 mm gives optimum performance to compact crucible furnace. It is resulting temperature achievements of 600 °C in 35 minutes.

1. Introduction
According to the regulation of Directorate General of Primary and Secondary Education of Indonesian Education and Culture Ministry number 06/D.DD5/KK/2018 dated 7 June 2018 about VHS expertise spectrum [1], competency in casting process should be possessed by graduates of mechanical engineering program of vocational high school (VHS). It is the concern of VHS as one of skilled labor provider due the nowadays conditions of most ASEAN nations which deal with the lack of skilled worker [2]. This is important because casting is a basic process in product manufacturing.
Furnace is primary equipment in casting process to melt the metal. Crucible furnace is most suitable one for casting practice at VHS. Compared to other kind of furnace, crucible furnace have advantages such as simple construction, easy to made, to operate, to maintain and low cost. Distinctive characteristic of crucible furnace is the used of crucible pot placed on support block. The crucible furnace is also has two holes which is one at the bottom and the other at the upper. The bottom hole which generally in the tangential direction is to supply heat while the upper hole is for throwing out the combustion waste. The energy source of crucible furnace could be from charcoal, oil, or gas [3, 4, 5, 6]. However, gas fueled crucible furnace, especially liquid petroleum gas (LPG), is most suitable for casting practice at VHS based on availability, high energy, low cost, and ease of use. Gas fueled crucible furnace is being developed continuously [7, 8, 9, 10, 11].

At this time, compact crucible furnace is the most appropriate furnace for VHS and it has been applied [9,10]. The compact crucible furnace has compact dimension of 450x450x900 mm and simple construction. This furnace able to melt 3 kg aluminum in 40-50 minutes with average LPG consumption 2 kg. The bottom hole of compact crucible furnace is lie precisely below the crucible pot. The high pressure stove to burn LPG is placed under the bottom hole.
Transfer of heat in crucible furnace occur in two mechanism, which is, convection and conduction. Heat that generated by high pressure stove is transferred to bottom of the crucible pot and then spread over the side of crucible pot. Furthermore, the heat transferred conductively through crucible pot wall to the metal inside of pot. The mechanism is illustrate in figure 1.
Innovations is conducted to improve performance and increase energy efficiency of crucible furnace [11, 12]. Guide way on the inside wall of crucible furnace was developed by Tanaka et.al [12]. The purposes of this innovation is to make the heat flow spirally around crucible pot. Guide way makes heat contact longer to pot. It is been proven improving the furnace efficiency. Similarly, Arianto et.al. [11] develop a spiral finned crucible pot. Fin made of steel welded to pot spirally. The idea is similar with guide way. The advantage is the steel fin could absorb heat which then transferred to metal inside the pot. However, both innovations above rather difficult to implement to compact crucible furnace. Compact dimension and small heating chamber of compact crucible furnace prohibit to apply it. Thus, other innovation should be conduct to optimize performance of compact crucible furnace.

It can be observe from figure 2 that crucible pot has a corner portion. It is clear that it will affecting efficiency of compact crucible furnace. Heat from below could not move smoothly at that portion. As a result, if the pot position too low some heat will turn back and flew away, but if too high, pot heating rate will decrease. This study is aimed at optimizing performance of compact crucible furnace by optimizing pot position.

2. Method

The compact crucible furnace with high pressure stove has heating chamber diameter of 350 mm. Crucible pot made from steel pipe with 170 mm outside diameter, 8 mm thickness, and 250 mm height. Steel plate of 10 mm thick welded to the bottom of the pipe. Placement of pot inside compact crucible furnace is illustrated in figure 2. Pot support made from 3 mm thick steel plate. The pot support design is showed in figure 3. The variation of pot support height are 20, 40, 60, 80, and 100 mm.

The steps of experimental procedure are: (1) Weighing 3 kg of aluminium, melted, and let it solidify in the crucible pot; (2) Warmed up the furnace up to 30-40 °C and placed pot support; (3) Heating the aluminium that had been prepared in the first step until it melt; (4) Measure the temperature changes
on aluminium surface and at inside wall of pot. Temperature changes of inside pot was measured at 25, 85, and 150 mm from top side. The aluminium surface 185 mm from top side of pot. The temperature was measured every 5 minutes using infrared thermometer Krisbow KW06-409 until the aluminium melted. (5) Repeat the steps above for other pot support variation.

3. Result and Discussion

Figure 4 shows compact crucible furnace equipped with high pressure stove at the bottom [10]. Fire brick with fire clay used as heat insulation at the inside of furnace. The exhaust pipe to throw away combustion waste is extended and deflected act as economizer [8]. Figure 5 shows crucible pot from steel pipe. Steel plate of 1 mm and 20x20 mm is tack welded on the inside of pot. It is used as temperature measuring point, welded at distance of 25 mm (point A), 85 mm (point B), and 150 mm (point C) from top side of the pot. The aluminium surface (point D) is at 185 mm from top side of pot. Pot support can be seen in figure 6. It is made from steel plate of 3 mm thick. The pot support height vary of 20, 40, 60, 80, and 100 mm.

Figure 4. Compact crucible furnace with economizer

Figure 5. Crucible pot with temperature measuring point

Figure 6. Pot support from left: 20, 40, 60, 80, and 100 mm

Figure 7 presenting the effect of height of pot support to the performance of compact crucible furnace. It is observed that in first 5 minutes, highest temperature is at point A for all of height variation of pot support. This indicates that heat from stove move wide when hit bottom side of crucible pot. It is move away from pot wall and then move upward along outside wall of pot as illustrate in figure 8. The fact that in first 5 minutes, lowest temperature always at aluminium surface in the pot strengthen the argument above. The aluminium surface is at 75 mm above bottom side of pot, thus undirectly exposed by heat because the heat flow moving wide. Heat absorbed by aluminium is spread from bottom and upper pot.
Figure 7. Effect of pot support height to compact crucible furnace performance
(a) 20 mm; (b) 40 mm; (c) 60 mm; (d) 80 mm; (e) 100 mm
During 35 minutes of heating, it is observed that pot support of 100 mm gives lowest temperature achievement which contrast with the support of 60 mm that generate highest temperature. This is shows that support of 60 mm develop optimum performance to compact crucible furnace. Moreover, pot support of 20 mm gain temperature higher than the 100 mm. The wide gap between pot and stove explain how pot support of 100 mm resulting lowest temperature. However, with 20 mm of pot support, fire from stove directly hit the bottom of pot, moving widened and few of it hit the wall of orifice input then turn back go outside as demonstrate in figure 9. Thus, pot support of 20 mm cannot gives optimum performance to compact crucible furnace.

Figure 10 reveal fire flow during heating on compact crucible furnace with height pot support of 20, 40, 60, 80, and 100 mm respectively. The increasing pot support height, the flame which wrap pot will higher. This indicate that increasing pot support height will decrease flame turn back away outside through the input orifice at the furnace bottom. Figure 10(e) clearly shows that flame could reach top side of crucible pot. This is consistent to figure 7(e) which indicate at 10 minutes up, temperature at point B, C, and D increase faster. This caused by heat that spread from bottom side and move upward of crucible pot. At minutes of 35, the temperature achievement on those three point already uniform.

4. Research Limitation
The crucible pot of 170 mm in diameter is used in this research and the input hole at the bottom of compact crucible furnace is 150 mm. The research result could different if using crucible pot with
different diameter. Likewise, if the diameter of input hole is different, the research result could be different.

5. Conclusion
Crucible pot support with height of 60 mm gives optimum performance to the compact crucible furnace. The temperature achievement is about 600 °C in 35 minutes.

6. References
[1] Directorate General of Primary and Secondary Education 2018 Regulation number 06/DD5/KK/2018 (Jakarta: Indonesian Education and Culture Ministry)
[2] Gross M 2017 Developing a competency standard for TVET teacher education in ASEAN countries J. Tech. and Voc. Education 23 279-87
[3] Aditya Nag M V and Dareddy R R 2012 Performance improvement of an oil fired furnace through oscillating combustion technology Int. J. Sci. & Eng. Research IJSER(2012)
[4] Ighodalo O A, Akue G, Enaboifo E and Oyedoh J 2011 Performance evaluation of the local charcoal-fired furnace for recycling aluminium J. Emerging Trends in Eng. and Appl. Sci. 2 448-50
[5] Olalerel A A, Dahunsi O A, Akintunde M A and Tanimola M O 2015 Development of a crucible furnace fired with spent engine oil using locally sourced materials Int. J. Innovation and Appl. Studies 2 281-88
[6] Suresh R and Nagarjun M G 2016 Construction and Performance analysis of Pit furnace by using Biodiesel Indian J. Sci. and Tech. IIST(2016)
[7] Soemowiagdo A L, Tiwan and Mujiyono 2014 Pengembangan tungku peleburan aluminium untuk mendukung kompetensi pengecoran di SMK program studi keahlian teknik mesin Inotek 18 80-94
[8] Soemowiagdo A L, Tiwan, and Mujiyono 2017 Crucible furnace with economizer for casting practice at mechanical engineering education department faculty of engineering yogyakarta state university J. Mech. Eng. Voc. Dynamics 2 21-27
[9] Ilyas M N and Soemowiagdo A L 2017 Compact crucible furnace for aluminium casting practice at muhammadiyah 1 salam VHS J. Mech Eng Voc Education 5 9-19
[10] Soemowiagdo A L, Tiwan, Sutopo and Nurdjito 2017 Sarana Praktik Pengecoran Aluminium Untuk SMK Program Keahlian Teknik Mesin, Proc. Nat. Conf. on Voc. Education (Yogyakarta) vol 1 (Yogyakarta: Faculty of Engineering/Yogyakarta State University) p 277-284
[11] Soemowiagdo A L, Tiwan, Widarto and Arddian A 2018 Spiral finned crucible pot Proc. 3rd. Int. Conf. on Industrial, Mechanical, Electrical, and Chemical Engineering (Surakarta) vol 1931 (America: A N Agung et al/ AIP) p 030066-1
[12] Tanaka A, Tsuri M, Ando H, Kikura M and Ueki M 2001 High efficiency crucible melting furnace for non-ferrous metals (accessed 10 August 2017) from: http://www.h-techno.com/en/seihin/asm.html

Acknowledgments
The authors are grateful for the financial support of the Institute of Research and Community Service, Yogyakarta State University. The authors wish to thank to the Dean of Faculty of Engineering Yogyakarta State University for using facilities of Material and Processing Laboratory.