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Analysis effect of wall dimensions on thermal resistance in furnace induction 1200 ⁰C

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ABSTRACT

The development of the metal hardening industry using electrical induction to increase the hardening temperature chamber is rapid. The temperature can reach 1200 °C quickly by adjusting the electricity input to the heater. However, the temperature can also decrease significantly if the thermal resistance of the room cannot prevent heat transfer outside. The research method uses analysis of other research and direct measurements on induction furnace machines. The machine specifications have maximum room temperature (T1= 1200 ℃), surrounding temperature (T2= 25.8 °C), and firebrick thermal conductivity (k= 4.78 J/s m°C). Researchers focused on testing variations of wall dimensions (breadth and thickness). Based on calculation results, the best thermal resistance is 1.1308 in dimension 2 with a breadth of 259 cm^2 and thickness of 14 cm. This is in accordance with the theory of thermal resistance that the higher thermal resistance produced, the higher the material's ability to inhibit the rate of heat flow.

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INTRODUCTION

A furnace is defined as a tool capable of providing heat treatment of materials and making other forms of its microstructure and properties (Suprastiyo & Harmi Tjahjanti, 2016). The use of furnaces has an important role in the world of research with the heat treatment of materials formed from the working process of each element in the furnace and transferred to the material to be heated. The heat transfer process is commonly known as the heat transfer process, which occurs due to a temperature difference in the system causing heat transfer.

The fast heat transfer rate from inside the hardening chamber to outside the wall will cause the hardening temperature to drop. The temperature of the hardening room causes this, the temperature of the surrounding environment, the thermal conductivity of the material making up the walls, and the considerable thermal resistance. The tropics' standard temperature or ambient temperature is around 25.8 – 27.1 °C (Budi et al., 2021). In the wall-building materials (cement and refractory stone), a heat transfer process will occur by conduction, which has thermal conductivity and thermal resistance. In this case, the researcher refers to other studies that have been conducted previously regarding the measurement of thermal conductivity of composites (a mixture of cement and refractory stone) and obtained a thermal conductivity value of 4.78 J/s m°C (Wardhani & Rahardjo, 2015). The next factor to be reviewed is thermal resistance in the hardening chamber.

The material's thermal resistance is used to reduce the heat transfer rate due to the temperature difference on the inside and outside of the room (Ajiwiguna et al., 2016). The Area of the wall material and the distance between the inner and outer sides or the thickness of the wall can affect the amount of thermal resistance. Therefore, it is very important to carry out an analysis or study of the influence of the dimensions (Area and thickness) of the room in order to determine the thermal resistance that exists on the furnace wall.

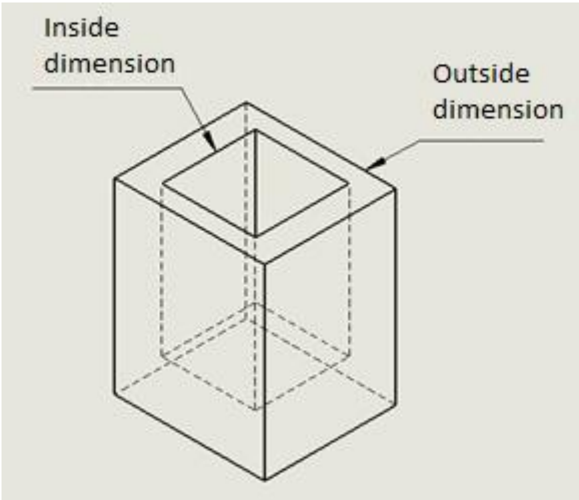

Figure 1. Furnace Machine Chamber

METHOD

The mechanism of the process of heat transfer or heat transfer occurs by conduction. This means the heat transfer process involves thermal conductivity in the test analysis. Thus, thermal conductivity is the ability of a material to absorb heat in each unit of time, material length, and temperature. The thermal conductivity values for the materials that make up the walls of the hardening chamber were obtained from other researchers who had previously conducted tests on cement and refractory stone in furnaces (Wright et al., 2003; Wardhani & Rahardjo, 2015; Pramesti & Akbar, 2021). Thus, in this study, an analysis will be carried out regarding the influence of the dimensions of the walls (Area and thickness) on the value of thermal resistance that occurs in the induction furnace to reduce the heat transfer rate.

Researchers reviewed some data from references before analyzing the thermal resistance on the wall dimensions of the 1200 ℃ induction furnace machine. Not only looking for references, but researchers also made direct measurements on a 1200 ℃ induction furnace machine made by the Gajah Tunggal Polytechnic Team. The data collection results are in the form of variations in dimensional measurement data (Area and thickness) of the walls of the 1200 ℃ induction furnace machine. The following are the dimensions of the room which will be shown in Table 1.

Tabel 1. Dimension Variation

Num.	Inside Dimensions (cm)	Outside Dimension (cm)	Thick (cm)
1	20 x 20	32 x 32	24
2	15 x 15	22 x 22	14
3	22 x 22	27 x 27	10
4	19 x 19	25 x 25	12
5	21 x 21	28 x 28	14

The following dimensional data is a variation of the dimensions of the furnace room, which will later be used to make an induction furnace with a temperature of 1200 °C. The research will focus on calculating the wall material's thermal resistance. Heat transfer occurs through conduction with an intermediary object (wall) (Wardhani & Rahardjo, 2015). The equation used in calculating the value of the thermal resistance to the displacement rate is as follows (Holman, 2008; Incropera et al., 2017)

$$q_k = \mathrm{Ka}\left[-\frac{\Delta T}{\Delta x}\right] \quad \text{atau} \quad \frac{q_k}{A} = \mathrm{k}\left[-\frac{\Delta T}{\Delta x}\right] \tag{1}$$

If heat is analogous to electricity, it will be:

$$q_k = \frac{T_2 - T_1}{\Delta x} kA \tag{2}$$

The relationship between thermal resistance and heat has an inversely proportional value:

$$R_{th} = \frac{\Delta \mathrm{T}}{q_k} \tag{3}$$

If the different temperatures are translated, then:

$$R_{th} = \frac{T_2 - T_1}{q_k} \tag{4}$$

Information:

q_k = heat

T_1 = Outdoor Temperature k = conductivity

T_2 = Heater Temperature A = Cross-sectional Area

Δx = Room Thickness R_{th} = Thermal Resistance

The data collection method based on several references produced data in the form of conductivity values (k = 4.78 J/s m °C), ambient temperature ($T1$ = 25.8 °C), and hardening room temperature ($T2$ = 1200 °C). These data will be used in calculating the thermal resistance value of the induction furnace in the 1200 ℃ hardening temperature.

The flow of activities carried out in this study is as follows:

1. Library Studies

   The first stage is the study of literature in which a search for references related to the existing process of the induction furnace.

2. The calculation for Heat Flow

   In the second stage, a calculation process is carried out on each wall dimension variation data in the form of area and wall thickness of the induction furnace thickness. Next, calculate the amount of heat based on the wall area.

3. Thermal Resistance Value

   The third stage is used to obtain the value of thermal resistance on various wall dimensions using the heat that has been searched for.

4. Get the dimension with the Best Barriers

   After calculating the value of the thermal resistance in each dimension, researchers can find out the dimensions (Area and thickness) of the wall that will be used as a reference in making an induction furnace so that it will get optimal heat.

RESULTS AND DISCUSSION

The following results in calculating the thermal resistance value for each dimension of the induction furnace wall.

Calculation of first-dimensional variation

The resistance value in the first dimension can be seen in Table 2. The heat flow value is given by:

$$q_k = \frac{T_2 - T_1}{\Delta x} kA$$

$$q_k = \frac{(1200-25{,}8)°\mathrm{C}}{24\ cm}(4{,}78\ \frac{J}{s} m°\mathrm{C}\ x\ 624\ cm^2)$$

$$q_k = 1.400{,}92\ °\mathrm{C}\ \frac{J}{s} m^2°\mathrm{C}$$

Furthermore, the thermal resistance value is given by:

$$R_{th} = \frac{T_2 - T_1}{q_k}$$

$$R_{th} = \frac{(1200 - 25{,}8)°\mathrm{C}}{1.400{,}92\ °\mathrm{C}\ \frac{J}{s} m^2°\mathrm{C}}$$

$$R_{th} = 0{,}8382 \frac{s}{J} m^2°\mathrm{C}$$

Table 2. First Dimension

Properties	Value
Outside Dimension (cm)	32 x 32
Inside Dimension (cm)	20 x 20
Thick (cm)	24
Total Area (cm^2)	624
Heat Flow $\left(°\mathrm{C}\ \frac{J}{s} m^2°\mathrm{C}\right)$	1.400,92
Resistance Value $\left(\frac{s}{J} m^2°\mathrm{C}\right)$	0,8382

Calculation of second-dimensional variation

The resistance value in the second dimension can be seen in Table 3. Through the same calculation as above, the heat flow is obtained:

$$q_k = \frac{T_2 - T_1}{\Delta x} kA$$

$$q_k = \frac{(1200-25{,}8)℃}{14\ cm} (4{,}78\ \frac{J}{s} m℃\ x\ 259\ cm^2)$$

$$q_k = 1.038{,}34℃\ \frac{J}{s} m^2℃$$

Then the thermal resistance value is:

$$R_{th} = \frac{T_2 - T_1}{q_k}$$

$$R_{th} = \frac{(1200 - 25{,}8)℃}{1.038{,}34\ ℃\ \frac{J}{s} m^2℃}$$

$$R_{th} = 1{,}1308 \frac{s}{J} m^2℃$$

Table 3. Second Dimensi

Properties	Value
Outside Dimension (cm)	22 x 22
Inside Dimension (cm)	15 x 15
Thick (cm)	14
Total Area (cm^2)	259
Heat Flow $\left(℃\ \frac{J}{s} m^2℃\right)$	1.038,34
Resistance Value $\left(\frac{s}{J} m^2℃\right)$	1,1308

Calculation third dimension variations

The resistance value in the third dimension can be seen in Table 4. The heat flow value is obtained:

$$q_k = \frac{T_2 - T_1}{\Delta x} kA$$

$$q_k = \frac{(1200-25{,}8)℃}{10\ cm} (4{,}78\ \frac{J}{s} m℃\ x\ 245\ cm^2)$$

$$q_k = 1.375{,}11℃\ \frac{J}{s} m^2℃$$

The thermal resistance value is:

$$R_{th} = \frac{T_2 - T_1}{q_k}$$

$$R_{th} = \frac{(1200 - 25{,}8)℃}{1.375{,}11\ ℃\ \frac{J}{s} m^2℃}$$

$$R_{th} = 0{,}8539\ \frac{s}{J} m^2℃$$

Table 4. Third Dimension

Properties	Value
Outside Dimension (cm)	27 x 27
Inside Dimension (cm)	22 x 22
Thick (cm)	10
Total Area (cm^2)	245
Heat Flow $\left(°C\ \frac{J}{s} m^2 °C\right)$	1.375,11
Resistance Value $\left(\frac{s}{J} m^2 °C\right)$	0,8539

Calculation of fourth-dimension variations

The resistance value in the fourth dimension can be seen in Table 5. The heat flow value is:

$$q_k = \frac{T_2 - T_1}{\Delta x} kA$$

$$q_k = \frac{(1200-25{,}8)°C}{12\ cm} (4{,}78\ \frac{J}{s} m°C\ x\ 264\ cm^2)$$

$$q_k = 1.234{,}78\ °C\ \frac{J}{s} m^2 °C$$

The thermal resistance value is:

$$R_{th} = \frac{T_2 - T_1}{q_k}$$

$$R_{th} = \frac{(1200 - 25{,}8)°C}{1.234{,}78\ °C\ \frac{J}{s} m^2 °C}$$

$$R_{th} = 0{,}9509\ \frac{s}{J} m^2 °C$$

Table 5. Fourth Dimension

Properties	Value
Outside Dimension (cm)	25 x 25
Inside Dimension (cm)	19 x 19
Thick (cm)	12
Total Area (cm^2)	264
Heat Flow $\left(°C\ \frac{J}{s} m^2 °C\right)$	1.234,78
Resistance Value $\left(\frac{s}{J} m^2 °C\right)$	0,9509

Calculation of fifth-dimension variations

The resistance value in the fifth dimension can be seen in Table 6. The heat flow value is:

$$q_k = \frac{T_2 - T_1}{\Delta x} kA$$

$$q_k = \frac{(1200-25{,}8)°C}{14\ cm} (4{,}78\ \frac{J}{s} m°C\ x\ 343 cm^2)$$

$$q_k = 1.375{,}11\ °C\ \frac{J}{s} m^2 °C$$

The thermal resistance value is:

$$R_{th} = \frac{T_2 - T_1}{q_k}$$

$$R_{th} = \frac{(1200 - 25{,}8)°C}{1.375{,}11\ °C\ \frac{J}{s} m^2 °C}$$

$$R_{th} = 0{,}8539 \frac{s}{J} m^2 °C$$

Table 6. Fifth Dimension

Properties	Value
Outside Dimension (cm)	28 x 28
Inside Dimension (cm)	22 x 22
Thick (cm)	14
Total Area (cm^2)	343
Heat Flow $\left(°C\ \frac{J}{s} m^2 °C\right)$	1.375,11
Resistance Value $\left(\frac{s}{J} m^2 °C\right)$	0,8539

The results of calculating thermal resistance are presented in Table 7.

Table 7. Results of calculating thermal resistance

Wall dimension	Wide (cm^2)	Thick (cm)	Thermal resistance $\left(\frac{s}{J} m^2 °C\right)$
1	624	24	0,8382
2	259	14	1,1308
3	245	10	0,8539
4	264	12	0,9509
5	343	14	0,8539

In Figure 2, it shows the comparison between the dimensional area and the thermal resistance. The same phenomenon occurs on the comparison between the wall thickness and the thermal resistance, that shows in Figure 3. The highest value is in the second dimension of 1.1308 and the lowest value is in the first dimension of 0.8382.

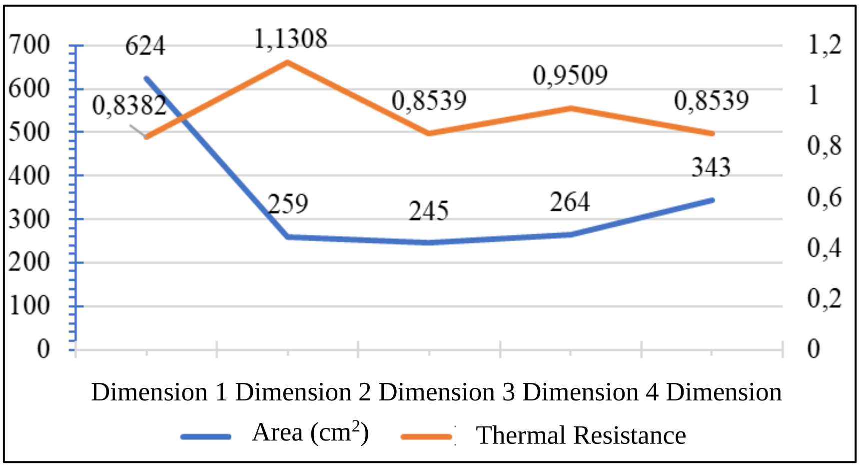

Figure 2. Wide vs. Thermal Resistance

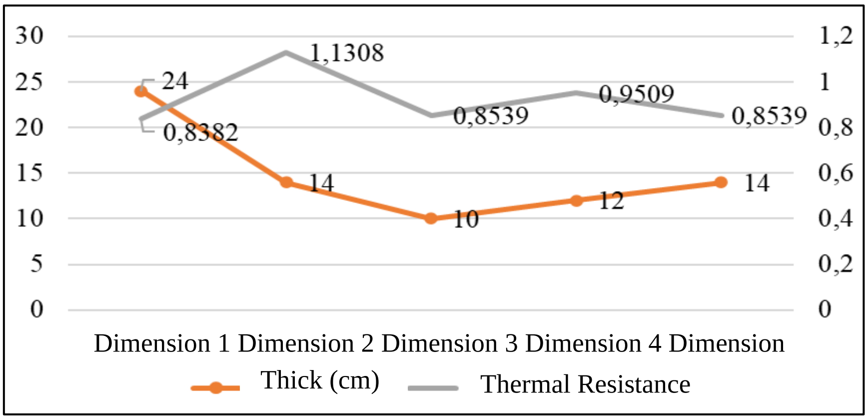

Figure 3. Thick vs. Thermal Resistance

The thermal resistance value obtained has a value that is inversely proportional to the value of the heat flow rate. The second dimension has a heat flow rate value of 1,038.34, while the heat flow rate value in the first dimension is 1,400.92. This is consistent with research on the thermal resistance theory conducted by (Holman, 2008; Ajiwiguna et al., 2016), based on this statement stated that the higher the value of the thermal resistance, the higher the ability of the material to inhibit the rate of heat flow.

CONCLUSION

Based on the calculation results, the thermal resistance value was carried out for each variation in the dimensions of the induction furnace, which has specifications for maximum room temperature (T_1 = 1200 °C) and ambient temperature (T_2 = 25.8 °C), as well as thermal conductivity for refractory stones (k = 4.78 J/s m°C). The most optimal thermal resistance value is 1.1308, which occurs in the second dimension with an outer side of 22 cm x 22 cm, an inner side of 15 cm x 15 cm, a thickness of 14 cm, and a heat flow of 1038.34. In contrast, the lowest thermal resistance value is 0.8382 in the first dimension with an outer side of 32 cm x 32 cm, an inner side of 20 cm x 20 cm, a thickness of 24 cm, and a heat flow of 1,400.92. This is to the theory of thermal resistance that the higher the thermal resistance produced, the higher the material's ability to inhibit the rate of heat flow. In the heat flow, changes can change the convection coefficient, so heat transfer by convection increases, and the thermal resistance becomes low.

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