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Energy Efficiency of High Temperature Electric Furnace Design

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Abstract
This study aims to 1) Plan and design an *electric furnace* with furnace room dimension of 260mm x 170mm x 160mm, 2) Plan and design an effective and efficient microcontroller-based heating system, and 3) Analyze the energy efficiency of *the electric furnace*. An electric furnace with dimensions of 260mm x 170mm x 160mm has been successfully manufactured with a heating capability of up to 1200 C, the electric furnace can heat a relatively low average power (±2200 Watt) than the electric furnace available in the market. The electric furnace combustion chamber coating material used has been known to be very efficient based on the wasted heat transfer rate from the electric furnace combustion chamber which is very small at the maximum temperature (4.55 W). Based on the heat generation method, furnace is broadly classified into two types namely combustion type (using fuel) and electric type
Keywords: Electric Furnace, Heat Transfer, Thermocouple Sensor, Energy Efficiency.

Introduction

Furnace (*Tungku*) is an equipment used to melt metal for the manufacture of machine parts (casting) or to heat material and change their shape (eg rolling, forging) or change its properties (heat treatment) [1]. Based on the heat generation method, *furnace* is broadly classified into two types namely combustion type (using fuel) and electric type [2]. The type of combustion *furnace* depends on the type of fuel used. Among them are furnaces that use fuel oil, coal, gas, or electricity. Ideally the furnace should heat as much material as possible until it reaches a uniform temperature with as little fuel as possible. The key to efficient furnace operation lies in the complete combustion of fuel with minimal excess air. Furnace operate at relatively low efficiency (as low as 7 percent) compared to other combustion equipment such as boiler (with efficiency of more than 90 percent) [3]. This is due to the high operating temperature in the furnace. For example, a furnace that heating the material to a temperature of 1200 °C will emit exhaust gases at a temperature of 1200 °C or more resulting in significant heat loss through the chimney [4].

Small-scale furnace that can control constantly and accurately have been applied to various research field, have become the standard for laboratory equipment in special form, and can be purchased complete [5]. However, certain application to certain material requires special furnace, which can be made to order, but can also be designed more roughly by the researcher, of course cheaper and possibly faster. This problem often occurs in postgraduate research, where financial resource is minimal, and each problem is different [6]. From the background of this problem, research was conducted to design an electric furnace and analyze its energy efficiency.

Literature Review

Electric Furnace Technology

An electric furnace is a mean of burning or heating or smelting a solid material using electric power. In general, the materials that are burned or melted in an electric furnace are ceramic materials, rice husks, shells, iron, steel, metal, glass and other solid materials [4]. In general, the combustion and smelting of solid materials are carried out in an electric furnace in order to maintain the desired parameter can be achieved. In addition to temperature parameter, maintaining the pressure and purity of the material is an important reason for the use of electric furnace [7].

In term of fuel source, electric furnace utilize electrical energy which is converted into heat energy. Furthermore, this heat energy will ripen or melt the solid material until it is as desired [8]. Burning with an electric furnace is the easiest and most efficient way of burning because electric furnace is usually equipped with adequate control equipment, such as an ignition switch/button which also function as a regulator (regulator of electrical energy), combustion program (burning time and temperature), thermocouple -pyrometer as a fuel temperature indicator. The parts of the electric furnace when viewed from the outside can be seen in figure 1.

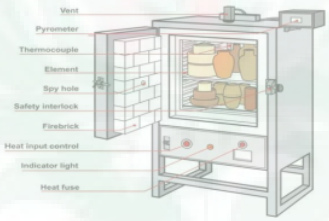

Figure 1. General shape and part of an electric furnace

Vent is a hole at the top of the furnace that serves to release water vapor during the combustion process. To determine the room temperature in the furnace room, a pyrometer is installed, which is a device that measures the height of the fuel temperature in the combustion chamber. Thermocouple is a tool that serves to transmit information on the temperature of the furnace to the pyrometer. On the inside of the wall is planted an element in the form of a coil to generate heat in the furnace. To observe the conditions in the combustion chamber, a Spy hole is inserted which is a hole to spy on the temperature stakes installed in the combustion chamber. Some other accessories are safety interlock, fire bricks, each of which functions as a furnace door protector to prevent the door from opening during the combustion process and as an effective and safe heat insulation. While the heat input control and indicator light each function to control the temperature during the combustion process and as an indicator light that indicates the presence or absence of incoming electricity. The last component is a heat fuse device to prevent the furnace from burning too high.

Space and Heating Element

The heating chamber is also stated as a heat-receiving kitchen for the combustion or smelting process. To be able to maintain heat in the electric furnace room, the furnace layer is given a refractory material. This material is a kind of mixture of fine powder that is molded into a certain shape and is resistant to high temperatures (above 1200ºC) so that it is able to maintain its strength. In general, this refractory material is used in lining furnaces, clines, incinerators, reactors and also for the manufacture of crucible. In addition to fire resistance, this material must be resistant to chemical treatment and physically stable at high temperature. Depending on the operating environment, refractory material must also be resistant to thermal shock, chemically and/or has a certain range of thermal conductivity and coefficient of thermal expansion. The layout of refractory material in the electric furnace heating chamber can be seen in Figure 2

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Figure 2. Interior view of the heating chamber of an electric furnace (Alaneme et al, 2010).

In the electric furnace there is a heating chamber filled with pipe element and attached to the wall of the combustion chamber. This pipe element is assembled in a spiral and then wound along the heating chamber as shown in Figure 3.

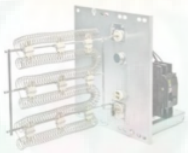

Figure 3. Electric furnace heating element assembled on the inside of the refractory wall

Some designs and materials of refractory metal heating elements are:

Metal Heating Element

Wire coil or "zigzag" electric heating element. Electric heating element and non-vacuum furnace used in electrical component is generally no different, mainly made of molybdenum wire. The coil is generally formed with a diameter of 2 to 2.5 mm from a wire material made of electrical molybdenum. The "zigzag" heating element is made of a wire rod of a larger cross section than the heating coil. They require higher strength and are designed to have a vacuum of not less than 0.1 to 100 Pa [9]. In addition to the zigzag shape, other forms of heating elements are like fibers or rods. This heating element is capable of reaching 2300 temperature. This electric heating material is generally made of tungsten, and sometimes with molybdenum (operating temperature below 1700). The ends of the rods are cast into the copper, forming a raised part, where the rods can be secured. The top end of each rod is cooled by water and brought out through the cover. The lower end of the rod is mounted on a water-cooled fan-shaped chassis. General electric heaters are made of tungsten rods, rods and their composition [3].

Graphite Heating Element

In addition to the refractory metal, the refractory graphite can be compared to a vacuum electric heating water heater. Graphite metal has good performance because it has a small change in resistance to temperature changes. Graphite has a high resistance, can be larger in the electrical body, the use of tens of volts of power. General graphite heating element for vacuum 0.1 a 100Pa, the use of 2200 temperature limit. Under the above vacuum conditions, the working life of graphite at 2300 , only a few dozen hours, and 2400 to 2500 , only a few hours. It should be noted that the thermal conductivity of graphite at low temperatures is good, and at high temperatures when the temperature drops to a fraction of the low temperature, it will cause the heating element and the outer surface temperature difference, resulting in mechanical stress, resulting [10].

In addition to the inner structure, the exterior is also a special concern in designing electric furnaces. The outer frame is made of steel which serves to hold the inner frame made of blocks made of aluminum oxide or alumina with the structural formula of Al2O3 which is quite brittle. Al2O3 also functions as a reflector [11]. so that heat can collect in the combustion chamber. Alumina (Al2O3) is a material that has good physical and chemical properties for various applications such as reflectors for furnaces,

because it has a very high melting temperature of up to 2051C and can maintain a temperature strength of 1500 C to 1700 C. In addition, Alumina has high electrical resistance and is resistant to thermal shock and corrosion, making it very suitable for refractory material.

Furnace Control System

In the design of this furnace, a sensor is needed that can read any changes in temperature. In the system designed, a type R thermocouple sensor is generally used which is capable of measuring temperatures up to 1500°C [12]. Thermocouple is temperature a sensor that can be used to measure temperature with high value. Therefore, thermocouple temperature sensor is widely used in industry. The thermocouple temperature sensor has a small output value with high noise, so it requires a signal conditioning circuit so that the output value can be read properly.

The control system used in electric furnace refers to Proportional, Integral and Derivative (PID) control. PID control system brow diagram can be seen in

Figure **4**. The proportional controller (P) plays a role in regulating a faster stable state, then the integral controller (I) plays a role in reducing the state of excessive condition (overshoot) in the room. While the Derivative controller (D) plays a role in making the system stable.

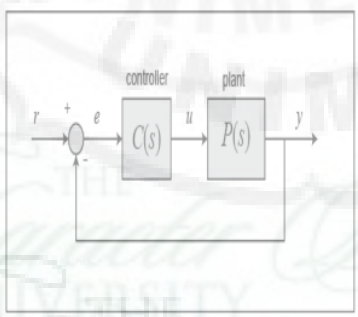

Figure 4. Control system general diagram

Where D(s) is the transfer function of PID control, and G(s) is the transfer function of plant control, while r is the input signal to the palate and e is the system error. The function u is the input that is controlled in the system and the function y is the output signal. Based on Figure 4 the PID control equation can be written as follows:

Equation 1. $$mv(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt}$$ **Equation 2.** $$K_i = K_p \frac{1}{T_i} \text{ dan } K_d = K_p Td$$

Where :

mv(t) = output from PID controller or Manipulated Variable

Kp = Proportional constant

Ti = Integral constant

Td = Derivative constant

To maximize the work of the controller, a minimum and maximum limit value is needed which will limit the value of the Manipulated Variable produced. The PID control component consists of three types, namely Proportional, Integrative and Derivative. All three can be used together or separately depending on the response we want to a plant as shown in

Figure **5**.

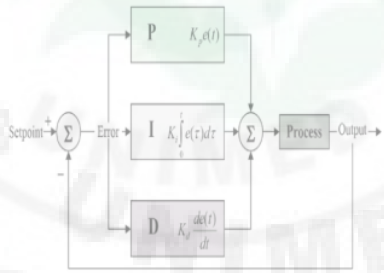

Figure 5. PID Control System used in electric furnace control.

Methods

The type of data obtained from this research is quantitative and qualitative data. Quantitative data in the form of exact number from the measurement result of standardized tools such as temperature rise measurement, electric voltage measurement, control system data. The data is in several numeric extension format that need to be processed and converted into graph and table. Furthermore, an analysis is carried out according to the phenomenon that occurs by comparing it to several results from previous reputable journal article. While the qualitative data include the result of the analysis of the efficiency of the electric furnace which can be described by qualitative analysis.

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Electric Furnace Temperature Rise Test

The manufacture of electric furnace requires specific data, including determining the rate of heat transfer in the combustion chamber. In determining the rate of heat transfer in an electric furnace, we must know the thermal conductivity (U) of each material.

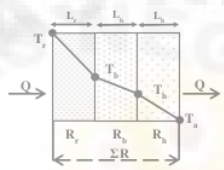

Figure 6. Combustion chamber lining material structure.

Based on

Figure 6. Combustion chamber lining material structure., it must be known in advance the amount of conductivity of each material used as a coating material for the combustion chamber in an electric furnace.

Table 1. Specification of electric furnace combustion chamber coating material.

Material	Thermal Conductivity W/(mK)	Layer thickness m
Refractory	1.51	0.030
Fire Resistant Brick	0.45	0.067
Hebel	0.13	0.061

Using the heat transfer rate equation below, we can calculate the heat released through each coating material for the electric furnace combustion chamber, namely:

Equation 3.

$$Q = \frac{\Delta T}{R} = \frac{(T_r - T_b)}{R}$$

Where : Q : heat from the surface area of the material, W.

R : Thermal resistance of the material surface area K/W.

tr : Tefractory temperature K.

Tb : Insulation brick temperature K.

Based on Equation 3 thermal resistance material can be known through,

Equation 4.

$$R_n = \frac{t_n}{k_n A}$$

Where: R_n : Thermal resistant material, K/W.

t_n : Material thickness, m.

k_n : Thermal Conductivity of material, W/mK

A : surface area of the material, m^2.

The test was carried out by operating the electric furnace until the room temperature reached the maximum temperature (1200°C) and held for 2 hours, observation is made by recording the time,

temperature rise in the room and the outer layer, voltage, and operating current of electric furnace heating, as presented in 4.

Table 2. Data on direct observation of time, temperature rise, voltage, and current on electric furnace testing

n	T_c	T_a	t_n	V	I
	°C	°C	*S*	Volt	Ampere
0	…	…	…	…	…
⋮	⋮	⋮	⋮	⋮	⋮
n	1200	…	…	…	…

Where:

n : index of observational data.

Tc : Temperature of combustion chamber,°C.

ta : outer layer temperature, °C.

t_n : time, s.

V : Electric furnace heating input voltage ,Volt.

I : Electric furnace heating input current, Ampere.

After the observation data is obtained, the researcher can analyze *the heat-loss* and temperature in each layer of the electric furnace combustion chamber so that they can analyze the total heat-loss in the electric furnace as energy loss, and researcher can analyze the power in the electric furnace heater during testing as Energy input, to be able to analyze the energy efficiency of the electric furnace, as the data can be presented in Table 4.

Table 3. Electric furnace test result data

n	T_c	T_r	T_b	T_h	T_a	Q_{loss}	t_n	V	I	P	η
	°C	°C	°C	°C	°C	Watt	*s*	Volt	Ampere	Watt	%
0	…	…	…	…	…	…	…	…	…	…	…
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
n	…	…	…	…	…	…	…	…	…	…	…

Where:

n : index of observational data.
tr : Refractory Coating temperature,°C.
Tb : The temperature of the refractory brick layer,°C.
Th : Hebel coating temperature,°C.
ta : outer layer temperature, °C.
Q_{loss} : total heat released in electric furnace, **watt**.
t_n : time, **s**.
V : Electric furnace heating input voltage ,**Volt.**
I : Electric furnace heating input current, **Ampere.**
P : Electric furnace heating power input, **Watt.**
η : Efficiency energy of electric furnace, **%**.

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Results and Discussion

Electric furnace test result

No-load electric furnace test

In this test, the electric furnace is operated without any sample (load) being heated. Set the temperature of the reach of the electric furnace to a maximum temperature of 1200 ºC . Observational data as shown in table 4.

Table 0. Test result of a no-load electric furnace.

n	TC	TA	mr	Voltage	Current
	ºC	ºC	*s*	V	A
0	33.00	30.00	0	227	10.0
1	40.00	30.00	123	217	11.5
2	50.00	30.00	199	216	9.9
3	60.00	30.00	256	216	8.8
4	70.00	30.00	311	216	9.7
5	80.00	30.00	362	216	9.2
6	90.00	30.00	400	216	9.5
7	100.00	30.00	448	216	9.6
8	110.00	30.00	498	216	6.8
9	120.00	30.00	549	216	11.4
10	130.00	31.00	591	216	11.2
11	140.00	31.00	640	218	9.4
12	150.00	31.00	696	216	9.1
13	160.00	31.00	752	216	10.6
14	170.00	31.00	808	216	10.4
15	180.00	31.00	868	216	9.9
16	190.00	31.00	930	216	11.0
17	200.00	31.00	997	217	9.5
18	210.00	31.00	1071	215	8.9
19	220.00	32.00	1149	215	10.5
20	230.00	32.00	1231	217	8.8
21	240.00	32.00	1317	216	9.3
22	250.00	32.00	1410	219	11.4
23	260.00	32.00	1507	216	9.8
24	270.00	32.00	1606	217	9.5
25	280.00	32.00	1708	217	12.2
26	290.00	32.00	1820	218	11.3
27	300.00	32.00	1932	215	9.2
28	310.00	32.00	2047	215	9.4
29	320.00	32.00	2180	215	9.0
30	330.00	33.00	2330	214	11.1
31	340.00	33.00	2476	215	11.5
32	350.00	33.00	2612	216	11.1
33	360.00	33.00	2763	216	10.0
34	370.00	33.00	2929	215	11.7
35	380.00	34.00	3091	217	11.7
36	390.00	34.00	3261	215	12.1

37	400.00	34.00	3418	216	9.7
38	410.00	34.00	3590	217	8.7
39	420.00	34.00	3727	216	9.2
40	430.00	35.00	3883	216	9.0
41	440.00	35.00	4058	216	9.1
42	450.00	36.00	4236	215	9.9
43	460.00	36.00	4403	214	11.1
44	470.00	36.00	4577	214	11.3
45	480.00	37.00	4751	214	11.5
46	490.00	37.00	4945	215	11.2
47	500.00	38.00	5160	214	11.5
48	510.00	38.00	5349	213	11.2
49	520.00	38.00	5559	213	11.1
50	530.00	39.00	5759	215	8.0
51	540.00	40.00	5980	213	11.1
52	550.00	40.00	6202	215	10.7
53	560.00	41.00	6446	216	9.6
54	570.00	41.00	6658	212	11.0
55	580.00	42.00	6892	213	10.2
56	590.00	42.00	7160	213	10.5
57	600.00	43.00	7430	212	10.7
58	610.00	44.00	7684	213	9.4
59	620.00	44.00	7949	213	10.6
60	630.00	45.00	8220	213	9.7
61	640.00	46.00	8488	213	11.2
62	650.00	46.00	8766	213	11.1
63	660.00	46.00	9050	214	10.8
64	670.00	46.00	9341	212	9.0
65	680.00	47.00	9617	216	11.3
66	690.00	47.00	9884	217	12.2
67	700.00	47.00	10157	216	10.2
68	710.00	48.00	10447	217	10.2
69	720.00	48.00	10752	215	9.9
70	730.00	49.00	11079	216	10.8
71	740.00	49.00	11425	216	11.0
72	750.00	50.00	11770	213	9.2
73	760.00	50.00	12137	213	9.9
74	770.00	51.00	12528	215	12.0
75	780.00	51.00	12899	215	11.8
76	790.00	52.00	13290	217	9.8
77	800.00	52.00	13723	215	11.3
78	810.00	53.00	14131	215	11.5
79	820.00	54.00	14565	215	11.5
80	830.00	55.00	14985	213	11.2
81	840.00	55.00	15433	214	11.0
82	850.00	56.00	15906	215	11.2
83	860.00	60.00	16415	212	10.2
84	870.00	61.00	16909	212	10.9
85	880.00	61.00	17436	213	11.6

86	890.00	62.00	17905	214	11.3
87	900.00	63.00	18413	213	10.8
88	910.00	64.00	18957	211	11.0
89	920.00	73.00	19623	212	11.0
90	930.00	76.00	202232	211	10.6
91	940.00	79.00	20902	211	10.3
92	950.00	81.00	21567	210	11.3
93	960.00	83.00	22215	219	11.4
94	970.00	85.00	22929	211	11.1
95	980.00	87.00	23648	210	10.8
96	990.00	89.00	24395	210	11.6
97	1000000	90.00	25143	210	11.3
98	1010.00	92.00	26083	211	10.0
99	1020.00	96.00	26845	210	9.3
100	1030.00	98.00	27587	213	11.2
101	1040.00	99.00	28139	219	11.9
102	1050.00	101.00	28688	219	11.0
103	1060.00	102.00	29168	221	11.6
104	1070.00	103.00	29674	219	9.8
105	100.00	104.00	30263	221	11.3
106	1090.00	106.00	30912	223	11.5
107	1100.00	108.00	31504	223	11.5
108	1110.00	109.00	32168	224	11.7
109	1120.00	110.00	32937	224	11.7
110	1130.00	112.00	33824	224	8.8
111	1140.00	114.00	34615	222	9.5
112	1150.00	116.00	35489	223	8.7
113	1160.00	117.00	36468	224	10.4
114	1170.00	120.00	37500	222	10.6
115	1180.00	124.00	38565	218	9.4
116	1190.00	128.00	40098	219	10.8
117	1200.00	135.00	41929	218	9.8
118	1204.00	143.00	42568	225	9.4
119	1209.00	144.00	43209	225	10.9
120	1206.00	145.00	43774	224	8.7
121	1200.00	146.00	44372	225	8.8
122	1200.00	146.00	44979	228	6.2
123	1200.00	147.00	45580	225	5.4
124	1200.00	148.00	46182	225	6.5
125	1200.00	149.00	46783	225	6.5
126	1200.00	150.00	47383	225	8.3

From these data, it can be seen that during the testing process, the measurement temperature increase in the combustion chamber (Tc), obtained a constant measurement temperature of 30ºC on the outer layer (Ta) , when the measurement temperature in the combustion chamber (Tc) is 31C to 120ºC. The measurement temperature increase in the outer layer (Ta) of 1ºC for every ±10ºC increase in the measurement temperature range of the combustion chamber (Tc) is 193ºC to 441 C. Until finally when the measurement temperature of the combustion chamber (Tc) reaches 1006ºC, the measurement temperature on the outer layer (Ta) is 164ºC. This indicates that the reduced heat energy (*thermal loss*) that occurs during the process of testing the temperature increase in the electric furnace is quite small.

To calculate the rate of heat transfer generated from the heating element, and also to calculate the temperature distribution in each layer in an electric furnace with a capacity of 2200 Watt. Some of the data obtained for the thermal conductivity of each electric furnace lining material are shown in table 3, the data describes the structure, thermal conductivity, and thickness of the coating material used in electric furnace.

To find out the total heat transfer rate in the electric furnace through the data on Table 4, Figure 3 explain the layer structure of the electric furnace material and use the heat transfer rate equation at Equation 3 so that the total heat energy is reduced (*thermal loss*) becomes:

Equation 5.

$$Q = \frac{(T_c - T_a)}{R_{total}}$$

$$Q = \frac{(T_c - T_a)}{\left(\frac{1}{h_c A} + \frac{L_r}{k_r A} + \frac{L_b}{k_b A} + \frac{L_h}{k_h A} + \frac{1}{h_a A}\right)}$$

Using temperature measurement data on each electric furnace coating material at Table 0., then converted into Kelvin, obtained reduced heat energy (*thermal loss*) when the measurement temperature in the combustion chamber reaches 1200°C (maximum).

Using the result of the calculation of the reduced heat energy (*thermal loss*) above, we can calculate the temperature distribution for each electric furnace lining material using Equation 5, then we get:

Equation 6.

$$Q = \frac{(T_c - T_r)}{R_c}, Q = \frac{(T_r - T_b)}{R_r}, Q = \frac{(T_h - T_a)}{R_a}$$

$$(T_c - T_r) = Q \times R_c \; (T_r - T_b) = Q \times R_b \; (T_h - T_a) = Q \times R_a$$

The temperature distribution in the Refractory layer (Tr) is

$$T_r = T_c - Q \times R_c$$
$$T_r = 1473{,}15 - 4{,}67 \times {,}100{,}16$$
$$T_b = 1473{,}15 - 467{,}91$$
$$T_b = 1005{,}24K = 732{,}09^{o}C$$

Temperature distribution on the Insulating Brick layer (Tb),

$$T_b = T_r - Q \times R_r$$
$$T_b = 1005{,}24 - 4{,}67 \times 0{,}48$$
$$T_b = 1005{,}24K - 2{,}23K$$
$$T_b = 1056K = 729{,}86^{o}C$$

Temperature distribution on the Hebel Brick layer (Th),

$$T_h = Q \times R_a + T_a$$
$$T_h = 4{,}67 \times 109{,}26 + 423{,}15$$
$$T_h = 510{,}45K + 423{,}15$$
$$T_h = 933{,}60K = 660{,}45^{o}C$$

So to calculate the thermal efficiency of the electric furnace. Using electric furnace heating voltage and current measurement data on Table 0. to calculate the electrical power required by the heating element, and using the result of the calculation of the reduced heat energy (*thermal loss*) above, then use the energy conversion efficiency equation in the following system,

Equation 7.

$$\eta = \frac{(E - E_{loss})}{E} \times 100\%$$

Where,

Ƞ = Energy efficiency, %.

E = Total energy required.

Eloss = Energy obtained from a heated material.

Using the electric energy equation,

Equation 8. $P = I \times V$

Where,

P = Electrical energy, Watt.

I = current strength, Ampere.

V = voltage, volt.

Based on the measurement data of the voltage and current measured on the heating element in Table 0. and use Equation 8, and by assuming the electrical energy required by the heating element as the input energy, and the reduced heat energy (thermal loss) as the energy obtained from a heated material. Use Equation 7 then we get,

$$P = I \times V$$
$$P = 8{,}3 \times 225$$
$$P = 1867{,}5\ \text{Watt}$$

$$\eta = \frac{(E - E_{loss})}{E} \times 100\%$$
$$\eta = \frac{(1867{,}5W - 4{,}67W)}{1867{,}5W} \times 100\%$$
$$\eta = 99{,}75\%$$

Based on the result of the above calculations, we can see that the thermal efficiency of the electric furnace (at the measurement of the combustion chamber temperature of 1200ºC) is 99.75%, which means that 1867.5 Watt of electrical energy needed by the electric furnace heating element to heat the combustion chamber is only 0.25. % of wasted energy goes to the outer layer of the electric furnace. Using the calculation result above, the reduced heat energy (*thermal loss*), the temperature distribution of each electric furnace coating material, the electrical energy of the heating element, and also the energy efficiency of the electric furnace can be obtained from each temperature measurement data displayed on table 1, so that we can present it in table 5.

Table 5. The result of the calculation of the temperature distribution on each electric furnace combustion chamber coating material, and the reduced heat energy (*thermal loss*) of the electric furnace in the no-load electric furnace test

n	TC	TR	TB	TH	TA	QLoss	mr	V	I	Power	η
	C	C	C	C	C	Watt	*s*	Volt	A	Watt	%
0	33.00	31.66	31.66	31.46	30.00	0.01	0	227	10.0	2270	100.00
1	40.00	35.54	35.52	34.86	30.00	0.04	123	217	11.5	2496	100.00
2	50.00	41.09	41.04	39.72	30.00	0.09	199	216	9.9	2138	100.00
3	60.00	46.63	46.57	44.58	30.00	0.13	256	216	8.8	1901	99.99
4	70.00	52.17	52.09	49.45	30.00	0.18	311	216	9.7	2095	99.99
5	80.00	57.72	57.61	54.31	30.00	0.22	362	216	9.2	1987	99.99
6	90.00	63.26	63.13	59.17	30.00	0.27	400	216	9.5	2052	99.99
7	100.00	68.81	68.66	64.03	30.00	0.31	448	216	9.6	2074	99.98
8	110.00	74.35	74.18	68.89	30.00	0.36	498	216	6.8	1469	99.98
9	120.00	79.89	79.70	73.75	30.00	0.40	549	216	11.4	2462	99.98
10	130.00	85.88	85.67	79.13	31.00	0.44	591	216	11.2	2419	99.98

11	140.00	91.43	91.19	83.99	31.00	0.48	640	218	9.4	2049	99.98
12	150.00	96.97	96.72	88.85	31.00	0.53	696	216	9.1	1966	99.97
13	160.00	102.51	102.24	93.71	31.00	0.57	752	216	10.6	2292	99.97
14	170.00	108.06	107.76	98.57	31.00	0.62	808	216	10.4	2246	99.97
15	180.00	113.60	113.28	103.43	31.00	0.66	868	216	9.9	2138	99.97
16	190.00	119.15	118.81	108.30	31.00	0.71	930	216	11.0	2376	99.97
17	200.00	124.69	124.33	113.16	31.00	0.75	997	217	9.5	2062	99.96
18	210.00	130.23	129.85	118.02	31.00	0.80	1071	215	8.9	1914	99.96
19	220.00	136.22	135.82	123.39	32.00	0.84	1149	215	10.5	2258	99.96
20	230.00	141.77	141.35	128,26	32.00	0.88	1231	217	8.8	1910	99.95
21	240.00	147.31	146.87	133.12	32.00	0.93	1317	216	9.3	2009	99.95
22	250.00	152.85	152.39	137.98	32.00	0.97	1410	219	11.4	2497	99.96
23	260.00	158,40	157.91	142.84	32.00	1.01	1507	216	9.8	2117	99.95
24	270.00	163.94	163.43	147.70	32.00	1.06	1606	217	9.5	2062	99.95
25	280.00	169,48	168,96	152.56	32.00	1.10	1708	217	12.2	2647	99.96
26	290.00	175.03	174.48	157.42	32.00	1.15	1820	218	11.3	2463	99.95
27	300.00	180.57	180.00	162.29	32.00	1.19	1932	215	9.2	1978	99.94
28	310.00	186.12	185.52	167.15	32.00	1.24	2047	215	9.4	2021	99.94
29	320.00	191.66	191.05	172.01	32.00	1.28	2180	215	9.0	1935	99.93
30	330.00	197.65	197.02	177.38	33.00	1.32	2330	214	11.1	2375	99.94
31	340.00	203.19	202.54	182.24	33.00	1.37	2476	215	11.5	2473	99.94
32	350.00	208.74	208.06	187.11	33.00	1.41	2612	216	11.1	2398	99.94
33	360.00	214.28	213.58	191.97	33.00	1.45	2763	216	10.0	2160	99.93
34	370.00	219.82	219.11	196.83	33.00	1.50	2929	215	11.7	2516	99.94
35	380.00	225.81	225.08	202,20	34.00	1.54	3091	217	11.7	2539	99.94
36	390.00	231.36	230.60	207.07	34.00	1.58	3261	215	12.1	2602	99.94

37	400.00	236.90	236.12	211.93	34.00	1.63	3418	216	9.7	2095	99.92
38	410.00	242.44	241.65	216.79	34.00	1.67	3590	217	8.7	1888	99.91
39	420.00	247.99	247.17	221.65	34.00	1.72	3727	216	9.2	1987	99.91
40	430.00	253.98	253.14	227.02	35.00	1.76	3883	216	9.0	1944	99.91
41	440.00	259.52	258.66	231.89	35.00	1.80	4058	216	9.1	1966	99.91
42	450.00	265.51	264.63	237.26	36.00	1.84	4236	215	9.9	2129	99.91
43	460.00	271.05	270.15	242.12	36.00	1.89	4403	214	11.1	2375	99.92
44	470.00	276.60	275.68	246.98	36.00	1.93	4577	214	11.3	2418	99.92
45	480.00	282.59	281.65	252.36	37,00	1.97	4751	214	11.5	2461	99.92
46	490.00	288.13	287.17	257.22	37,00	2.02	4945	215	11.2	2408	99.92
47	500.00	294.12	293.14	262.60	38.00	2.06	5160	214	11.5	2461	99.92
48	510.00	299.66	298.66	267.46	38.00	2.10	5349	213	11.2	2386	99.91
49	520.00	305.21	304.18	272.32	38.00	2.14	5559	213	11.1	2364	99.91
50	530.00	311,20	310.15	277.69	39.00	2.18	5759	215	8.0	1720	99.87
51	540.00	317.19	316,12	283.07	40.00	2.22	5980	213	11.1	2364	99.91
52	550.00	322.73	321.65	287.93	40.00	2.27	6202	215	10.7	2301	99.90
53	560.00	328,72	327.62	293.31	41.00	2.31	6446	216	9.6	2074	99.89
54	570.00	334.26	333.14	298.17	41.00	2.35	6658	212	11.0	2332	99.90
55	580.00	340.25	339.11	303.54	42.00	2.39	6892	213	10.2	2173	99.89
56	590.00	345,80	344.63	308,40	42.00	2.44	7160	213	10.5	2237	99.89
57	600.00	351.79	350,60	313.78	43.00	2.48	7430	212	10.7	2268	99.89
58	610.00	357,77	356.57	319.15	44.00	2.52	7684	213	9.4	2002	99.87
59	620.00	363.32	362.09	324.02	44.00	2.56	7949	213	10.6	2258	99.89
60	630.00	369.31	368.06	329,39	45.00	2.60	8220	213	9.7	2066	99.87
61	640.00	375,30	374.04	334.77	46.00	2.64	8488	213	11.2	2386	99.89

62	650.00	380.84	379.56	339.63	46.00	2.69	8766	213	11.1	2364	99.89
63	660.00	386.38	385.08	344.49	46.00	2.73	9050	214	10.8	2311	99.88
64	670.00	391.93	390.60	349.35	46.00	2.78	9341	212	9.0	1908	99.85
65	680.00	397.92	396.57	354.73	47,00	2.82	9617	216	11.3	2441	99.88
66	690.00	403.46	402.10	359.59	47,00	2.86	9884	217	12.2	2647	99.89
67	700.00	409.01	407.62	364.45	47,00	2.91	10157	216	10.2	2203	99.87
68	710.00	414.99	413.59	369.82	48.00	2.95	10447	217	10.2	2213	99.87
69	720.00	420.54	419.11	374.69	48.00	2.99	10752	215	9.9	2129	99.86
70	730.00	426.53	425.08	380.06	49.00	3.03	11079	216	10.8	2333	99.87
71	740.00	432.07	430.60	384.92	49.00	3.07	11425	216	11.0	2376	99.87
72	750.00	438.06	436.57	390,30	50.00	3.11	11770	213	9.2	1960	99.84
73	760.00	443.60	442.10	395.16	50.00	3.16	12137	213	9.9	2109	99.85
74	770.00	449.59	448.07	400.53	51.00	3.20	12528	215	12.0	2580	99.88
75	780.00	455.14	453.59	405,40	51.00	3.24	12899	215	11.8	2537	99.87
76	790.00	461.13	459.56	410.77	52.00	3.28	13290	217	9.8	2127	99.85
77	800.00	466.67	465.08	415.63	52.00	3.33	13723	215	11.3	2430	99.86
78	810.00	472.66	471.05	421.01	53.00	3.37	14131	215	11.5	2473	99.86
79	820.00	478.65	477.02	426.38	54.00	3.41	14565	215	11.5	2473	99.86
80	830.00	484.64	482.99	431.76	55.00	3.45	14985	213	11.2	2386	99.86
81	840.00	490.18	488.51	436.62	55.00	3.49	15433	214	11.0	2354	99.85
82	850.00	496.17	494.48	441.99	56.00	3.53	15906	215	11.2	2408	99.85
83	860.00	503.50	501.80	448.91	60.00	3.56	16415	212	10.2	2162	99.84
84	870.00	509.49	507.77	454.29	61.00	3.60	16909	212	10.9	2311	99.84
85	880.00	515.03	513.29	459.15	61.00	3.64	17436	213	11.6	2471	99.85
86	890.00	521.02	519.26	464.52	62.00	3.68	17905	214	11.3	2418	99.85

87	900.00	527.01	525.23	469.90	63.00	3.72	18413	213	10.8	2300	99.84
88	910.00	533.00	531.20	475.27	64.00	3.76	18957	211	11.0	2321	99.84
89	920.00	542.55	540.75	484.76	73.00	3.77	19623	212	11.0	2332	99.84
90	930.00	549.43	547.62	491.16	76.00	3.80	202232	211	10.6	2237	99.83
91	940.00	556.31	554.49	497.57	79.00	3.83	20902	211	10.3	2173	99.82
92	950.00	562.75	560.90	503.45	81.00	3.87	21567	210	11.3	2373	99.84
93	960.00	569.18	567.32	509.34	83.00	3.90	22215	219	11.4	2497	99.84
94	970.00	575.62	573.74	515.23	85.00	3.94	22929	211	11.1	2342	99.83
95	980.00	582.05	580.16	521.12	87.00	3.97	23648	210	10.8	2268	99.82
96	990.00	588.49	586.58	527.01	89.00	4.01	24395	210	11.6	2436	99.84
97	1000000	594.48	592.55	532.39	90.00	4.05	25143	210	11.3	2373	99.83
98	1010.00	600.91	598.96	538,28	92.00	4.08	26083	211	10.0	2110	99.81
99	1020.00	608.24	606.28	545.19	96.00	4.11	26845	210	9.3	1953	99.79
100	1030.00	614.68	612.69	551.08	98.00	4.15	27587	213	11.2	2386	99.83
101	1040.00	620.66	618,66	556.46	99.00	4.19	28139	219	11.9	2606	99.84
102	1050.00	627.10	625.08	562.35	101.00	4.22	28688	219	11.0	2409	99.82
103	1060.00	633.09	631.05	567.72	102.00	4.26	29168	221	11.6	2564	99.83
104	1070.00	639.08	637.02	573.10	103.00	4.30	29674	219	9.8	2146	99.80
105	100.00	645.07	642.99	578,47	104.00	4.34	30263	221	11.3	2497	99.83
106	1090.00	651.50	649.41	584,36	106.00	4.38	30912	223	11.5	2565	99.83
107	1100.00	657.94	655.83	590.25	108.00	4.41	31504	223	11.5	2565	99.83
108	1110.00	663.93	661.80	595.63	109.00	4.45	32168	224	11.7	2621	99.83
109	1120.00	669.92	667.77	601.00	110.00	4.49	32937	224	11.7	2621	99.83
110	1130.00	676.35	674.19	606.89	112.00	4.53	33824	224	8.8	1971	99.77
111	1140.00	682.79	680.61	612.78	114.00	4.56	34615	222	9.5	2109	99.78

112	1150.00	689.22	687.02	618.67	116.00	4.60	35489	223	8.7	1940	99.76
113	1160.00	695.21	692.99	624.04	117,00	4.64	36468	224	10.4	2330	99.80
114	1170.00	702.09	699.86	630.45	120.00	4.67	37500	222	10.6	2353	99.80
115	1180.00	709.42	707.17	637.36	124.00	4.70	38565	218	9.4	2049	99.77
116	1190.00	716.74	714.49	644.28	128.00	4.72	40098	219	10.8	2365	99.80
117	1200.00	725.41	723.14	652.74	135.00	4.74	41929	218	9.8	2136.4	99.78
118	1204.00	731.19	728.93	658,79	143.00	4.72	42568	225	9.4	2115	99.78
119	1209.00	734.41	732.14	661.74	144.00	4.74	43209	225	10.9	2452.5	99.81
120	1206.00	733.19	730.93	660.79	145.00	4.72	43774	224	8.7	1948,8	99.76
121	1200.00	730.31	728.07	658.39	146.00	4.69	44372	225	8.8	1980	99.76
122	1200.00	730.31	728.07	658.39	146.00	4.69	44979	228	6.2	1413.6	99.67
123	1200.00	730.75	728.52	658,90	147.00	4.68	45580	225	5.4	1215	99.61
124	1200.00	731.20	728.96	659.42	148.00	4.68	46182	225	6.5	1462.5	99.68
125	1200.00	731.65	729.41	659.93	149.00	4.68	46783	225	6.5	1462.5	99.68
126	1200.00	732.09	729.86	660.45	150.00	4.67	47383	225	8.3	1867.5	99.75

Based on data on table 5. we can find out the characteristic of the temperature distribution of each coating material with respect to time, and the reduced heat energy (*thermal loss*) in the electric furnace.

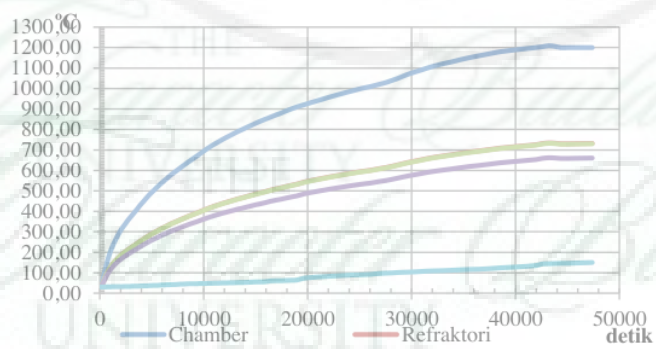

Figure 6. Graph of the temperature characteristic of each electric furnace coating material in the no-load test.

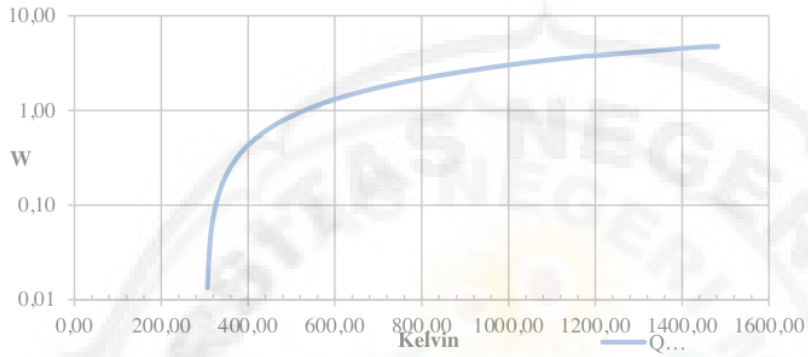

Figure 7. The graph of the characteristic of the thermal loss of the electric furnace against the measured chamber temperature in the no-load test.

Based on figure 6, and figure 7 we can know that the temperature distribution in the material of each electric furnace lining is quite efficient as an electric furnace chamber.

Testing of electric furnace with load

In this test, the electric furnace is operated by placing a heated sample (load). Set the temperature of the reach of the electric furnace to a maximum temperature of 1200 °C . Observational data as shown in table 6.

Table 6. Test result of electric furnace with load

n	Tc	T_A	tn	Voltage	Current
	°C	°C	*s*	V	A
0	33.00	30.00	0	227	10.0
1	40.00	30.00	123	217	11.5
2	50.00	30.00	199	216	9.9
3	60.00	30.00	256	216	8.8
4	70.00	30.00	311	216	9.7
5	80.00	30.00	362	216	9.2
6	90.00	30.00	400	216	9.5
7	100.00	30.00	448	216	9.6
8	110.00	30.00	498	216	6.8
9	120.00	30.00	549	216	11.4
10	130.00	31.00	591	216	11.2
11	140.00	31.00	640	218	9.4
12	150.00	31.00	696	216	9.1
13	160.00	31.00	752	216	10.6
14	170.00	31.00	808	216	10.4
15	180.00	31.00	868	216	9.9
16	190.00	31.00	930	216	11.0
17	200.00	31.00	997	217	9.5
18	210.00	31.00	1071	215	8.9
19	220.00	32.00	1149	215	10.5

20	230.00	32.00	1231	217	8.8
21	240.00	32.00	1317	216	9.3
22	250.00	32.00	1410	219	11.4
23	260.00	32.00	1507	216	9.8
24	270.00	32.00	1606	217	9.5
25	280.00	32.00	1708	217	12.2
26	290.00	32.00	1820	218	11.3
27	300.00	32.00	1932	215	9.2
28	310.00	32.00	2047	215	9.4
29	320.00	32.00	2180	215	9.0
30	330.00	33.00	2330	214	11.1
31	340.00	33.00	2476	215	11.5
32	350.00	33.00	2612	216	11.1
33	360.00	33.00	2763	216	10.0
34	370.00	33.00	2929	215	11.7
35	380.00	34.00	3091	217	11.7
36	390.00	34.00	3261	215	12.1
37	400.00	34.00	3418	216	9.7
38	410.00	34.00	3590	217	8.7
39	420.00	34.00	3727	216	9.2
40	430.00	35.00	3883	216	9.0
41	440.00	35.00	4058	216	9.1
42	450.00	36.00	4236	215	9.9
43	460.00	36.00	4403	214	11.1
44	470.00	36.00	4577	214	11.3
45	480.00	37,00	4751	214	11.5
46	490.00	37,00	4945	215	11.2
47	500.00	38.00	5160	214	11.5
48	510.00	38.00	5349	213	11.2
49	520.00	38.00	5559	213	11.1
50	530.00	39.00	5759	215	8.0
51	540.00	40.00	5980	213	11.1
52	550.00	40.00	6202	215	10.7
53	560.00	41.00	6446	216	9.6
54	570.00	41.00	6658	212	11.0
55	580.00	42.00	6892	213	10.2
56	590.00	42.00	7160	213	10.5
57	600.00	43.00	7430	212	10.7
58	610.00	44.00	7684	213	9.4
59	620.00	44.00	7949	213	10.6
60	630.00	45.00	8220	213	9.7
61	640.00	46.00	8488	213	11.2

62	650.00	46.00	8766	213	11.1
63	660.00	46.00	9050	214	10.8
64	670.00	46.00	9341	212	9.0
65	680.00	47,00	9617	216	11.3
66	690.00	47,00	9884	217	12.2
67	700.00	47,00	10157	216	10.2
68	710.00	48.00	10447	217	10.2
69	720.00	48.00	10752	215	9.9
70	730.00	49.00	11079	216	10.8
71	740.00	49.00	11425	216	11.0
72	750.00	50.00	11770	213	9.2
73	760.00	50.00	12137	213	9.9
74	770.00	51.00	12528	215	12.0
75	780.00	51.00	12899	215	11.8
76	790.00	52.00	13290	217	9.8
77	800.00	52.00	13723	215	11.3
78	810.00	53.00	14131	215	11.5
79	820.00	54.00	14565	215	11.5
80	830.00	55.00	14985	213	11.2
81	840.00	55.00	15433	214	11.0
82	850.00	56.00	15906	215	11.2
83	860.00	60.00	16415	212	10.2
84	870.00	61.00	16909	212	10.9
85	880.00	61.00	17436	213	11.6
86	890.00	62.00	17905	214	11.3
87	900.00	63.00	18413	213	10.8
88	910.00	64.00	18957	211	11.0
89	920.00	73.00	19623	212	11.0
90	930.00	76.00	202232	211	10.6
91	940.00	79.00	20902	211	10.3
92	950.00	81.00	21567	210	11.3
93	960.00	83.00	22215	219	11.4
94	970.00	85.00	22929	211	11.1
95	980.00	87.00	23648	210	10.8
96	990.00	89.00	24395	210	11.6
97	1000000	90.00	25143	210	11.3
98	1010.00	92.00	26083	211	10.0
99	1020.00	96.00	26845	210	9.3
100	1030.00	98.00	27587	213	11.2
101	1040.00	99.00	28139	219	11.9
102	1050.00	101.00	28688	219	11.0
103	1060.00	102.00	29168	221	11.6

104	1070.00	103.00	29674	219	9.8
105	100.00	104.00	30263	221	11.3
106	1090.00	106.00	30912	223	11.5
107	1100.00	108.00	31504	223	11.5
108	1110.00	109.00	32168	224	11.7
109	1120.00	110.00	32937	224	11.7
110	1130.00	112.00	33824	224	8.8
111	1140.00	114.00	34615	222	9.5
112	1150.00	116.00	35489	223	8.7
113	1160.00	117.00	36468	224	10.4
114	1170.00	120.00	37500	222	10.6
115	1180.00	124.00	38565	218	9.4
116	1190.00	128.00	40098	219	10.8
117	1200.00	135.00	41929	218	9.8
118	1204.00	143.00	42568	225	9.4
119	1209.00	144.00	43209	225	10.9
120	1206.00	145.00	43774	224	8.7
121	1200.00	146.00	44372	225	8.8
122	1200.00	146.00	44979	228	6.2
123	1200.00	147.00	45580	225	5.4
124	1200.00	148.00	46182	225	6.5
125	1200.00	149.00	46783	225	6.5
126	1200.00	150.00	47383	225	8.3
127	1200.00	151.00	47990	225	5.4
128	1200.00	152.00	48591	225	6.5
129	1200.00	153.00	49192	225	6.5

From these data, it can be seen that during the testing process, the measurement temperature increase in the combustion chamber (Tc), obtained a constant measurement temperature of 30ºC on the outer layer (Ta) , when the measurement temperature in the combustion chamber (Tc) is 33C to 120ºC. An increase in the measurement temperature of the outer layer (Ta) of 1ºC for every ±10 ºC increase in the measurement temperature range of the combustion chamber (Tc) of 130ºC to 440ºC was obtained. Until finally when the measurement temperature of the combustion chamber (Tc) reaches 1200ºC, the measurement temperature on the outer layer (Ta) is 150ºC. This indicates that the reduced heat energy (*thermal loss*) that occurs during the process of testing the temperature increase in the electric furnace is quite small.

To calculate the rate of heat transfer generated from the heating element, and also to calculate the temperature distribution in each layer in an electric furnace with a capacity of 2200 Watt. Some of the data obtained for the thermal conductivity of each electric furnace lining material are shown in **Error! Reference source not found.**, the data describes the structure, thermal conductivity, and thickness of the coating material used in electric furnace.

To find out the total heat transfer rate in the electric furnace through the data on table 3, figure 3 explain the layer structure of the electric furnace material and use the heat transfer rate equation using Equation 5 the reduced heat energy *(thermal loss)* is obtained when the measurement temperature in the combustion chamber reaches 1200 ºC (maximum):

$$Q = \frac{(1473{,}15 - 426{,}15)}{\left(\frac{1}{(0{,}24)(0{,}04)}\right) + \left(\frac{(0{,}03)}{(1{,}51)(0{,}04)}\right) + \left(\frac{(0{,}07)}{(0{,}45)(0{,}04)}\right) + \left(\frac{(0{,}06)}{(0{,}13)(0{,}04)}\right) + \left(\frac{1}{(0{,}21)(0{,}04)}\right)}$$

$$Q = \frac{(1473{,}15 - 426{,}15)}{(100{,}16) + (0{,}48) + (3{,}58) + (11{,}28) + (114{,}47)}$$

$$Q = \frac{1047}{229{,}97} = 4{,}55W$$

Using the result of the calculation of the reduced heat energy (*thermal loss*) above, we can calculate the temperature distribution for each electric furnace lining material using Equation 6, then we get each temperature distribution in the Refractory Layer, Insulating Brick (Tb), and Hebel Brick (Th) layers are:

The temperature distribution in the Refractory layer (Tr) is

$$T_r = T_c - Q \times R_c$$
$$T_r = 1473{,}15 - 4{,}55 \times {,}100{,}16$$
$$T_b = 1473{,}15 - 456{,}02$$
$$T_b = 1017{,}13K = 743{,}98^oC$$

Temperature distribution on the Insulating Brick layer (Tb),

$$T_b = T_r - Q \times R_r$$
$$T_b = 1017{,}13 - 4{,}55 \times 0{,}48$$
$$T_b = 1005{,}24K - 2{,}17K$$
$$T_b = 1014{,}96K = 741{,}81^oC$$

Temperature distribution on the Hebel Brick layer (Th),

$$T_h = Q \times R_a + T_a$$
$$T_h = 4{,}55 \times 109{,}26 + 426{,}15$$
$$T_h = 521{,}16K + 426{,}15$$
$$T_h = 947{,}31K = 674{,}16^oC$$

So to calculate the thermal efficiency of the electric furnace. Using electric furnace heating voltage and current measurement data on table 6.

Table to calculate the electrical power needed by the heating element, and using the result of the calculation of the reduced heat energy (*thermal loss*) above, then use the conversion energy efficiency equation in a system.

Based on the measurement data of the voltage and current measured on the heating element in table 4 and use Equation 8, and by assuming the electrical energy required by the heating element as the input energy, and the reduced heat energy (*thermal loss*) as the energy obtained from a heated material. Use Equation 7 then we get,

$$P = I \times V$$
$$P = 6{,}5 \times 225$$
$$P = 1462{,}5\,Watt$$

$$\eta = \frac{(E - E_{loss})}{E} \times 100\%$$
$$\eta = \frac{(1462{,}5W - 4{,}55W)}{1462{,}5W} \times 100\%$$
$$\eta = 99{,}69\%$$

Based on the result of the above calculation, we can see that the thermal efficiency of the electric furnace (at the measurement of the combustion chamber temperature of 1200°C) is 99.69%, which means 1462.5 Watts of electrical energy needed by the electric furnace heating element to heat the combustion chamber, only 0.31 % of wasted energy goes to the outer layer of the electric furnace. Using the calculation result above, the reduced heat energy (*thermal loss*), the temperature distribution of each electric furnace coating material, the electrical energy of the heating element, and also the energy efficiency of the electric furnace can be obtained from each temperature measurement data displayed table 3, so that we can present it in table 7.

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Table 7. The result of the calculation of the temperature distribution on each electric furnace combustion chamber coating material, and the reduced heat energy (*thermal loss*) of the electric furnace in the no-load electric furnace test

n	Tc	T_R	T_B	T_H	T_A	Q_{Loss}	t_n	V	I	Power	η
	°C	°C	°C	°C	°C	Watt	*s*	Volt	A	Watt	%
0	33.00	31.69	31.69	31.49	30.00	0.01	0	227	10.0	2270	100.00
1	40.00	35.64	35.62	34.98	30.00	0.04	123	217	11.5	2496	100.00
2	50.00	41.29	41.25	39.96	30.00	0.09	199	216	9.9	2138	100.00
3	60.00	46.93	46.87	44.93	30.00	0.13	256	216	8.8	1901	99.99
4	70.00	52.58	52.50	49.91	30.00	0.17	311	216	9.7	2095	99.99
5	80.00	58.22	58,12	54.89	30.00	0.22	362	216	9.2	1987	99.99
6	90.00	63.87	63.74	59.87	30.00	0.26	400	216	9.5	2052	99.99
7	100.00	69.51	69.37	64.84	30.00	0.30	448	216	9.6	2074	99.99
8	110.00	75.16	74.99	69.82	30.00	0.35	498	216	6.8	1469	99.98
9	120.00	80,80	80.61	74.80	30.00	0.39	549	216	11.4	2462	99.98
10	130.00	86.88	86.68	80.28	31.00	0.43	591	216	11.2	2419	99.98
11	140.00	92.53	92.30	85.26	31.00	0.47	640	218	9.4	2049	99.98
12	150.00	98.17	97.92	90.23	31.00	0.52	696	216	9.1	1966	99.97
13	160.00	103.81	103.55	95.21	31.00	0.56	752	216	10.6	2292	99.98
14	170.00	109.46	109.17	100,19	31.00	0.60	808	216	10.4	2246	99.97
15	180.00	115,10	114.79	105.17	31.00	0.65	868	216	9.9	2138	99.97
16	190.00	120.75	120.42	110.14	31.00	0.69	930	216	11.0	2376	99.97
17	200.00	126.39	126.04	115,12	31.00	0.73	997	217	9.5	2062	99.96
18	210.00	132.04	131.67	120,10	31.00	0.78	1071	215	8.9	1914	99.96
19	220.00	138.12	137.73	125.58	32.00	0.82	1149	215	10.5	2258	99.96
20	230.00	143.76	143.35	130.56	32.00	0.86	1231	217	8.8	1910	99.95
21	240.00	149.41	148.97	135.54	32.00	0.90	1317	216	9.3	2009	99.95

22	250.00	155.05	154.60	140.51	32.00	0.95	1410	219	11.4	2497	99.96
23	260.00	160.70	160.22	145.49	32.00	0.99	1507	216	9.8	2117	99.95
24	270.00	166.34	165.85	150.47	32.00	1.03	1606	217	9.5	2062	99.95
25	280.00	171.98	171.47	155.45	32.00	1.08	1708	217	12.2	2647	99.96
26	290.00	177.63	177.09	160.42	32.00	1.12	1820	218	11.3	2463	99.95
27	300.00	183.27	182.72	165.40	32.00	1.17	1932	215	9.2	1978	99.94
28	310.00	188.92	188.34	170,38	32.00	1.21	2047	215	9.4	2021	99.94
29	320.00	194.56	193.96	175.36	32.00	1.25	2180	215	9.0	1935	99.94
30	330.00	200.64	200.03	180.84	33.00	1.29	2330	214	11.1	2375	99.95
31	340.00	206.29	205.65	185.81	33.00	1.33	2476	215	11.5	2473	99.95
32	350.00	211.93	211.27	190.79	33.00	1.38	2612	216	11.1	2398	99.94
33	360.00	217.58	216.90	195.77	33.00	1.42	2763	216	10.0	2160	99.93
34	370.00	223.22	222.52	200.75	33.00	1.47	2929	215	11.7	2516	99.94
35	380.00	229.30	228.58	206.23	34.00	1.50	3091	217	11.7	2539	99.94
36	390.00	234.95	234.21	211.20	34.00	1.55	3261	215	12.1	2602	99.94
37	400.00	240.59	239.83	216.18	34.00	1.59	3418	216	9.7	2095	99.92
38	410.00	246.24	245.45	221.16	34.00	1.64	3590	217	8.7	1888	99.91
39	420.00	251.88	251.08	226.14	34.00	1.68	3727	216	9.2	1987	99.92
40	430.00	257.96	257.14	231.62	35.00	1.72	3883	216	9.0	1944	99.91
41	440.00	263.60	262.76	236.60	35.00	1.76	4058	216	9.1	1966	99.91
42	450.00	269.68	268.82	242.08	36.00	1.80	4236	215	9.9	2129	99.92

43	460.00	275.33	274.45	247.05	36.00	1.84	4403	214	11.1	2375	99.92
44	470.00	280.97	280.07	252.03	36.00	1.89	4577	214	11.3	2418	99.92
45	480.00	287.05	286.13	257.51	37.00	1.93	4751	214	11.5	2461	99.92
46	490.00	292.70	291.76	262.49	37.00	1.97	4945	215	11.2	2408	99.92
47	500.00	298.78	297.82	267.97	38.00	2.01	5160	214	11.5	2461	99.92
48	510.00	304.42	303.44	272.95	38.00	2.05	5349	213	11.2	2386	99.91
49	520.00	310.07	309.07	277.92	38.00	2.10	5559	213	11.1	2364	99.91
50	530.00	316.15	315,13	283.40	39.00	2.14	5759	215	8.0	1720	99.88
51	540.00	322.23	321.19	288,88	40.00	2.17	5980	213	11.1	2364	99.91
52	550.00	327.87	326.81	293.86	40.00	2.22	6202	215	10.7	2301	99.90
53	560.00	333.95	332.87	299.34	41.00	2.26	6446	216	9.6	2074	99.89
54	570.00	339.60	338,50	304.32	41.00	2.30	6658	212	11.0	2332	99.90
55	580.00	345,68	344.56	309,80	42.00	2.34	6892	213	10.2	2173	99.89
56	590.00	351.32	350,18	314.78	42.00	2.38	7160	213	10.5	2237	99.89
57	600.00	357,40	356.24	320.26	43.00	2.42	7430	212	10.7	2268	99.89
58	610.00	363.48	362.31	325.74	44.00	2.46	7684	213	9.4	2002	99.88
59	620.00	369.13	367.93	330.71	44.00	2.50	7949	213	10.6	2258	99.89
60	630.00	375.21	373.99	336.19	45.00	2.54	8220	213	9.7	2066	99.88
61	640.00	381.29	380.05	341.67	46.00	2.58	8488	213	11.2	2386	99.89
62	650.00	386.93	385.68	346.65	46.00	2.63	8766	213	11.1	2364	99.89
63	660.00	392.58	391.30	351.63	46.00	2.67	9050	214	10.8	2311	99.88

64	670.00	398.22	396.92	356.61	46.00	2.71	9341	212	9.0	1908	99.86
65	680.00	404.30	402.99	362.09	47.00	2.75	9617	216	11.3	2441	99.89
66	690.00	409.94	408.61	367.06	47.00	2.80	9884	217	12.2	2647	99.89
67	700.00	415.59	414.23	372.04	47.00	2.84	10157	216	10.2	2203	99.87
68	710.00	421.67	420.29	377.52	48.00	2.88	10447	217	10.2	2213	99.87
69	720.00	427.31	425.92	382.50	48.00	2.92	10752	215	9.9	2129	99.86
70	730.00	433.39	431.98	387.98	49.00	2.96	11079	216	10.8	2333	99.87
71	740.00	439.04	437.60	392.96	49.00	3.00	11425	216	11.0	2376	99.87
72	750.00	445.12	443.66	398.44	50.00	3.04	11770	213	9.2	1960	99.84
73	760.00	450.76	449.29	403.41	50.00	3.09	12137	213	9.9	2109	99.85
74	770.00	456.84	455.35	408.89	51.00	3.13	12528	215	12.0	2580	99.88
75	780.00	462.49	460.97	413.87	51.00	3.17	12899	215	11.8	2537	99.88
76	790.00	468.57	467.04	419.35	52.00	3.21	13290	217	9.8	2127	99.85
77	800.00	474.21	472.66	424.33	52.00	3.25	13723	215	11.3	2430	99.87
78	810.00	480.29	478.72	429.81	53.00	3.29	14131	215	11.5	2473	99.87
79	820.00	486.37	484.78	435.29	54.00	3.33	14565	215	11.5	2473	99.87
80	830.00	492.45	490.84	440.77	55.00	3.37	14985	213	11.2	2386	99.86
81	840.00	498.10	496.47	445.75	55.00	3.41	15433	214	11.0	2354	99.85
82	850.00	504.18	502.53	451.23	56.00	3.45	15906	215	11.2	2408	99.86
83	860.00	511.56	509.90	458.21	60.00	3.48	16415	212	10.2	2162	99.84
84	870.00	517.64	515.96	463.69	61.00	3.52	16909	212	10.9	2311	99.85

85	880.00	523.29	521.59	468.67	61.00	3.56	17436	213	11.6	2471	99.86
86	890.00	529.37	527.65	474.15	62.00	3.60	17905	214	11.3	2418	99.85
87	900.00	535.45	533.71	479.63	63.00	3.64	18413	213	10.8	2300	99.84
88	910.00	541.53	539.77	485.11	64.00	3.68	18957	211	11.0	2321	99.84
89	920.00	551.09	549.33	494.61	73.00	3.68	19623	212	11.0	2332	99.84
90	930.00	558.04	556.27	501.09	76.00	3.71	202232	211	10.6	2237	99.83
91	940.00	565.00	563.21	507.58	79.00	3.74	20902	211	10.3	2173	99.83
92	950.00	571.51	569.71	513.56	81.00	3.78	21567	210	11.3	2373	99.84
93	960.00	578.03	576.21	519.54	83.00	3.81	22215	219	11.4	2497	99.85
94	970.00	584.54	582.70	525.52	85.00	3.85	22929	211	11.1	2342	99.84
95	980.00	591.06	589,20	531.50	87.00	3.88	23648	210	10.8	2268	99.83
96	990.00	597.57	595,70	537.49	89.00	3.92	24395	210	11.6	2436	99.84
97	1000000	603.65	601.76	542.97	90.00	3.96	25143	210	11.3	2373	99.83
98	1010.00	610.17	608.26	548.95	92.00	3.99	26083	211	10.0	2110	99.81
99	1020.00	617.56	615.64	555.94	96.00	4.02	26845	210	9.3	1953	99.79
100	1030.00	624.07	622.14	561.92	98.00	4.05	27587	213	11.2	2386	99.83
101	1040.00	630.15	628,20	567,40	99.00	4.09	28139	219	11.9	2606	99.84
102	1050.00	636.67	634.70	573.38	101.00	4.13	28688	219	11.0	2409	99.83
103	1060.00	642.75	640.76	578.86	102.00	4.17	29168	221	11.6	2564	99.84
104	1070.00	648.83	646.82	584.34	103.00	4.20	29674	219	9.8	2146	99.80
105	100.00	654.91	652.88	589.82	104.00	4.24	30263	221	11.3	2497	99.83

106	1090.00	661.42	659.38	595,80	106.00	4.28	30912	223	11.5	2565	99.83
107	1100.00	667.94	665,88	601.78	108.00	4.31	31504	223	11.5	2565	99.83
108	1110.00	674.02	671.94	607.26	109.00	4.35	32168	224	11.7	2621	99.83
109	1120.00	680,10	678.00	612.74	110.00	4.39	32937	224	11.7	2621	99.83
110	1130.00	686.62	684.50	618.73	112.00	4.43	33824	224	8.8	1971	99.78
111	1140.00	693.13	691.00	624.71	114.00	4.46	34615	222	9.5	2109	99.79
112	1150.00	699.65	697.50	630.69	116.00	4.50	35489	223	8.7	1940	99.77
113	1160.00	705.73	703.56	636.17	117,00	4.54	36468	224	10.4	2330	99.81
114	1170.00	712.68	710.50	642.65	120.00	4.57	37500	222	10.6	2353	99.81
115	1180.00	720.06	717.87	649.64	124.00	4.59	38565	218	9.4	2049	99.78
116	1190.00	727.45	725.25	656.63	128.00	4.62	40098	219	10.8	2365	99.80
117	1200.00	736.14	733.93	665.12	135.00	4.63	41929	218	9.8	2136.4	99.78
118	1204.00	741.89	739.68	671.13	143.00	4.61	42568	225	9.4	2115	99.78
119	1209.00	745.14	742.93	674.12	144.00	4.63	43209	225	10.9	2452.5	99.81
120	1206.00	743.89	741.68	673.13	145.00	4.61	43774	224	8.7	1948,8	99.76
121	1200.00	740.94	738.75	670.65	146.00	4.58	44372	225	8.8	1980	99.77
122	1200.00	740.94	738.75	670.65	146.00	4.58	44979	228	6.2	1413.6	99.68
123	1200.00	741.37	739.18	671.15	147.00	4.58	45580	225	5.4	1215	99.62
124	1200.00	741.81	739.62	671.65	148.00	4.57	46182	225	6.5	1462.5	99.69
125	1200.00	742.24	740.06	672.15	149.00	4.57	46783	225	6.5	1462.5	99.69
126	1200.00	742.68	740.50	672.65	150.00	4.57	47383	225	8.3	1867.5	99.76

127	1200.00	743.11	740.93	673.16	151.00	4.56	47990	225	5.4	1215	99.62
128	1200.00	743.55	741.37	673.66	152.00	4.56	48591	225	6.5	1462.5	99.69
129	1200.00	743.98	741.81	674.16	153.00	4.55	49192	225	6.5	1462.5	99.69

Based on data on table 7 we can find out the characteristic of the temperature distribution of each coating material with respect to time, and the reduced heat energy (*thermal loss*) in the electric furnace.

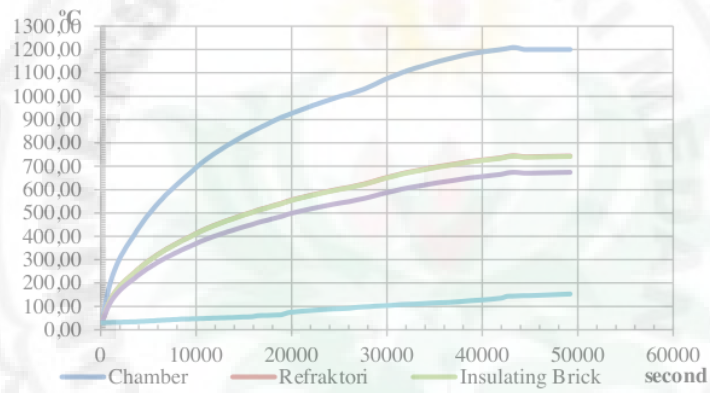

Figure 8. Graph of the temperature characteristic of each electric furnace coating material on testing with a load.

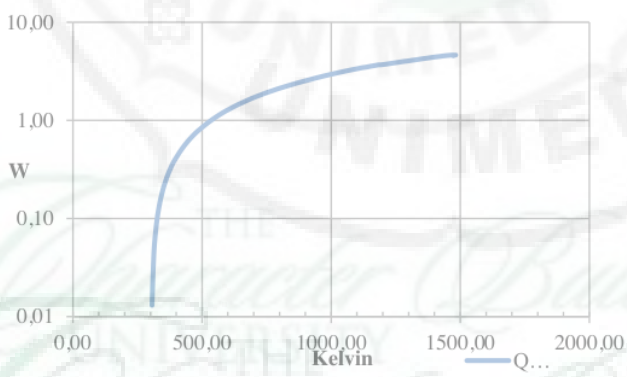

Figure 9. Graph of the thermal loss characteristic of the electric furnace against the measured chamber temperature in the load test.

Based on figure 8, and figure 9, we can know that the temperature distribution in the material of each electric furnace lining is very efficient as an electric furnace chamber.

Conclusion

An electric furnace with a furnace room dimension of 260mm x 170mm x 160mm has been successfully manufactured with a heating capability of up to 1200 ºC, an electric furnace can heat with a relatively low average power (±2200 Watt) than electric furnaces available in the market. The electric furnace

combustion chamber coating material used has been known to be very efficient based on the wasted heat transfer rate from the electric furnace combustion chamber at the maximum temperature (4.55 W).

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