Enhanced Cooling Process of Furnace Using Vortex Tube Cooling Device

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Abstract. A furnace is a heating device, which is used for heating samples up to 1350°C. The conventional method to reduce the temperature of the furnace to room temperature requires more than 8 hours. Therefore, a vortex tube cooling device is used to enhance the cooling process. The vortex tube is a small cooling device that uses compressed gas to produce cold flow. In this study, 3 cooling methods were compared; the conventional method, room temperature compressed gas cooling method, and vortex tube cooling method. From the results, it is clear that the vortex tube is able to enhanced the cooling process. Comparing to the conventional method, the vortex tube can reduce the temperature 2-hour faster.

1 Introduction

The vortex tube (also called as Ranque Hilsch vortex tube) is a mechanical device that separates a compressed air into cold and hot streams without any moving parts or chemical reactions. It consists of cold exit, tangential nozzle, vortex chamber, tube, control valve, and a hot exit, as shown in Fig. 1.

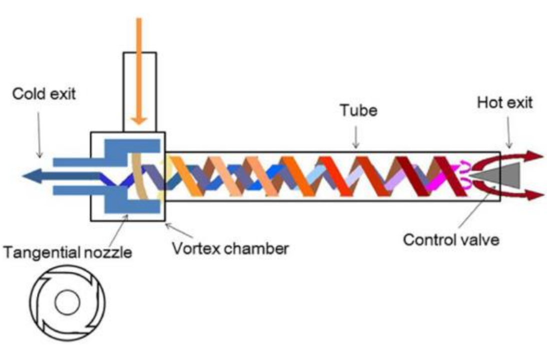

Fig. 1. Schematic diagram of vortex tube [1].

S. E. Rafiee et al. [2] investigated the differences cone angle on convergence vortex tube that 15°, 20°, 25° and 30°. They reported that cone angle, $\alpha = 30°$ leads to 50.60% higher heating performance at the cold flow ratio of 0.75 and provides higher cooling efficiency

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which is 43.76%. G. S. Kumar et al. reported that the best cone angle is 20° [3]. However, S. E. Rafiee et al. [2] reported the cone angle, $\alpha = 30°$ is the best cone angle. K. Devade and A. Pise [4] studied the effect of cone angle 30°, 45°, 60° and 90° in their experiment. From their study, they reported that angle of 45° is the best cone angle because it gives maximum cooling effect while for 60° angle provided the better heating effect. B. Markal et. al. [5] investigated four different cone angle, $\alpha = 30°, 45°, 60°, 90°$. It observed that the effect of the cone angle on the performance changes depends to the value of the length to inner diameter ratio, L/D. The result shows that the smaller angle is better to use in order to improve the performance of the vortex tube with smaller L/D. However, Y. Xue and M. Arjomandi reported different results [6]. They studied various numbers of cone angle which is 2.5°, 3.8°, 4.8°, 6.7°, 8.6, 12.3°, 17.9°, 23.1°. In this study, the inlet pressure was varied from 2 until 4 bar to determine the optimum angle. From this figure, it is understood that the highest cooling efficiency obtained at 4 bar with a cone angle of 2.5°.

K. Devade and A. Pise [4] investigated the cold diameter to inner diameter ratio, d/D of 0.36, 0.43 and 0.50. The inner diameter, D is 14mm. From their study, it can be understood that the d/D = 7mm has the highest COP (0.18) when the inlet pressure is 5 bars. S. U. Nimbalkar and M. R. Muller [7] studied the energy flux separation of the vortex tube. It can be understood that at 60% of cold fraction regardless of diameter ratio and inlet pressure is the maximum performance. The highest energy flux separation achieves when the d/D is 0.50 within the cold fraction 60% to 80%. From these research, it is clear that 0.50 of diameter ratio is the optimum value of the cold exit diameter.

A furnace can produce a high-temperature heating area up to 1350°C. A conventional method to reduce the temperature until 30°C usually takes more than 8 hours. Therefore, in this study, the vortex tube cooling device is used to reduce the high-temperature furnace. Three methods of the cooling process will be compared, and the cooling rate and time consumption will be clarified.

2 Methodology

2 1 Furnace

The furnace that was used in this experiment is shown in

Fig. 2**. The specifications of the furnace are shown in**

Table 1. The furnace was heated until the temperature reached 1350°C. The cooling process was conducted through three cooling methods, which will be explained in details later in subsection 0.

Fig. 2. Furnace used in the experiment.

Table 1 Furnace specifications.

Model	HTF-14/200-5
Serial NO	0339/15
Temperature measurement	Thermocouple Type-R
Date of manufactured	January 2015
Max Temperature	1400°C
Max constant temperature	1350°C
Power	240VAC/1P 50HZ

2.2 Vortex tube

The vortex tube is shown in Fig. 3. This vortex tube was manufactured by a company in China. It is made from stainless steel and has a length of 15 cm. The compressed air inlet, cold flow outlet and hot flow outlet are shown in this figure, respectively. In this research, the cold flow that exits through the cold flow outlet was connected to the high-temperature furnace to reduce its temperature. This process is one of the three cooling methods.

Fig. 3. Vortex tube.

2.3 Cooling methods and apparatus setup

In this research, three cooling methods were applied, and the performance of the methods was compared. The three cooling methods are named Conventional method, Non-VT and VT, respectively. The details are shown in Table 2. For the conventional method, the heated furnace was leaved to be cooled naturally by the ambient air until the temperature drop to 30°C. For Non VT and VT cooling method, an apparatus was connected to the furnace, as shown in Fig. 4. The pressure of compressed air from the compressor was regulated by a pressure regulator. Then, the flow was controlled by the control valve to flow through the vortex tube (VT flow) or not (Non VT flow). The mass flow rate and the flow temperature of the flow that enters the furnace was measured by a flow meter and thermocouple Type-K, respectively. The temperature of the furnace was measured and displayed by thermocouple Type-R and temperature display, respectively. These two devices are a built-in device of the furnace. To determine the optimum setup of the cooling process, the cold flow mass flow rate and inlet pressure for Non VT and VT cooling method were varied at 60, 80, 100 lpm and 4, 5, 6 bar, respectively, as shown in Table 2.

Table 2 Cooling methods comparison.

No	Cooling method	Description	Type of gas	Mass flow rate (lpm)	Inlet pressure (gage; bar)	Temperature
1	Conventional method	Furnace is leaved to be cooled naturally by the ambient air.	Ambient air	0	0	Room temperature
2	Non VT	Room temperature compressed air is injected into the furnace.	Compressed air	60, 80, 100	4, 5, 6	Room temperature
3	VT	Cold flow from vortex tube is injected into the furnace.	Compressed air	60, 80, 100	4, 5, 6	Cold flow temperature

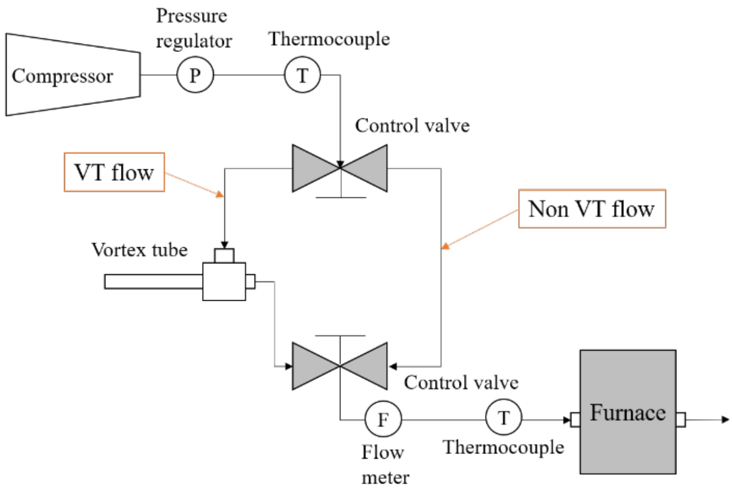


Fig. 4. Schematic diagram of the experimental setup for Non-VT and VT cooling methods.

2.4 Governing equations

To measure the performance of vortex tube, a temperature difference between the inlet and cold outlet was used, as shown in Eq. (1).

$$\Delta T_c = T_c - T_i \text{ [°C]} \tag{1}$$

Here, T_c is the cold flow temperature, and T_i is the inlet temperature.

Eq. (2) was used to measure the cooling rate. Here, T_n represents the temperature at n reading point, and T_{n+1} represents the temperature at n+1 reading point, which is 20 minutes after the temperature measurement of T_n.

$$\dot{C} = \frac{T_n - T_{n+1}}{20} \text{ [°C/min]} \tag{2}$$

3 Results and discussions

3.1 Performance of vortex tube

The performance of vortex tube is measured using the temperature difference between the inlet temperature and cold flow temperature. In this research, the inlet pressure and cold flow mass flow rate were varied at 60, 80, 100 lpm and 4, 5, 6 bar, respectively. The result for the temperature differences is shown in Fig. 5. From this figure, it is clear that increasing the cold flow mass flow rate increases the temperature difference, i.e. the lower temperature of cold flow is generated. Likewise, increasing the inlet pressure increases the temperature differences. Inlet pressure of 6 bar and cold flow mass flow rate of 100 lpm produces the maximum temperature differences (-7.23°C).

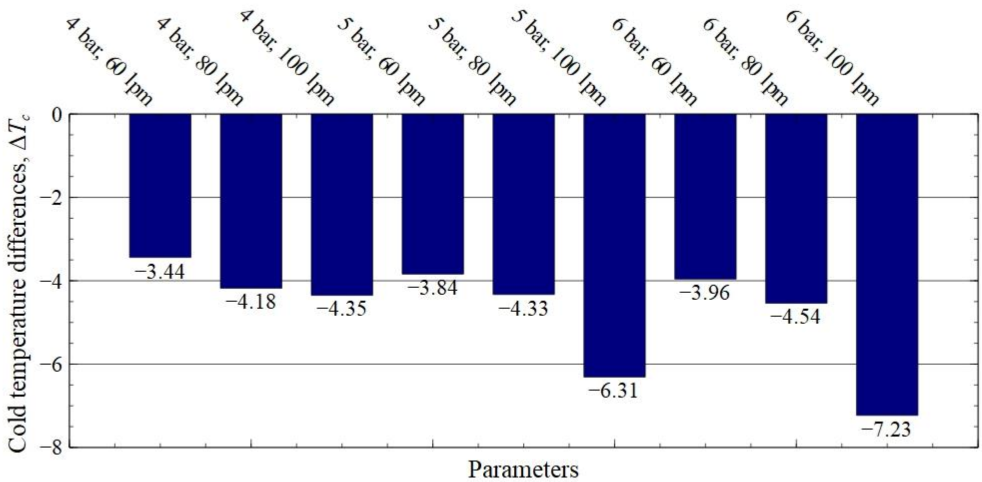
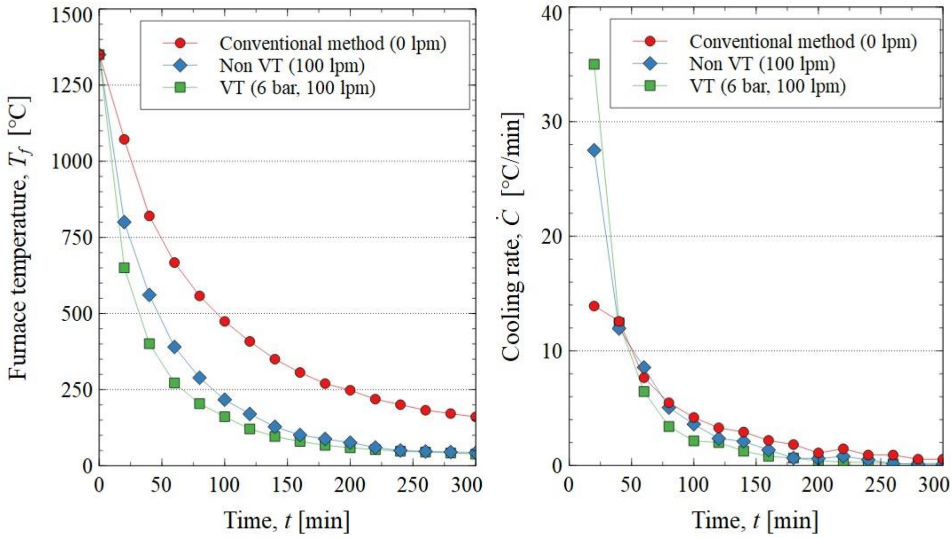


Fig. 5. Cold temperature difference, ΔT_c for all parameters.

3.2 Furnace temperature and cooling rate

As mentioned above, the inlet pressure and mass flow rate were varied at 60, 80, 100 lpm and 4, 5, 6 bar, respectively. For comparison purpose, only the inlet pressure of 6 bar and mass flow rate of 100 lpm will be discussed. The overall results will be discussed in subsection 0.

Fig. 6 (a) and (b) shows the effect of cooling methods on the furnace temperature and cooling rate, respectively. As can be seen from Fig. 6 (a), the furnace temperature significantly drop when Non-VT and VT cooling methods were used. Comparing with the conventional method that has no air flow, the air flow from Non-VT and VT enhanced the heat transfer process. This allows the heat from the furnace is absorbed by the air flow, and exits the furnace. The VT cooling method reduces the furnace temperature faster than Non-VT cooling method due to the lower air flow temperature. From Fig. 5, when the inlet pressure is 6 bar and the air flow is 100 lpm, VT produced 7.23°C lower temperature than the Non-VT. From Fig. 6 (b), it is clear that the VT cooling method produces the highest cooling rate in the first 20 minutes. At t = 80 minutes, the conventional method had the highest cooling rate. This is due to the furnace temperature was still high comparing to Non-VT and VT, which results in a higher temperature difference between the furnace and ambient. At t = 260 minutes, the cooling rate of Non VT and VT is almost 0. This shows that the furnace temperature is constant and almost equal to the ambient temperature.



(a) (b)

Fig. 6. Comparison of cooling methods; (a) Furnace temperature, (b) Cooling rate.

3.3 Overall results for all parameters

Fig. 7 shows the time required for all cooling methods to reduce the furnace temperature from 1350°C to 30°C. The x-axis represents the parameters of all cooling methods, and the y-axis represents the time taken until the furnace temperature is reduced to 30°C.

From this figure, it can be understood that conventional method requires 580 minutes (9 hours 40 minutes) to reduce the furnace temperature to 30°C. The lowest time required was obtained when using VT cooling method at inlet pressure of 6 bar and mass flow rate of 100 lpm, which is 410 minutes (6 hours 50 minutes). Compare to the conventional method, using VT cooling method reduced the cooling time up to 3 hours (170 minutes), which equals to 29.3% of cooling time reduction. It is also clear that increasing the mass flow rate reduces the cooling time for Non VT and VT. Compare to Non VT which use room temperature compressed air, using VT to decrease the compressed air temperature before entering the furnace is proven to be a better cooling method.

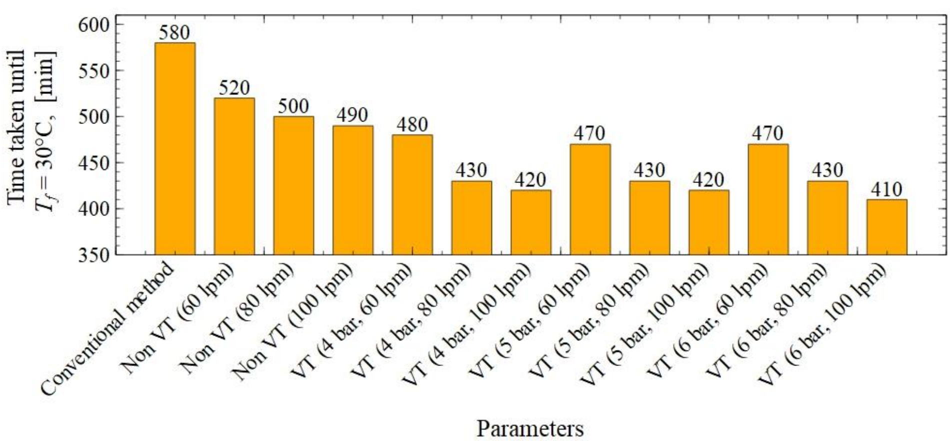


Fig. 7. Overall results for all parameters.

4 Conclusions

Three cooling methods were compared to determine the best cooling method to reduce the high-temperature furnace from 1350°C to 30°C. The first cooling method is the conventional method, which use the stagnant ambient air to reduce the temperature. The second method is using a room temperature compressed gas with 60 lpm to 100 lpm of flow. The last method is using a vortex tube, which can create a cold flow from a compressed gas. The conclusions are as follow:

1. The vortex tube produces the lowest cold flow temperature when the inlet pressure is 6 bar, and the flow rate is 100 lpm.
2. In the first 20 minutes, the cooling rate of VT cooling method is the highest.
3. Compare to the conventional method, using VT and Non VT cooling method reduce the cooling time up to 170 minutes and 90 minutes, respectively.

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