DEVELOPMENT OF
HIGH EFFICIENCY COMBUSTOR SYSTEM
FOR INDUSTRIAL FURNACE

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BORANG PENGESAHAN STATUS TESIS

JUDUL: <u>DEVELOPMENT OF HIGH EFFICIENCY COMBUSTOR SYSTEM FOR INDUSTRIAL FURNACE</u>

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DEVELOPMENT OF
HIGH EFFICIENCY COMBUSTOR SYSTEM
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PUTERI NORFAZREEN BINTI RAZALI

Thesis submitted in partial fulfilment of the requirements
for the award of
Bachelor of Mechanical Engineering with Manufacturing Engineering

Faculty of Mechanical Engineering
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UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "*Development Of High Efficiency Combustor System For Industrial Furnace*" is written by Puteri Norfazreen bt Razali. I have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project an in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been daily acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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Dedicated to my beloved parents for their everlasting love, guidance and support in the whole journey of my life,

ABSTRACT

Nowadays, there are many researches that include high temperature of combustion. This research developed high efficiency combustor system for industrial furnace. Objectives of this research are to study the performance of combustion system and propose a new design of combustor system for industrial furnace. 99.5% of pure zinc was heated in the furnace within two hours and the sprue gas went through nanoparticle collector. The apparatus involved in this experiment are diesel blower, cooling tower, circulating pump, collector tank, furnace, infrared thermometer and thermocouples. All the temperatures distribution from the furnace until the nanoparticle collector system is measured. The result obtained is collected and there are three samples were provided. The smallest particle size obtained from the ZnO is 503.5 ηm and the largest size is 12.7 µm. At 300 second highest temperature in the furnace was at channel 6 which is 1069.52 ^{o}C while the lowest temperature obtained at channel 16 which is 139.06 °C. The proposed design is able to produce zinc oxide but not able to achieve nano size particle. The recommendations that can be used for future works are change the nano cloth to smaller nano filter and these samples should be test to validate their properties.

ABSTRAK

Pada masa kini, terdapat banyak penyelidikan yang berasaskan pembakaran pada suhu tinggi. Objektif kajian ini adalah untuk mengkaji prestasi sistem pembakaran dan mencadangkan reka bentuk baru sistem pembakaran untuk relau industri. 99.5 % zink tulen dipanaskan di dalam relau selama dua jam dan wap yang terhasil disalurkan melalui system pengutip zarah nano. Radas-radas yang terlibat dalam eksperimen ini adalah penghembus diesel, tangki penyejuk, pam pengedar, tangki pengumpul, relau, termometer inframerah dan termogandingan. Semua pengagihan suhundari relau sehingga sistem pengumpul zarah nano diukur. Keputusan yang diperoleh dikumpulkan dan tiga sampel telah disediakan. Saiz terkecil yang diperoleh dari zink oksida ialah 503.5 ηm dan saiz terbesar ialah 12.7 μm. Pada saat ke 300, suhu tertinggi relau terletak pada saluran 6 iaitu 1069.52 °C manakala suhu terendah terletak pada saluran 16 iaitu 139.06 °C. Reka bentuk yang dicadangkan mampu menghasilkan zink oksida tetapi tidak berjaya mencapai saiz zarah nano. Cadangan yang boleh digunakan untuk kajian akan dating ialah menukar penapis nano kepada saiz yang lebih kecil dan sampel yang diperoleh haruslah diuju untuk mengesahkan sifatnya.

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LIST OF SYMBOLS

W_{fuel}	Work done by fuel, (*J*)
$\dot{m}_g$	Mass of an individual droplets, (*kg/s*)
N	Num of fuel droplets entering chamber per unit time
ρ	Droplet Density, (kg/m^3)
A	Air
F	Fuel
CV	Control Volume
$\dot{m}$	Mass Flow Rate (*kg/s)*
η	Efficiency
Ψ	Exergy

LIST OF ABBREVIATIONS

FYP	Final year project
$C_{12}H_{23}$	Diesel
O	Carbon
H	Hydrogen
O_2	Silver
N_2	Oxygen
CO_2	Aluminum Oxide/Alumina
H_2O	Water
ZnO	Zinc Oxide
OEC	Oxygen – Enrichment Combustion

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

This invention is to demonstrate a production of nanoparticle by using low cost method. The industrial furnace is used to heat the metal to initiate the formation of nanoparticle. This method is found to be very easy, low cost and practical to produce of zinc oxide due to low melting temperature of the metal. The heating and melting process is conducted at atmospheric temperature and pressure without presence of inert gas.

1.2 OBJECTIVES

In this study, there are several objectives that will be fulfilling as follow:

i. Study the performance of combustion system.
ii. To analyze and propose a new design of combustor system for industrial furnace.

1.3 SCOPES

There are several scopes that must be fulfilling in this research. There are stated as follow:

i. To conduct experimental works of industrial furnace to produce nanoparticle.
ii. Data analysis and report writing.

1.4 RESEARCH FLOWCHART

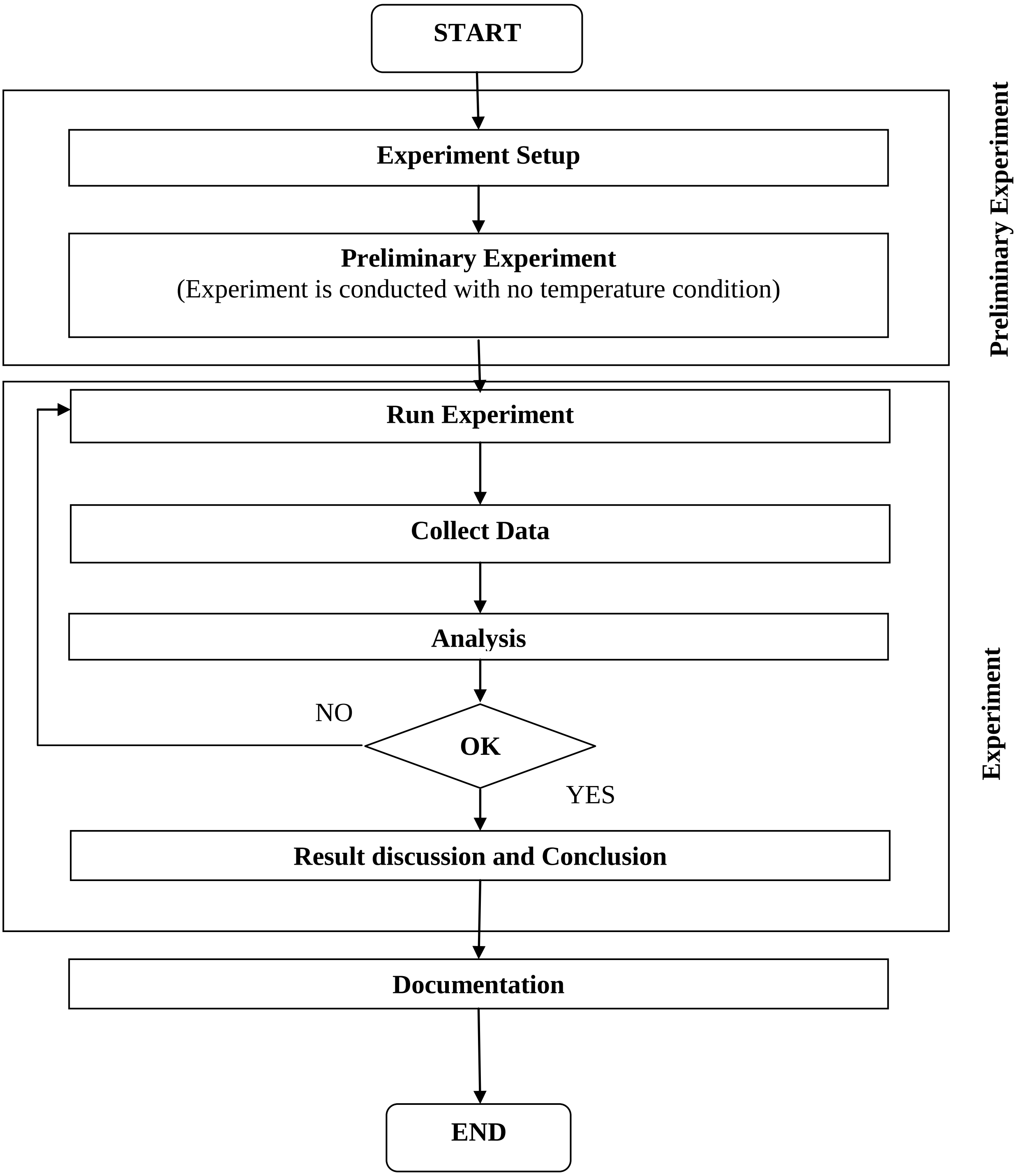


Figure 1.1: Research Flow Chart

1.5 OUTLINE OF REPORT

Chapter 1 discussed about the background of the research project. Then the objectives and the scopes of this research project were indentified. The process of the whole project can be seen through the flow chart and outline of the report is stated all the description about the chapter that contain in the report.

From the chapter 2, presents the topic that included in literature review is the method of nanoparticle synthesis including combustion method, combustion system, ideal design of combustor system and the example of combustor system also can be found in this chapter. Furthermore, this chapter also discuss about properties of zinc oxide nanoparticle and experimental study of zinc oxide nanoparticle synthesis.

Chapter 3 allocates the research methodology. It begins with the research flow chart then followed by preliminary experimental setup and covers on the facilities used and method of conducting experiment.

In chapter 4, all the temperature measured from the experimental works is shown and it can be understand through the plotted graph. The ZnO powder obtained from the combustion also were discussed in this chapter also brief explanation about nanoparticle collector system and how to make it.

Moreover, in chapter 5 all the conclusions that being made from the whole experimental and research project is discussed. The recommendations about the research also were stated to improve the future works.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Nanotechnology involves the characterization, fabrication and or manipulation of structure; devices or materials that have at least one dimension (or contain components with at least one dimension) that is approximately 1–100 nm in length. When particle size is reduced below this threshold, the resulting material exhibits physical and chemical properties that are significantly different from the properties of macro scale materials composed of the same substance. Research in the nanotechnology field has skyrocketed over the last decade, and already there are numerous companies specializing in the fabrication of new forms of nanosized matter, with anticipated applications that include medical therapeutics and diagnostics, energy production, molecular computing and structural materials. In 2008, nanotechnology demanded over $15 billion in worldwide research and development money (public and private) and employed over 400,000 researchers across the globe (Richard A. Yetter, *et al*, 2009)

The application of nanoparticles that can be found is in food packaging. In order to protect food from dirt or dust, oxygen, light microorganisms, moisture and variety of other destructive or harmful substance, the packaging must be safe, cheap to produce, light weight, easy to dispose of or reuse and resistant to physical abuse. In this case, most of food manufacturer use polymer nanocomposites to produce food packaging. In some applications high barrier to migrations or gas diffusion are undesirable, such as in packages for fresh fruit and vegetables whose shelf life is dependent on access to a continual supply of oxygen for sustained cellular respiration (Duncan and T. V, 2011).

The other example of application in nanoparticles is the use of reinforcing agents, opacifiers and pigments also fabrication of optical fibers. The products that involve are silica, titania and black carbon.

The requirement to use the furnace which is efficient and clean production is able to yield products reduced energy input, raw materials consumption, equipment degradation, and liquid, gas and solid wastes. The main characteristics of furnace are large amount of energy utilized, the relevance of technological processes occurring in that equipment for the final product quality, the significant part of the production time spent in these units, the involved thermo physical processes that are complex and the difficulty to access and measure the phenomena inside this unit (Nogueira, 1997).

Furnace is a device in which technology released as heat either by consumption of fuel or electricity was used the temperature of material for the purpose of modifying it or produced new material. Figure 2.1 shows the example of furnace (O. A. Ighodalo, 2011).

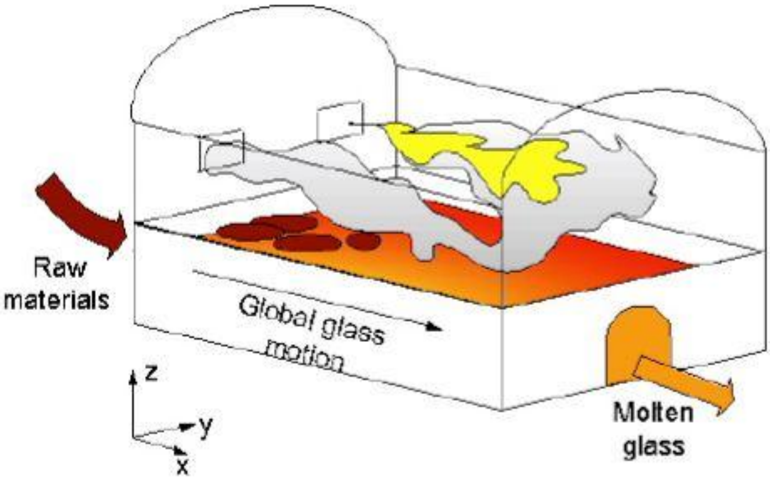


Figure 2.1: Glass melting furnace

Source: O. Auchet, 2005

2.2 TYPES OF FURNACE

There are many types of furnace. Basic function of furnace is provides high temperature combustion. The several types of furnaces are blast furnace, aluminium melting furnace, bell furnace and forge furnace.

2.2.1 Blast Furnace

Blast furnace is commonly used as smelting to produce industrial molten pig iron from iron oxides, coke and flux. The process need continuous flow of air pre-heated at high temperature which is above 1000 °C. The alternative energy source for this process is the sensible heat coming from preheated air. Figure 2.2 show the example of blast furnace (S. Jinsheng, 2008).

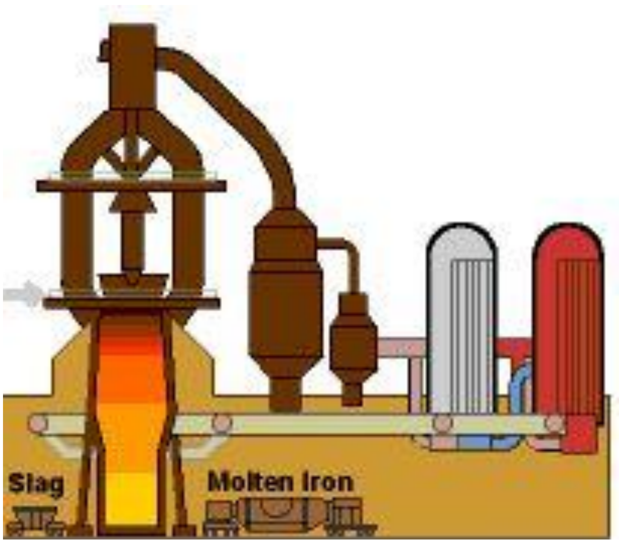


Figure 2.2: Blast furnace

Source: J. A. Ricketts

2.2.2 Aluminium Melting Furnace

This type of furnace is used to produce melting aluminium for industries used such as packaging and construction. These furnaces usually have large capacities increase up to 110 metric tons of scrap. Furthermore, it used nature gas as fuel to melt large volumes of raw aluminium scrap. Figure 2.3 shows the example of aluminium melting furnace (Penmetsa and S. R. Raju, 2004).

Figure 2.3: Aluminium melting furnace
Source: Wesmen Group of Companies, India

2.2.3 Bell Furnace

This type of furnace known as bell-type furnace is used for annealing process in heat treatment. The bell type annealing cold rolling product with high quality was produce. Annealing and hot rolling process is conducted to relieve stress and this process is work under high temperature. Figure 2.4 shows the example of bell furnace (Zhang X, *et al*, 2008).

Figure 2.4: Bell-type furnace

Source: Direct Industries

2.2.4 Forge Furnace

Forge furnace is commonly used in forging process for heat treatment. These furnaces operated with the temperature range of 200 – 1200 °C. Due to the high temperature and uniform heat, this furnace can provide very fast temperature change when it is operated. Figure 2.5 shows forge furnace commonly used for forging process (S Sheikh, 2008).

Figure 2.5: Forge furnace

Source: Heat Treat Furnace HTF Inc

2.3 PURPOSE OF FURNACE

Furnace always involved with the industry that needed high temperature combustion. It commonly help manufacturing industries by provided the certain range temperature. The mainly listed purposes of furnace are production iron and steel, production of glass, food industry, ceramic process and nanoparticle synthesis.

2.3.1 Production of Iron and Steel

Production of iron and steel is very important to construction packaging industries. This process required blast furnace and aluminium melting furnace. Figure 2.6 shows the schematic diagram of production of iron and steel. Coal or coke has been used to assist the molten metal from this process.

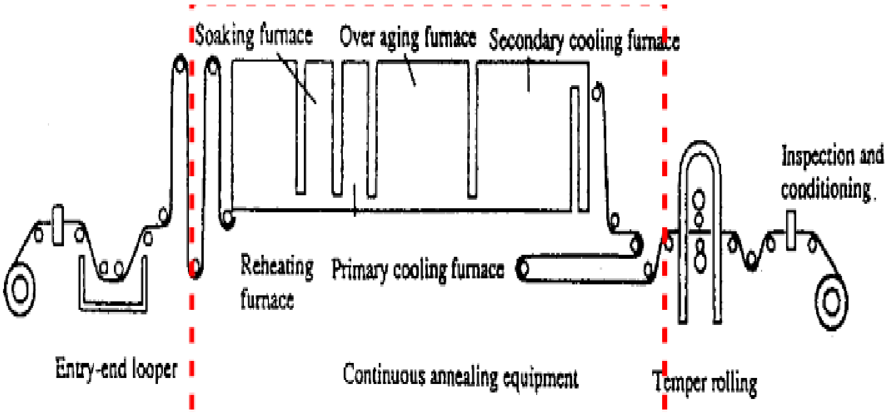


Figure 2.6: Production of iron and steel

Source: S Jinsheng, 2008

2.3.2 Production of Glass

The function of furnace in this process is to provide heat to melt the glass. Molten glass is easy to be shaped but it is only occur in certain temperature. For glass melting process, the raw materials have to be heated continuously. The functions of furnace in this process are to supply continuous heat to heat up the raw materials and melt it. Figure 2.7 show the example of glass melting furnace process (C. P. Ross and G.L. Tincher, 2004).

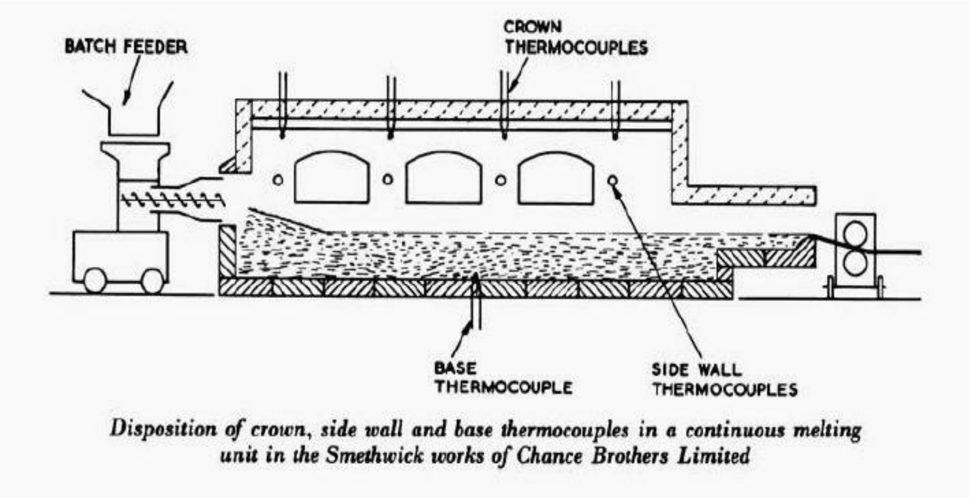


Figure 2.7: Process of glass melting

Source: J.A.Stevenson, 1966

2.3.3 Food Industry

In food technology, the furnace is widely used to provide heat at certain temperature. The temperature that commonly being use in food manufacturing is below 500°C. The temperature used must be not too high to prevent food from burning. Moreover, in food manufacturing the furnace noted as clay oven which was used to bake pizza and bread also to cook the chicken and meat. Figure 2.8 show the example of clay oven.

Figure 2.8: Clay oven

Source: S. Brookes, 2010

2.3.4 Ceramic Process

A study by P. J. Nel and A. Tauber (1970) reported that in ceramic making process, the furnace will be used to provide heat at temperature range of 1200 to 1250 °C. This step will affect the quality of a ceramic depending on the furnace atmosphere and heating rage. After the raw material is heat up in furnace it will be go through cooling process. The common type of furnace is used in this industry is electric furnace.

2.3.5 Nanoparticle Synthesis

Experimental study by A. Moezzi and A. M. McDonagh (2012) have discuss about French method that commonly used in industrial to produce zinc oxide (ZnO). This process used high temperature to produce zinc nanoparticle. It is stated that by increasing the excess of reactant air (oxygen), the process for ZnO to become quenching become faster and finer particles could be produce. This can be achieved by using better circulation of air aor forced flow of compress air in combustion zone. The product will result in higher specific surface area. Figure 2.9 showed the French process that is common used in industry.

Figure 2.9: French process
Source: A. Moezzi and A. M. McDonagh, 2012

2.4 FURNACE DESIGN

The optimization heat transfer process is the design priority of oxy-fuel furnace. The cost of fuel has to be balance by the energy efficiency of the oxy-fuel furnace. In order to modelling a high efficiency of furnace, a few parameters have to be considered. The considered parameters that have give attention are the solution of conservation equation for mass, momentum, energy and combustion related to chemical. The combustion model is based on the ideal of single step reaction between the fuel and the air (M.Nogueira and M.d.G.Carvelho, 1997).

Table 2.1: Influence of combustion aspect ratio on the furnace performance

No	Aspect ratio(width/length)	Efficiency (W_{fuel}/W_{Load})
1	1.00	0.57
2	1.16	0.56
3	1.32	0.54

Table 2.1 shows the effect of the combustion chamber aspect ratio on the furnace performance. The aspect ratio of the furnace is determined by the width of the furnace divide by length of the combustion chamber. The ideal size of furnace is the length and the width of the combustion chamber is same. When aspect ratio is equal to 1.00, it gives the efficiency of the combustion system 0.57.

The example of the calculation on length and width to get the high efficiency of combustion system as state below;

$$\text{Width} = 300\text{mm},\ \text{length} = 300\text{mm} \tag{2.1}$$

$$\text{Aspect ratio} = \frac{width}{length} = \frac{300.00}{300.00} = 1.00 \tag{2.2}$$

Table 2.2: Influence of distance between burner and melt on the furnace performance

No	Burner height (m)	Efficiency (W_{fuel}/W_{Load})
1	0.23	0.57
2	0.37	0.56
3	0.51	0.54

Table 2.2 shows the influence between burner and melting place on the furnace performance. When the value of burner height is increase, the effieciency of the furnace performance also decrease. Note that when burner height is 0.23m the value of efficiency of the furnace performance is 0.57. It can be conclude that when designing the high efficiency of furnace performance, the burner height must be lower value.

Table 2.3: Influence of combustion chamber height on the furnace performance

No	Chamber height (m)	Efficiency (W_{fuel}/W_{Load})
1	1.00	0.57
2	1.16	0.56
3	1.32	0.54

The next parameter that contributes to the furnace efficiency is the influence of combustion chamber height on the furnace performance. Table 2.3 shows when the chamber height is increasing, the furnace performance is decreasing. In order to get ideal size for high efficiency of the furnace performances, the height must be lower value. When the value of chamber height is 1.00 meter, the efficiency of furnace performance is the highest value which is 0.57.

Furthermore, in order to design a high efficiency of combustor system, the physical value that must be considered is the porosity effect. In the physical of the furnace, it is compulsory to add porosity effect with the good reason. Porosity in furnace can help the combustor system in cooling process. In gas extraction aspects, the way porosity can help is if the porosity of the load increase, cooling is more efficient. More heat is extracted from the furnace volume and the extraction temperatures are higher. The porosity load mentioned before was referring to the volume of the porosity.

The wall of the combustor system also gives impact to performance. The wall is insulated from cement in order to reflect the heat. As the ambient and the wall heat loss coefficients are assumed to be constant, the determinant factor will be temperature of the gases. In combustion chamber, the gas temperatures are higher for low porosity settings and heat loses through the wall increase.

In a study a performance of a regenerative furnace done by T. Ishii (2002) expressed that the roof of furnace must be not too high because more fuel is needed to heat gases inside the furnace and the furnace thermal efficiency will be lower. If it too low, the heat loss through furnace roof will increase. In addition, experimental work done by T. Ishii gave result that thermal efficiency of the furnace at height of 2.5 meter and 3.5 meter are lower than 2.0 meter.

H. Kobayashi (2004) stated that in a furnace, oxy-fuel placed either in the side walls in the crown and angled down toward the unmelted batch area to accelerate the melting and fining rate.

2.5 COMBUSTION SYSTEM

Combustion system will transfer energy stored in chemical bond to heat that can be used for variety of ways. Behind the flame that produced in combustion as product, the flame, it will include combustion space, the temperature and pressure rise in the unburned gas. When using diesel burner, premixed and diffusion flames were produced. In a premixed flame, the fuel and the oxidizer are mixed at the molecular level prior to the occurrence of any significant chemical reaction. Diffusion is defined as fuel molecules diffuse toward the flame from one direction while oxidizer molecules diffuse toward the flame from the opposite direction.

Basic stoichiometry that include in this combustion system is given

$$C_xH_y + a(O_2 + 3.76N_2) \rightarrow xCO_2 + (y/2)H_2O + 3.76aN_2 \qquad (2.3)$$

Where

$$a = x + y/4 \qquad (2.4)$$

For the theoretical value that applied in this research, the stoichiometry is shown as below;

$$C_{12}H_{23} + 17.75\ (O_2 + 3.76N_2) \rightarrow 12CO_2 + 11.5H_2O + 66.74N_2 \qquad (2.5)$$

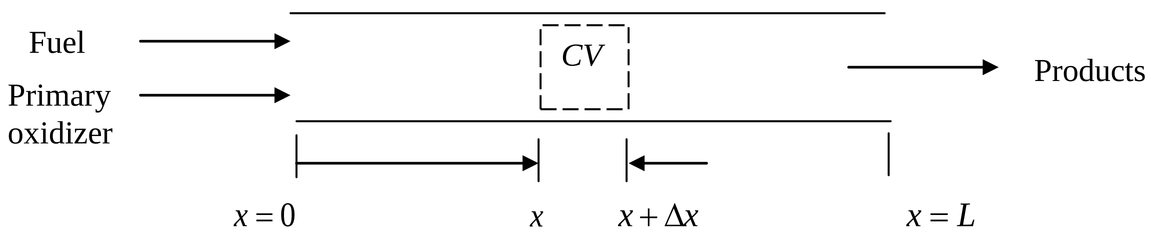


Figure 2.10: Combustor system

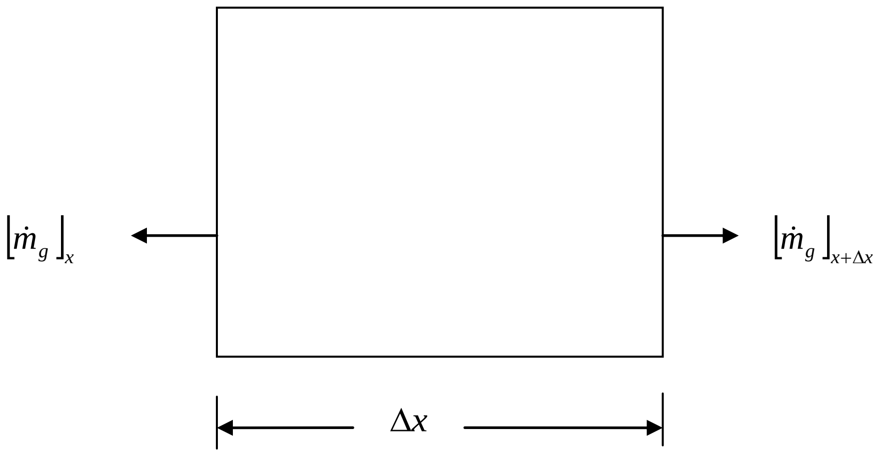


Figure 2.11: Details of control-volume analysis

The combustor system had constant cross-section area. Fuel droplets, uniformly distributed across combustor, evaporated as they move downstream in an oxidizer stream. The fuel vapour is assumed to mix with the gas phase and burn instantaneously. This causes the gas temperature to rise, speeding the vaporization of the droplets. The gas velocity increases because droplet vaporization, and possibly, secondary addition, add mass to the gas phase and because combustion decrease the gas density.

The following assumptions will be embodied in the combustor system of a liquid-fueled combustor:

i. The combustor system comprises with single component fuel phase.
ii. The flow is one dimensional which x-axis.

iii. The effects of friction and velocity changes on pressures are neglected. This implies the pressure is constant for example dP/dx = 0 and simplifies the vaporization problem.

iv. The fuel is introduced as a stream of monodisperse droplets which is all droplets have the same diameter and velocity at any axial location.

v. The droplet temperature assumed fixed at the boiling point.

The mathematical modeling for the combustor system is introduced. It used to determine droplet diameter, fuel evaporation rate and droplet velocity. The combustor system was assumed to be a steady-state, steady-flow and control volume analysis.

From Figure 2.10 and 2.11 the term $\dot{m}'_{\mathrm{lg}}$ is the mass flowrate of fuel per unit length going from the liquid phase into the gas phase which is fuel vaporation rate. The rate at liquid fuel exists the control volume at $x + \Delta x$ is less than that entering at x by the amount of mass flowrate. The flowrate of liquid through the combustor can be related to the number of fuel droplets entering the chamber per unit time, $\dot{N}$, and the mass of an individual droplets, m_d.

$$\dot{m}_l = \dot{N} m_d \tag{2.6}$$

Or

$$\dot{m} = \frac{\dot{N}\rho_l \pi D^3}{6} \tag{2.7}$$

ρ_l = droplet density

D = droplet diameter

The number of droplets entering the combustor per unit time is easily related to the initial fuel flow rate and assumed initial droplet size, D_0. The equations are

$$\dot{m}_{l,0} = \frac{\dot{N}\rho_l \pi D_0^3}{6} \tag{2.8}$$

And

$$\dot{N} = \frac{6\dot{m}_{l,0}}{\pi\rho_l D_0^3} \tag{2.9}$$

The air-fuel ratio can be determined by using below equation;

$$(A/F)_{\text{stoic}} = \left(\frac{m_{air}}{m_{fuel}}\right)_{stoic} = \frac{4.76a}{1}\frac{MW_{air}}{MW_{fuel}} \tag{2.10}$$

Where MW_{air} and MW_{fuel} are the molecular weights of the air and fuel, respectively.

The equivalence ratio, Φ, is usually use to determine quantitatively whether a fuel-oxidizer mixture is rich, lean, or stoichometric. The equivalence ratio is defined as

$$\Phi = \frac{(A/F)_{stoic}}{(A/F)} = \frac{(F/A)}{(F/A)_{stoic}} \tag{2.11}$$

For fuel mixtures, $\Phi > 1$ and for fuel –lean mixtures, $\Phi < 1$.
From equation 2.10, the theoretical equation that be calculated from this research is

$$\text{AF}_{\text{th}} = \frac{\text{m}_{\text{air}}}{\text{m}_{\text{fuel}}}$$

$$= \frac{17.75(4.76)(29)}{(1)(200)}$$

$$= 12.25\,\frac{\text{kg air}}{\text{kg fuel}}$$

$$\%\text{excess air} = \left(\frac{AF_{act}\text{-}AF_{th}}{AF_{th}}\right)(100\%)$$

$$\frac{14.7\text{-}12.25}{12.25}(100)=20\%$$

$$\text{mixture strength},\emptyset=\frac{\left(\frac{A}{F}\right)_{stoic}}{\left(\frac{A}{F}\right)_{act}}$$

$$=\frac{12.25}{14.7}=0.8333=83\%$$

From the equation, when conducted the experimental works, 12.25 kilograms air per kilograms fuel which is diesel is being used.

2.6 OXYGEN ENRICHMENT COMBUSTION (OEC)

Oxygen-enhanced combustion known as OEC which means combustion process is enhanced by using an oxidant that contains a higher proportion of O_2 than in air. Most of combustion processes use air as oxidant (C. E. Baukal, 1998). There are typical benefits using air as oxidant especially for furnace efficiency. The benefits as follows:

i. Increased thermal efficiency
ii. Increased processing rates
iii. Reduced flue gas volumes
iv. Reduces pollutant emissions

Oxygen-enrichment increases the partial pressure of oxygen leading to accelerate of the combustion rate and thus the rate of char burn out of the cold water fuel droplets decrease in the total amount of the nitrogen in the combustion air which reduces the volume of the air and flue gas (T. S. McIlvried,, *et al*)

2.7 FURNACE EFFICIENCY

Efficiency of furnace can be analyzed by using energy and exergy analysis. Exergy is a measurement of the maximum useful work as in a specified final state in equilibrium with its surroundings. Exergy destruction is a measure of irreversibility that is the source of performance loss (Aljundi, 2009).

Exergy of fuel can be expressed by equation 2.11.

$$\varepsilon_f = h_f - Tosf \qquad (2.10)$$

Energy and efficiencies for the combustion principle of the furnace re considered as follow equations:

$$\eta = \frac{\text{Energy in product outputs}}{\text{Energy in inputs}} \qquad (2.11)$$

$$\Psi = \frac{\text{Exergy in product outputs}}{\text{Exergy in inputs}} \qquad (2.12)$$

$$\text{Energy input} - \text{Energy output} = \text{Energy accumulation} \qquad (2.13)$$

$$\text{Exergy input} - \text{Exergy output} - \text{Exergy consumption} = \text{Exergy accumulation} \qquad (2.14)$$

It is clearly stated that energy is conserved while exergy is consumed due to irreversibility. Exergy is not be conserved but it is destroyed or lost (M. Hasanuzzaman, 2011).

2.8 OPTIMIZATION OF FURNACE PERFORMANCE

A research done by A. Martensson, 1992 stated there are several factors to increase furnace performance. These factors can be considered to maximize furnace performance. The variables that affected for efficient furnace operations as follow:

i. Furnace gas and wall temperature
ii. Stock temperatures
iii. Fuel and combustion flows
iv. Oxygen content of exhaust gas
v. Position of each stock item in the furnace.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter describes in details how the experiment will conduct to get various data. The main concern of this project is the synthesis of zinc oxide nanoparticle with furnace reactor that will be applied in industrial field which is the data will be generated from analysis that will be conducted in experimental work. The result from the experimental work will be used for convenience graph and dimensionless variable to validate previous research result and numerical study result. Method of experimental setup, parameters and analysis of taken data will be discussed further in this chapter.

Finally, overall process and step by step how to carry on this research from the beginning until the end was shown by Figure 3.1 in order to successfully complete this project.

3.2 RESEARCH FLOW CHART

This research flow chart is divides into two phases which are preliminary experiment and experiment. It is shown in Figure 3.1, while conducting preliminary experiment, experiment is setup and calibrates the apparatus to produce the zinc nanoparticle from the furnace reactor. In experiment, zinc oxide will be synthesized with the various temperatures and data will were collected.

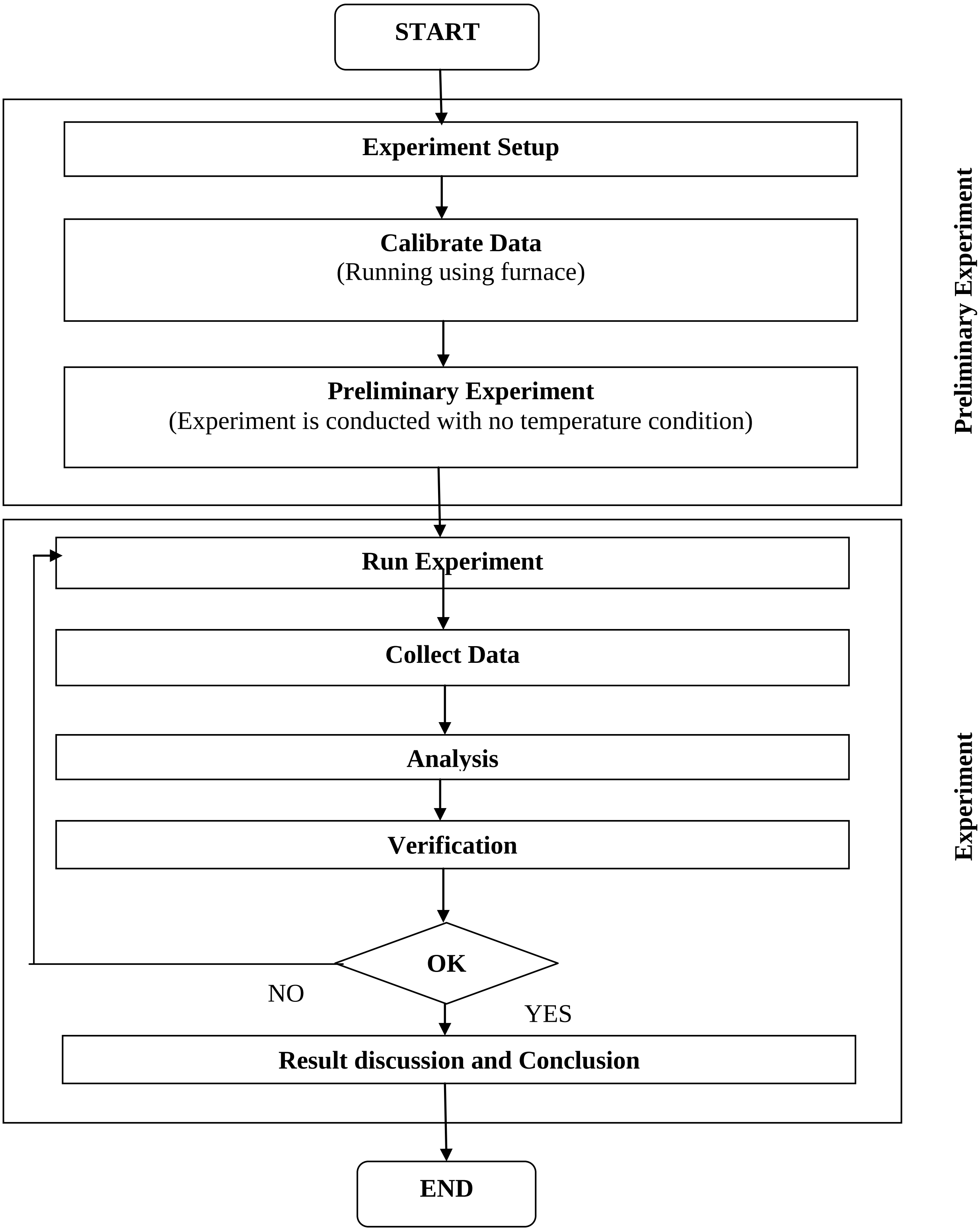


Figure 3.1: Project Flow Chart

3.3 PRELIMINARY EXPERIMENT SETUP

The schematic diagram of preliminary experiment is shown in Figure 3.2. The set up was consisting of furnace and strainer. The size of strainer is 10 mm. 6 kg of zinc is used to be burn into the furnace. After about 120 minutes the heating process, it is left to cool down while the strainer is put on the top of the furnace. Before 120 minutes, the zinc not achieved gaseous state yet.

The sprue gas that comes out from the furnace from the heating process may contain various size of zinc oxide nanoparticle. All the dust of zinc oxide is collect to check whether it is in nano size. Infrared thermometer is used to take temperature from the test.

Figure 3.2: Furnace reactor with strainer at the top

3.4 NANOPARTICLE COLLECTOR SYSTEM

The schematic diagram of zinc oxide nanoparticle synthesis with furnace reactor is shown by Figure 3.3. The system of consist furnace as reactor, cooling tower and nano filter. The temperature is measured by infrared thermometer after 10 minutes the experiment was running. Vacuum is put on top of cooling tower and the nano filter. Cooling tower is used to lower the temperature of vapor that come out from the furnace in order to produce nanoparticle.

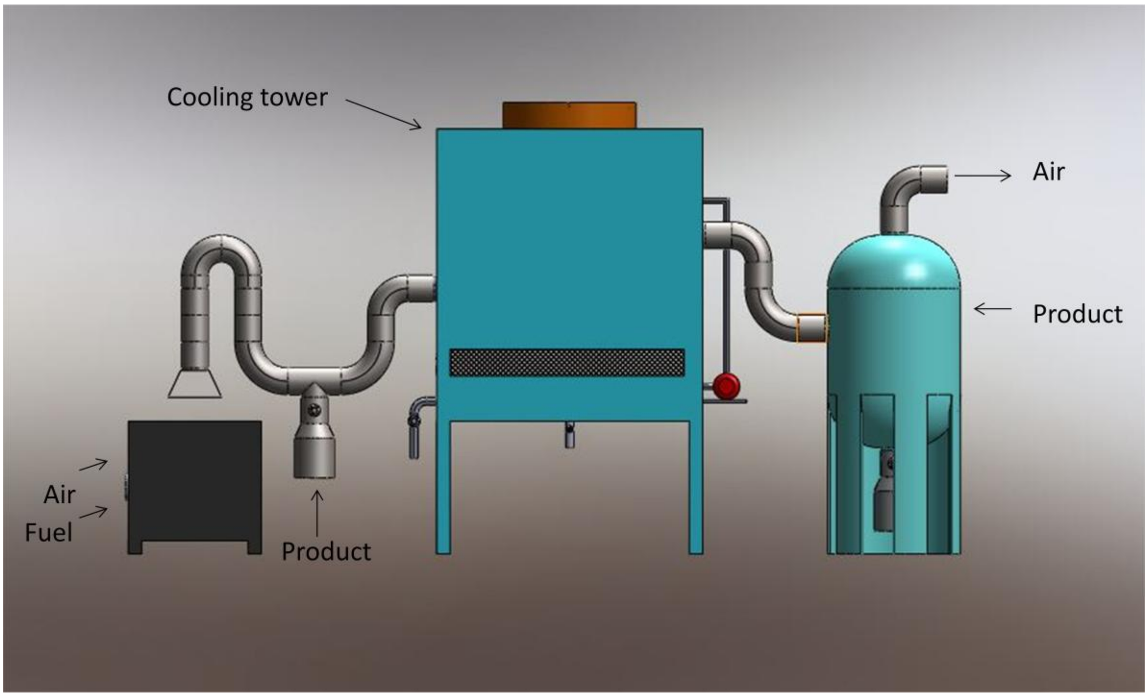


Figure 3.3: Design of Nanoparticle Collector System Plant

Figure 3.4: Nanoparticle Collector System

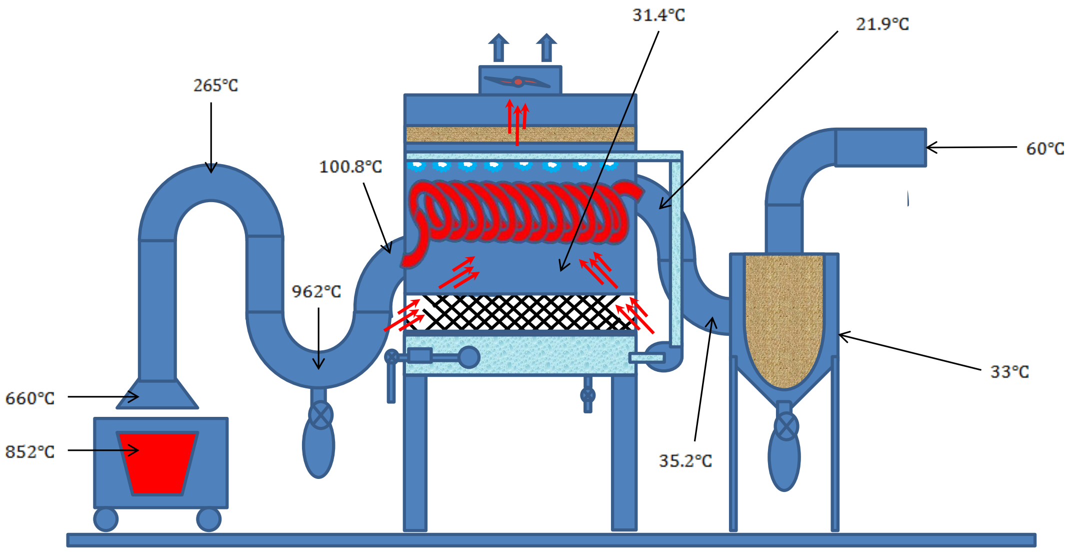


Figure 3.5: Temperature Distribution

Figure 3.5 show the temperatures along the system while experiment is conducted. The temperature is taken after 10 minutes the experiment is run. The temperature of cooling water is always check to make sure it is low. Otherwise it is not to be efficient to lower the temperature of the gas that comes in.

3.5 EXPERIMENT SETUP

In this section, the experiment step is clarified. Steps by steps of the experiment flow can be seen by follow:

i. 5.2 kg of pure zinc is heated in the furnace.
ii. Wait for about 30 minutes.
iii. The nano collector system is turned on.
iv. Experiment is run about 120 minutes.
v. All the dust is collected.

Figure 3.6: 99.5% of Pure Zinc

Figure 3.7: The experiment is running about 120 minutes

Figure 3.8: The temperature is taken to make sure it is always at low value

Figure 3.9: The sprue gas of zinc after it is heated

The whole experiment process was noted as follow:

i. 5.2 kg of 99.5% of pure zinc is placed inside the furnace.
ii. The diesel blower is switched on.
iii. Temperature at furnace and nanoparticle system collector was measured.
iv. The experiment is run about two hours.
v. Switch off the diesel blower.
vi. Zinc oxide is collected from inside the furnace and collector tanks.

3.6 EXPERIMENT APPARATUS

3.6.1 Diesel Blower

A diesel blower is used for external help for the furnace to start the fire. When the fire is start, it need blower to make the fire reach inside the furnace. Since the experiment is design inside the room and to avoid the fire burn the whole system, it need blower to place the fire at the right place. This diesel blower have can burn diesel at rate 5×10^{-3} liter per second. Diesel blower is plugged into the electrical source and it is placed at the inlet of the furnace. This apparatus also provide air to assist the combustion process. Diesel engine comes with burner and it provides heat for the combustion process. Figure 3.10 show the diesel blower that used in this experiment.

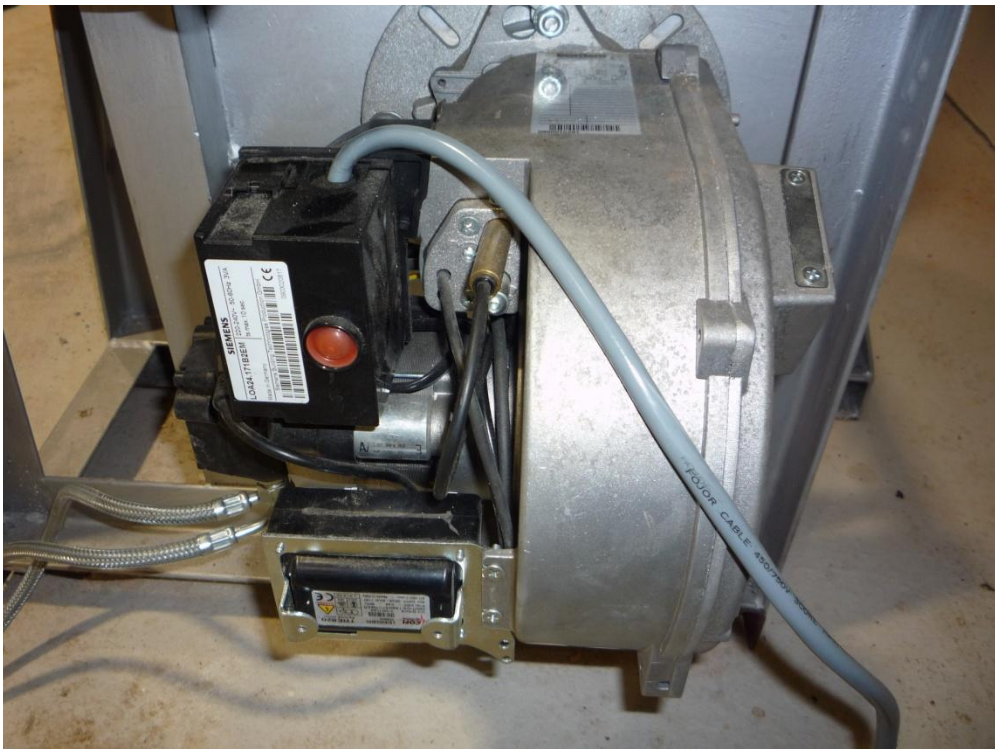


Figure 3.10: Diesel blower

3.6.2 Cooling Tower

In this experiment, cooling is very important because it will be use to turn the temperature down. The water in cooling tower has to be low temperature otherwise the system will not cooling down. The ice cube is added to make sure the water bath is always at low temperature. The temperature was measured every ten minutes. Figure 3.11 shows cooling tower that used to run this experiment.

Figure 3.11: Cooling tower

3.6.3 Circulating Pump

A circulating pump is used as external device means to force the water from the bottom tank to enter the top of cooling water. An electric motor with capacity of 0.5 horse power is used to drive the circulation pump with variable speed. Figure 3.12 shows the circulating pump with variable motor that used in this experiment.

Figure 3.12: Circulating pump for cooling tower

3.6.4 Infrared Thermometer

Due to the high temperature, the best way to measure the temperature is by using infrared thermometer. This kind of thermometer is suitable because the temperature can be measured even though from the far. The reading also can be hold so the reading can lasted for 10 seconds. Figure 3.13 shows the infrared thermometer used in this experiment.

Figure 3.13: Infrared thermometer

3.6.5 Collector Tank

All the dust from the furnace will be collect to this tank. This tank is used to collect the remaining dust from the path. Collector tank was placed next to the cooling tower so the dust in this tank is lower from the dust at the in front. Figure 3.14 shows the collector tank.

Figure 3.14: Collector Tank

3.6.6 Furnace

The furnace that used in this experiment is made of castable refractory cement. This type of material can stand heat up to 1200°C. It mixed with another ceramics materials to make sure it can stand high temperature. The dimension of this furnace is one meter height, 0.7 meter width. Figure 3.15 shows the furnace that used in this experiment. The specimen was burned in this furnace to get the sprue gas.

Figure 3.15: Furnace

All the arrangement of the experiment setup had shown in Figure 3.16 and the function of each apparatus have summarized in Table 3.1.

3.6.7 Thermocouples

16 thermocouples K- type were provided to conduct this experiment as shown in Figure 3.16 and four thermocouples were placed in per section along the furnace. This PICO technology has 0.1°C resolution and need to calibrate before fixing them at specified location.

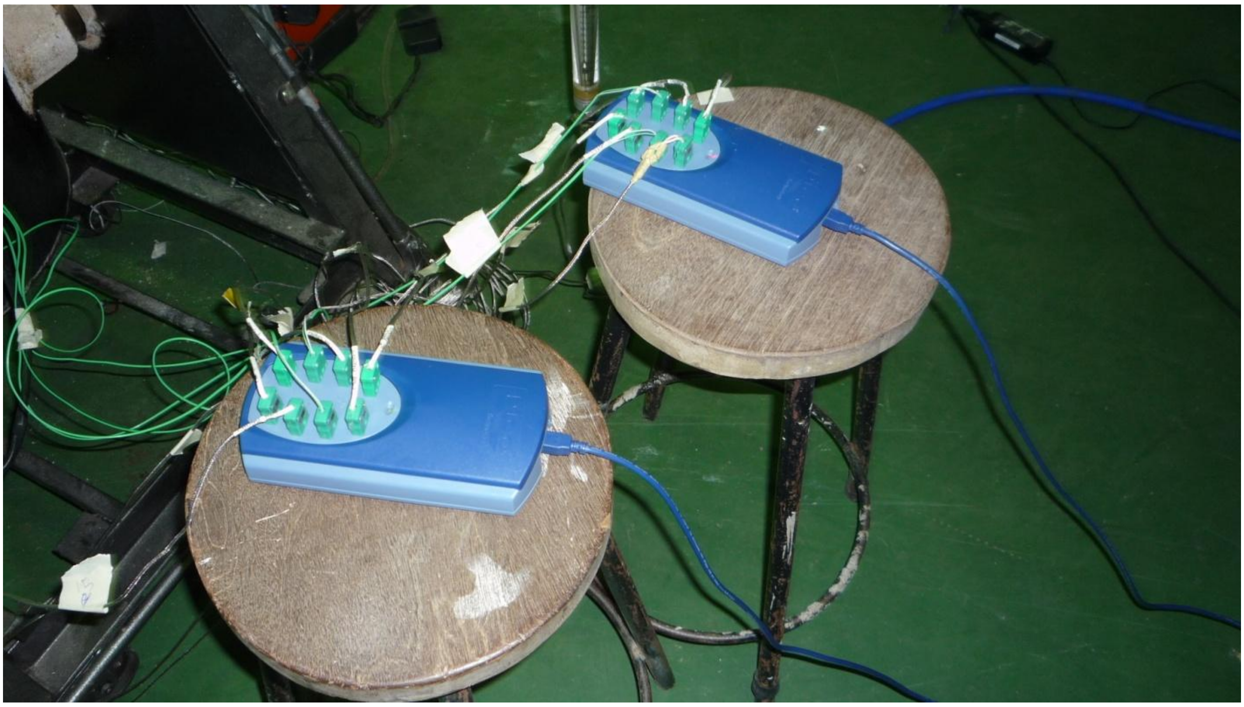


Figure 3.16: Thermocouples PICO technology

Figure 3.17: Apparatus arrangement

Description:-

i. Diesel Blower.
ii. Cooling tower.
iii. Circulating Pump.
iv. Collector Tank.
v. Furnace.
vi. Infrared thermometer.
vii. Thermocouples.

Table 3.1: Summarize Function for Each apparatus

No	Apparatus	Function
1	Diesel Blower	External force to heat up the furnace, supply air and heat to the furnace for combustion
2	Cooling Tower	Turn down the temperature from the furnace
3	Circulating Pump	Force the water from the bottom tank go to the top of cooling tower
4	Collector Tank	Collect the final product
5	Furnace	Pure zinc was burned inside the furnace to get the sprue gas
6	Infrared Thermometer	To measure the temperature when running the experiment
7	Thermocouples	To measure temperature along the furnace

3.7 MEASUREMENT POINTS OF FURNACE

There are 16 points known as channel noted as measurement point to see the temperature distribution along the furnace. These temperatures were taken by the thermocouple. Figure 3.18 show the point how the thermocouple was placed.

Regarding Figure 3.19, the top view of the furnace and summary of the point or channel along the furnace. The point is placed by anti-clockwise from bottom to the top of the furnace. So all place in the furnace can be measured.

Figure 3.18: Method to placed thermocouple

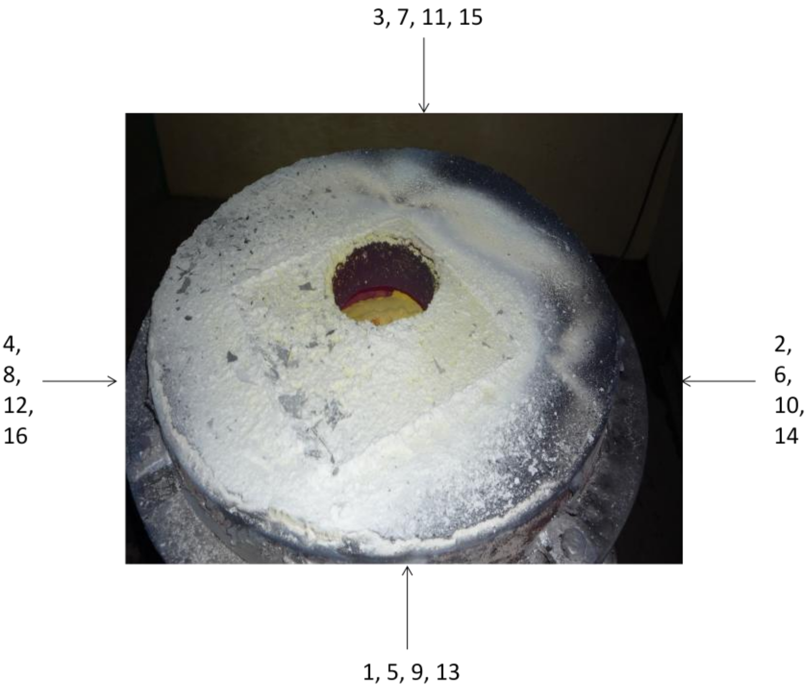


Figure 3.18: Top view of the furnace

3.8 FABRICATION OF NANOPARTICLE COLLECTOR SYSTEM

There are three component parts that welded together in fabricating process of nanoparticle system. The parts as follow:

i. Chimney.
ii. Cooling tower.
iii. Cyclone.

3.8.1 Chimney

The chimney located top of the furnace. When the flue gas leaves the furnace, it will enter the nanoparticle collector system through the chimney. The steps to fabricate chimney stated as follow:

i. Four plates were cut and welded together to form of the chimney.
ii. A square plate with a 3inch diameter hole from the centre is welded to the chimney.
iii. A piece of 3 inch pipe is cut and welded to the hole.
iv. A U-shaped pipe is welded to the pipe.
v. Another piece of pipe is welded to the other end of the U shaped pipe.
vi. Two 3 inch elbows is welded together and connected to the pipe.
vii. Another piece of pipe is welded to the elbow.
viii. An elbow is than welded to the free end of the pipe.
ix. The chimney was painted to avoid rust.

Figure 3.20 shows the chimney of the nanoparticle system collector. In Figure 3.21 shows the connected part between the chimney and the inlet pipe of cooling tower.

Figure 3.20: Elbow chimney

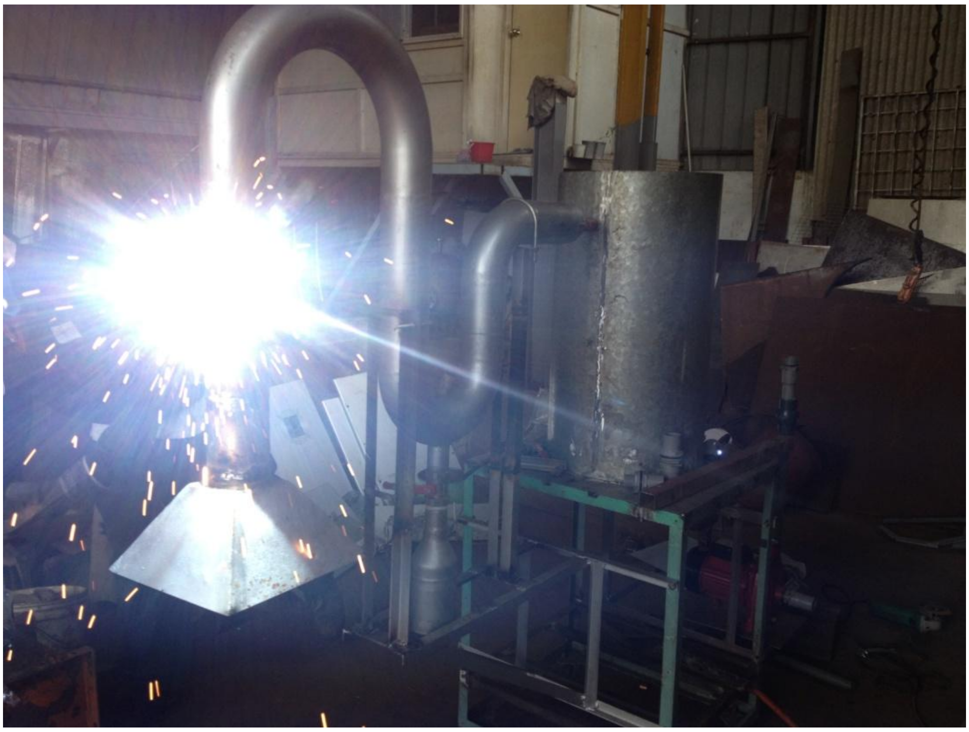


Figure 3.21: Chimney and inlet of cooling tower welded together

3.8.2 Cooling Tower

Cooling tower is used to drop the hot temperature of sprue gas. This device must be done perfectly to make sure it is efficient. The steps to make cooling tower as follow;

i. Form a cylinder from a square steel plate with height 0.75 meter and welded it.
ii. Placed a spiral copper coil inside the cylinder and welded it to make sure there is no way the sprue gas was leaked.
iii. Two L – shaped angle bars are welded inside the cylinder to support the cooling coil.
iv. The cylinder was placed in vertical to have a square shaped at the bottom of the cooling tower. The square shaped made from the L-shaped angle bar also acted as water tank.
v. This part is welded together with the chimney.

Figure 3.22 shows a spiral copper coil placed inside the cylinder while Figure 3.23 shows the water tank for the cooling tower.

Figure 3.22: A spiral copper coil placed inside the cylinder

Figure 3.23: Water tank for cooling tower

3.8.3 Cyclone

Cyclone is a place where the product of combustion would be trapped here and. The filter cloth with nano size will be placed here so that the dust will trapped. It is made from cylinder because air or dust will be spinning before being discharged on the air. The steps to build the cyclone were stated as follow:

i. Form a cylinder and welded it.
ii. A cone shaped is welded to the cylinder to make sure that all the dust to be gathered at the bottom of the cyclone.
iii. The cyclone is attached with the cooling tower by using connector elbow steel pipe.

Figure 3.24 shows the cyclone and Figure 3.25 shows the nano cloth that placed inside the cyclone.

Figure 3.24: Cyclone

Figure 3.25: Nano size cloth that placed inside the cyclone

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This section will present the experiment analysis result from the beginning until the end of the experiment. All evaluated data that being calculated then present as non-dimensionless result and graph. The comparison between the samples also stated in this chapter.

4.2 TEMPERATURE OF THE FURNACE

The temperature of the furnace is measured to see the temperature along the furnace. There are 16 points called as channel measured in this research. Every channel has different temperature behaviour due to the place of the thermocouple. Table 4.1 shows the reading taken from the furnace. Figure 4.1 until 4.16 show the temperature distribution of the furnace.

Table 4.1: Furnace temperature from channel 1 to channel 8

Time	**Temperature of channel (°C)**							
(sec)	1	2	3	4	5	6	7	8
300	846.23	960.74	643.39	780.95	994.44	1097.42	749.73	796.79
600	870.28	1049	804.57	909.94	952.39	1186.58	879.81	881.67
900	762.37	696.31	700.5	759.87	810.35	1112.48	824.26	748.05
1200	686.09	613.66	649.76	662.23	726.76	1077.69	760.62	674.24
1500	638.27	548.94	605.34	588.93	689.39	873.59	720.1	619.04

Table 4.2: Furnace temperature from channel 9 to channel 16

Time (sec)	Temperature of channel (°C)							
	9	10	11	12	13	14	15	16
300	892.93	971.06	873.14	756.63	671.73	380.08	918.16	139.06
600	898	1075.85	943.06	839.83	770.36	588.74	957.45	301.97
900	788.49	1029.14	998.51	763.19	730.56	695.34	1035.85	451.02
1200	714	897.33	905.28	715.77	682.55	701.4	932.25	551.11
1500	670.24	786.9	795.56	676.71	650.73	675.89	809.59	601.13

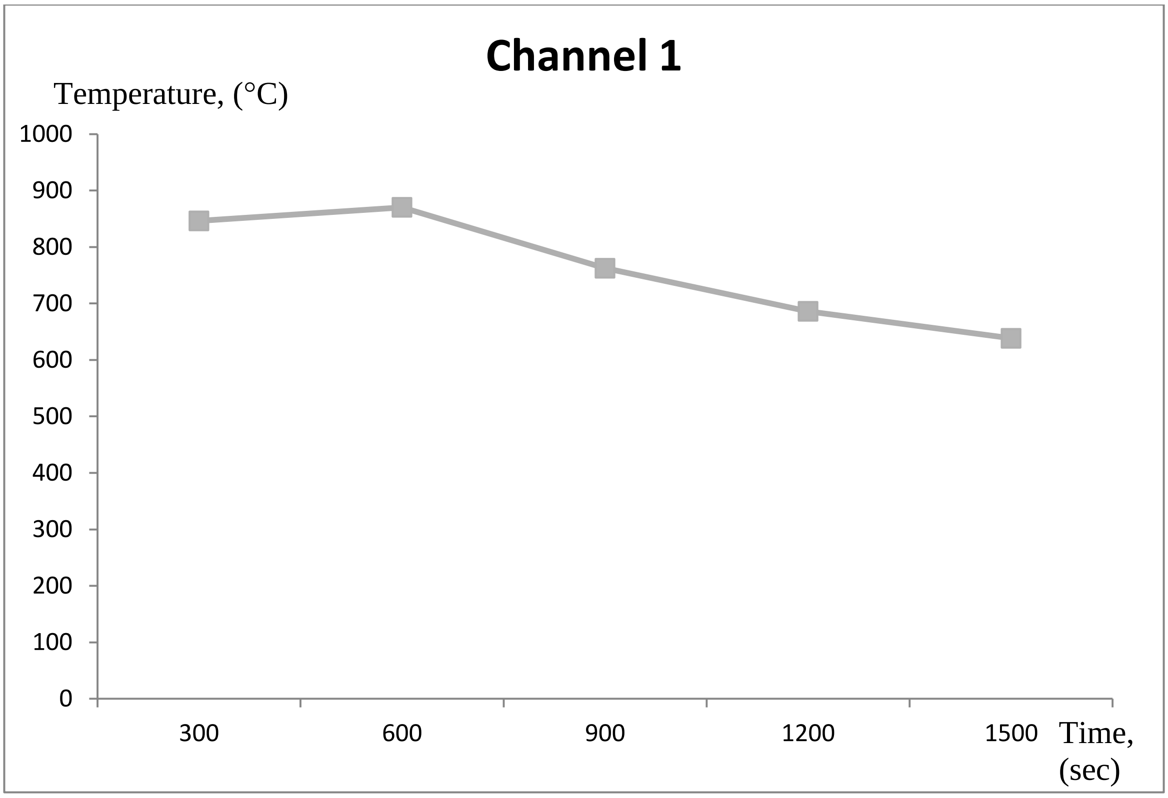


Figure 4.1: Temperature profile of channel 1

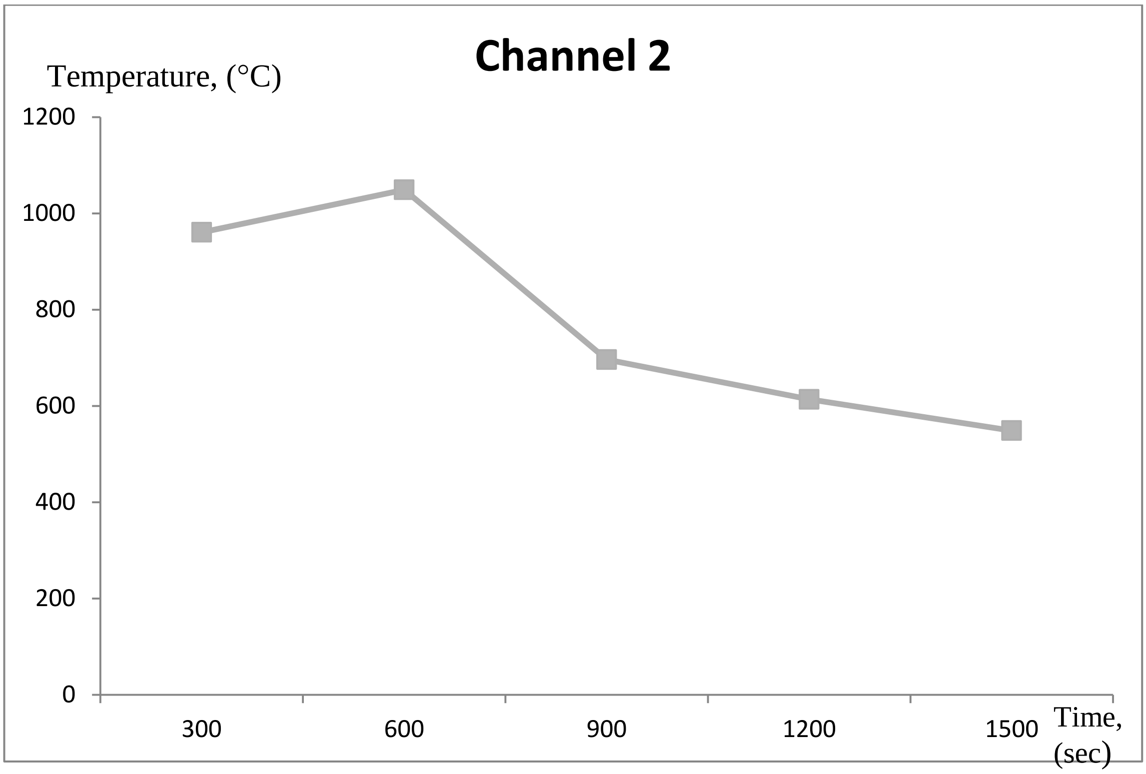


Figure 4.2: Temperature profile of channel 2

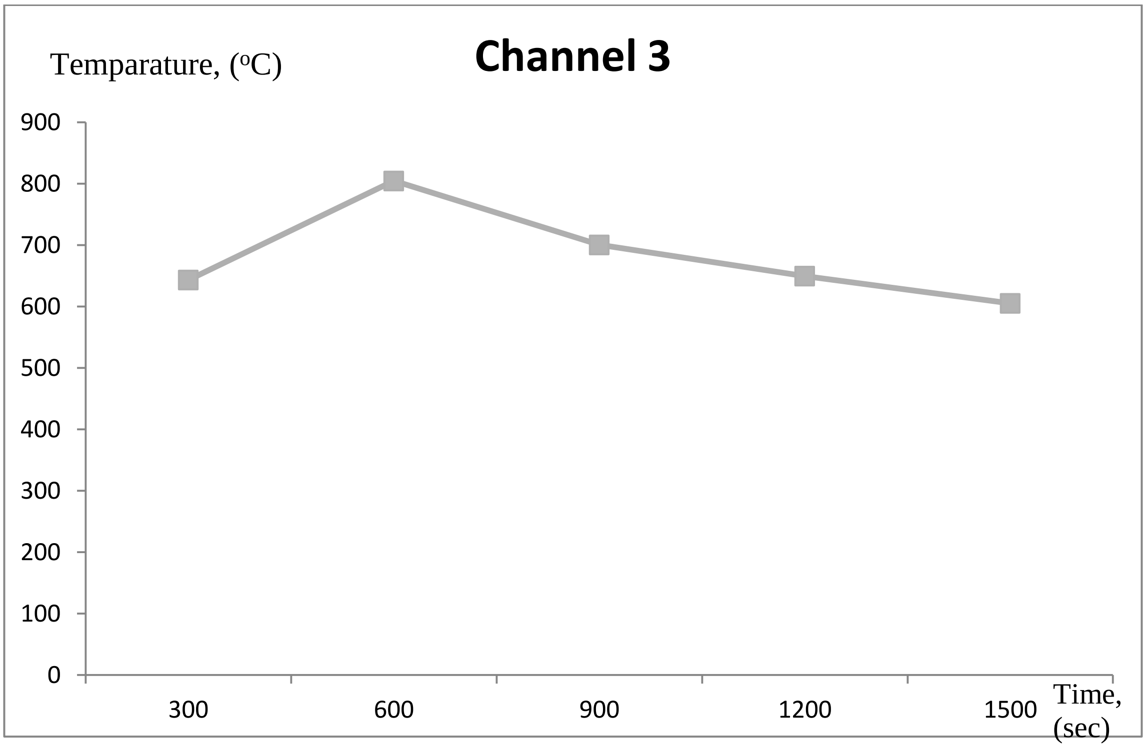


Figure 4.3: Temperature profile of channel 3

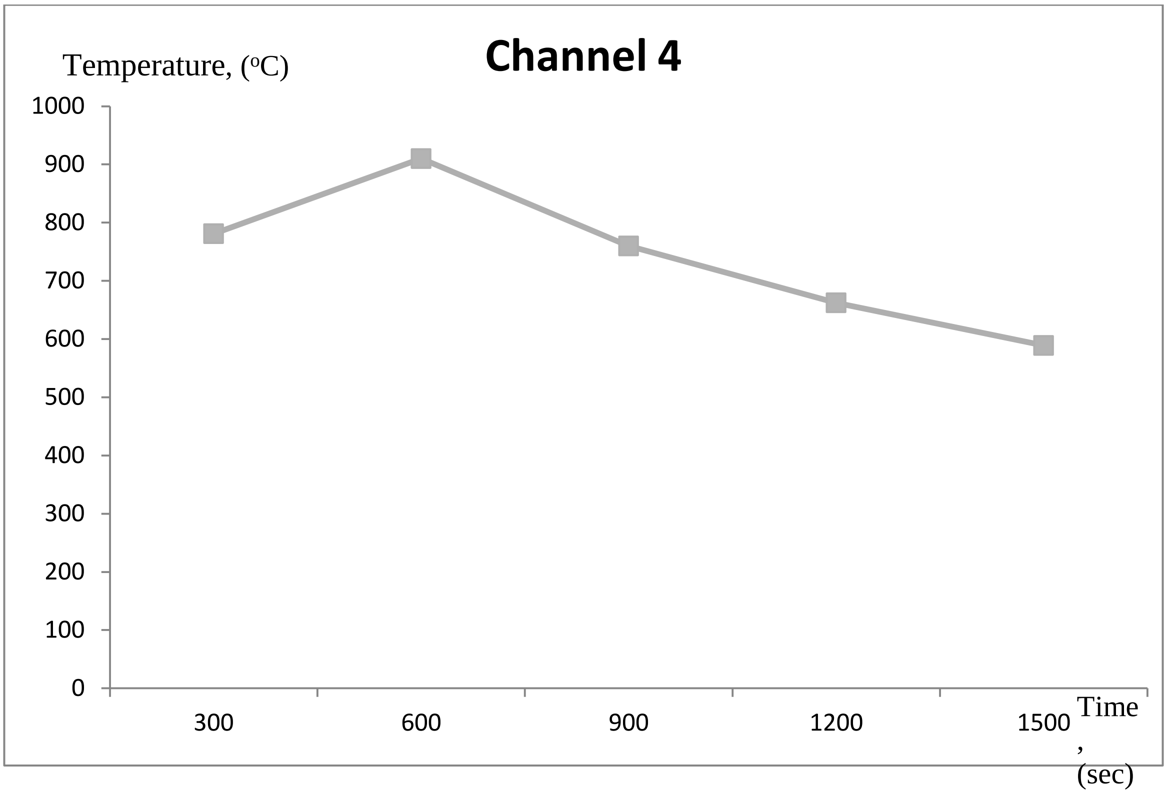


Figure 4.4: Temperature profile of channel 4

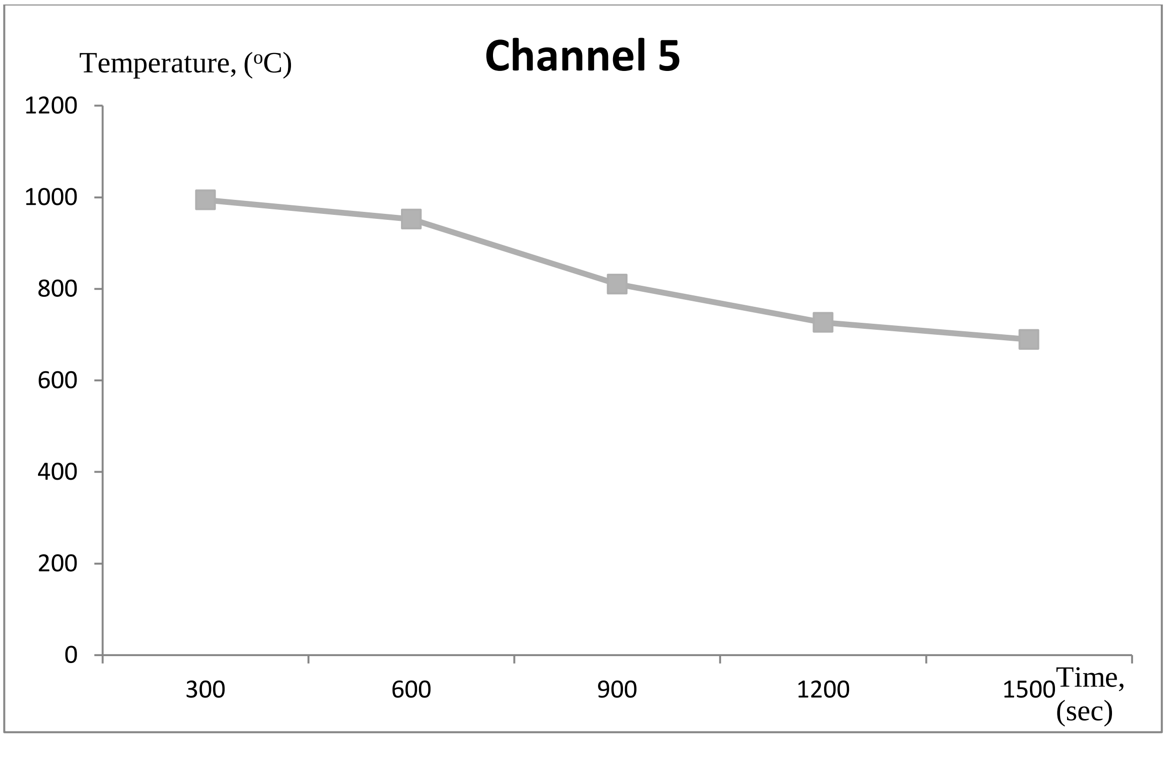


Figure 4.5: Temperature profile of channel 5

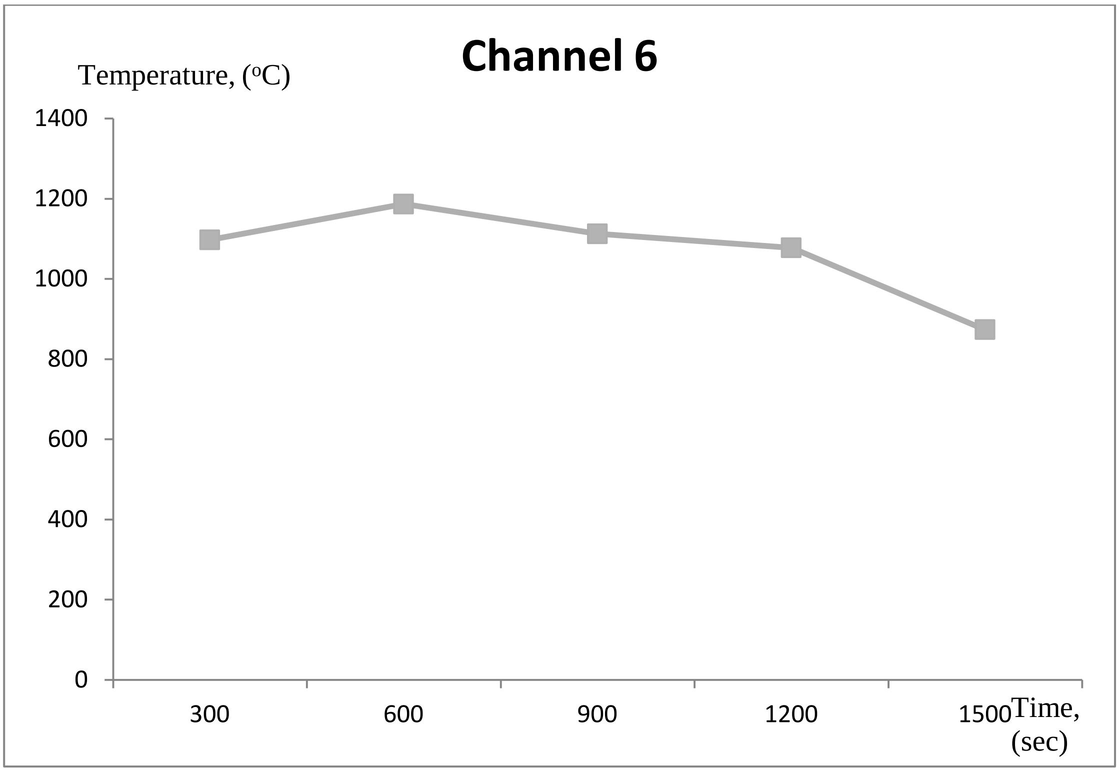


Figure 4.6: Temperature profile of channel 6

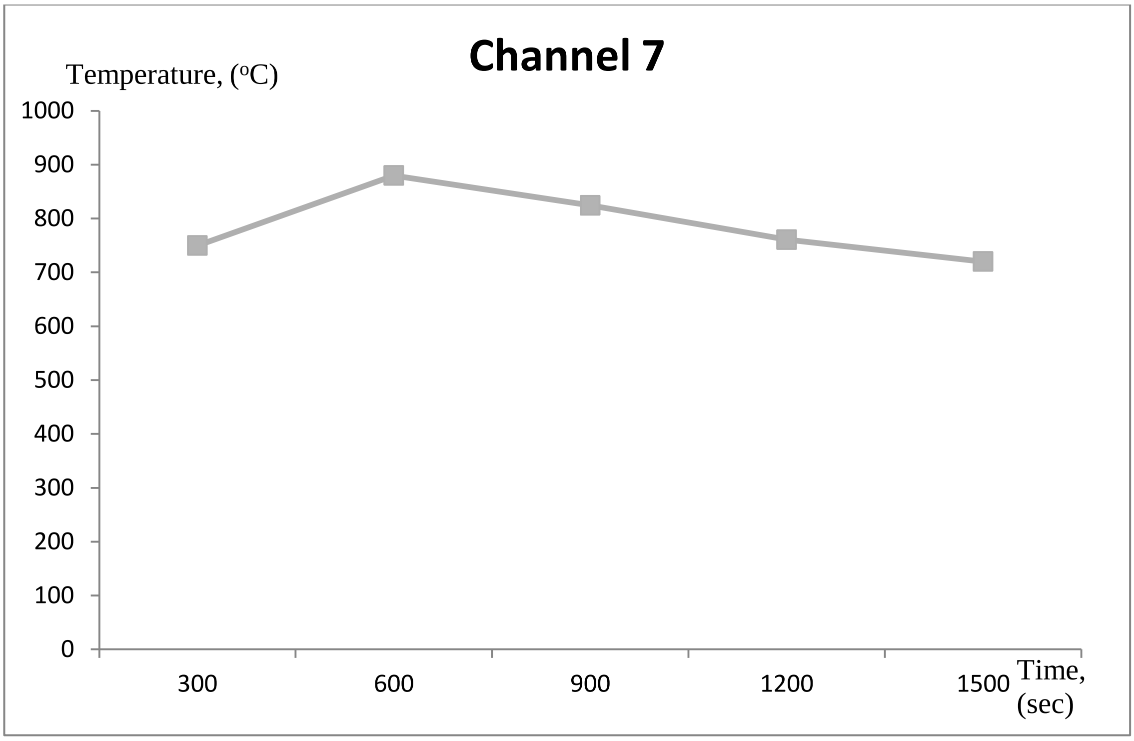


Figure 4.7: Temperature profile of channel 7

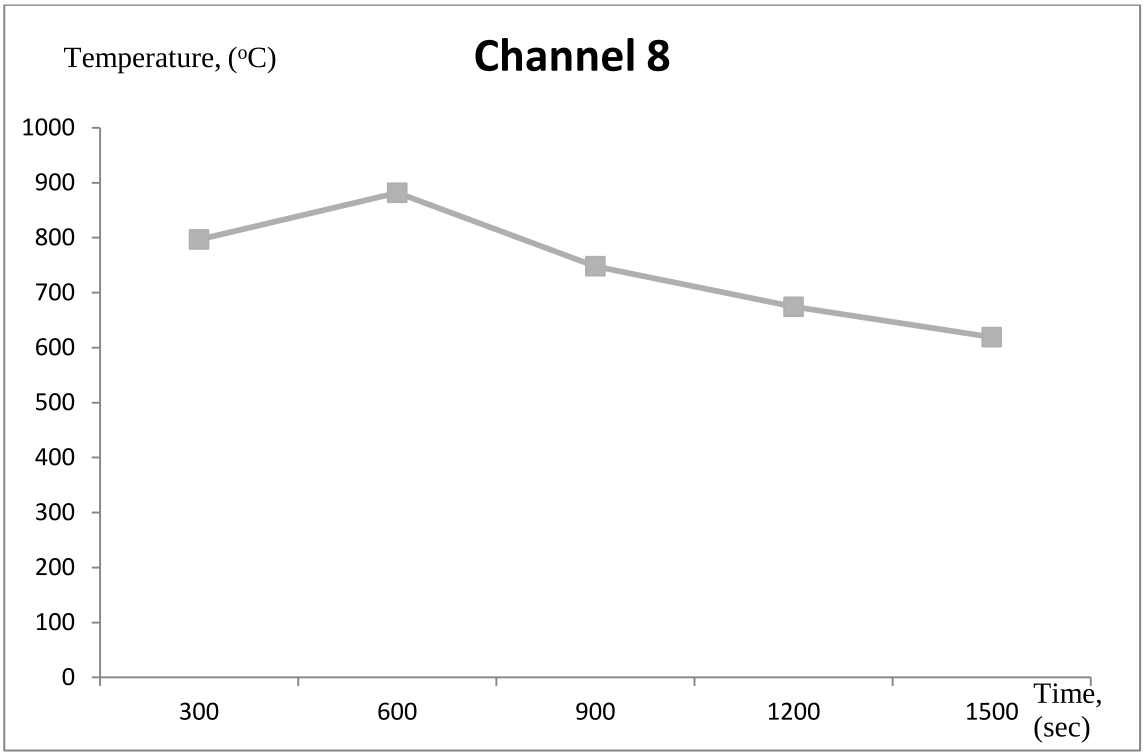


Figure 4.8: Temperature profile of channel 8

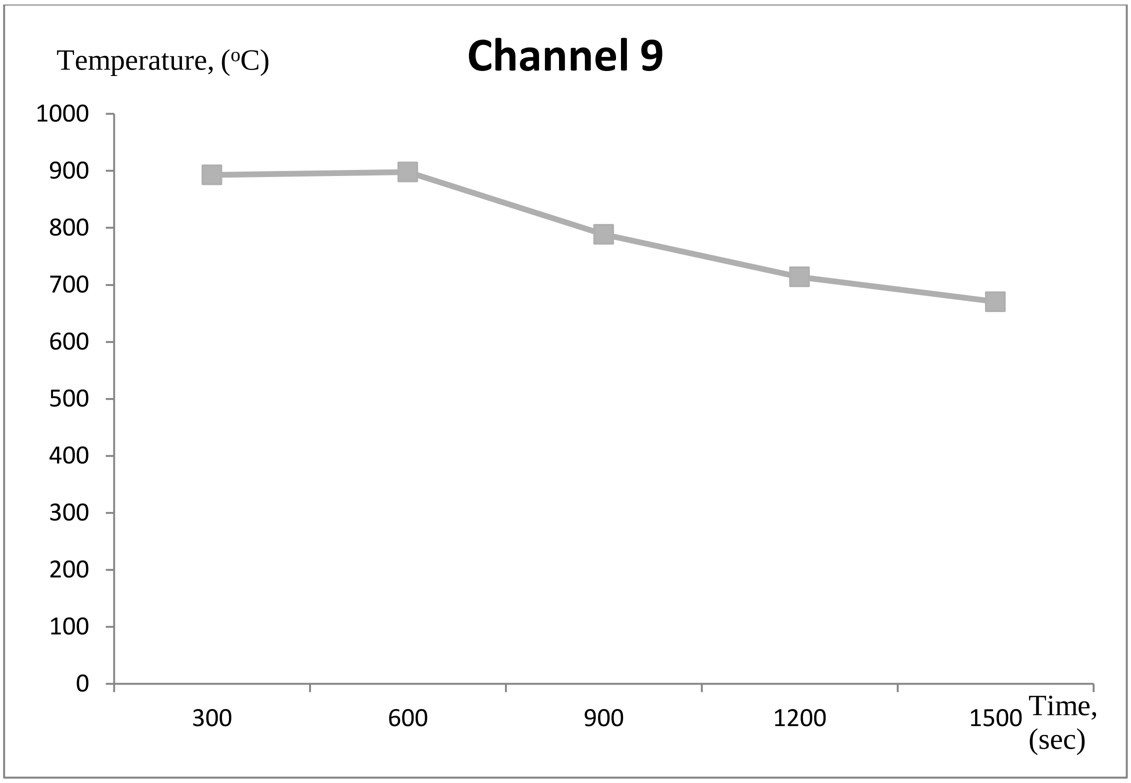


Figure 4.9: Temperature profile of channel 9

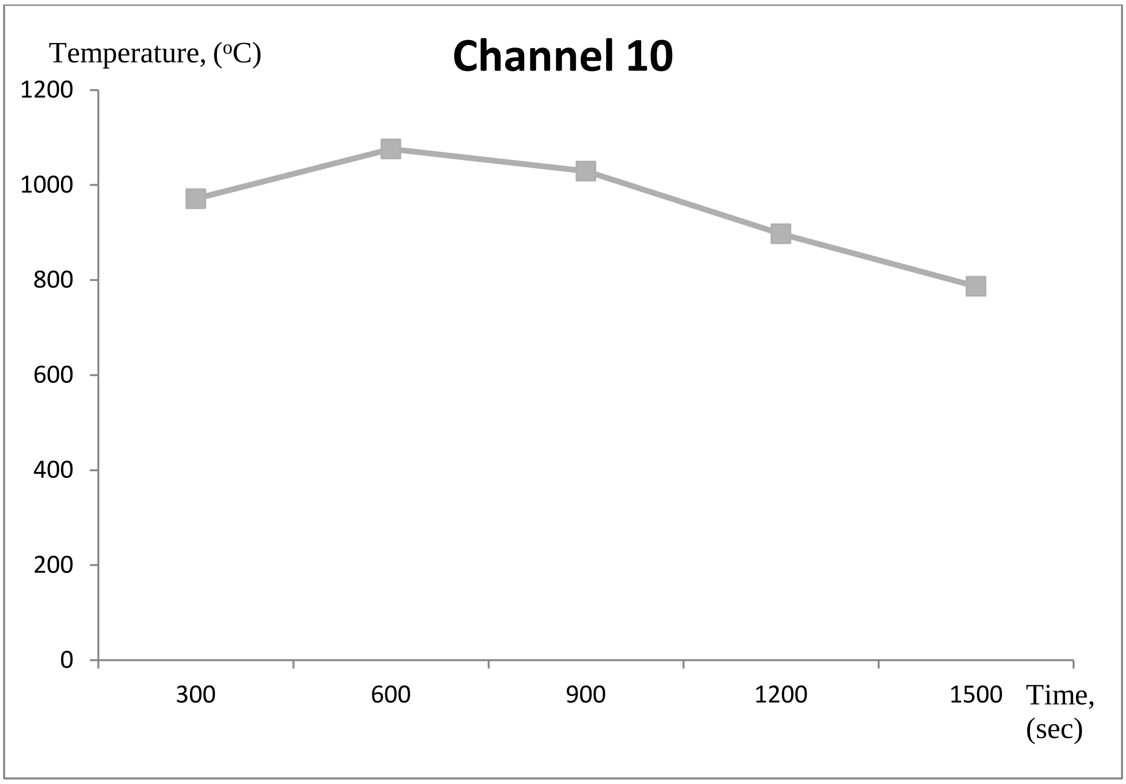


Figure 4.10: Temperature profile of channel 10

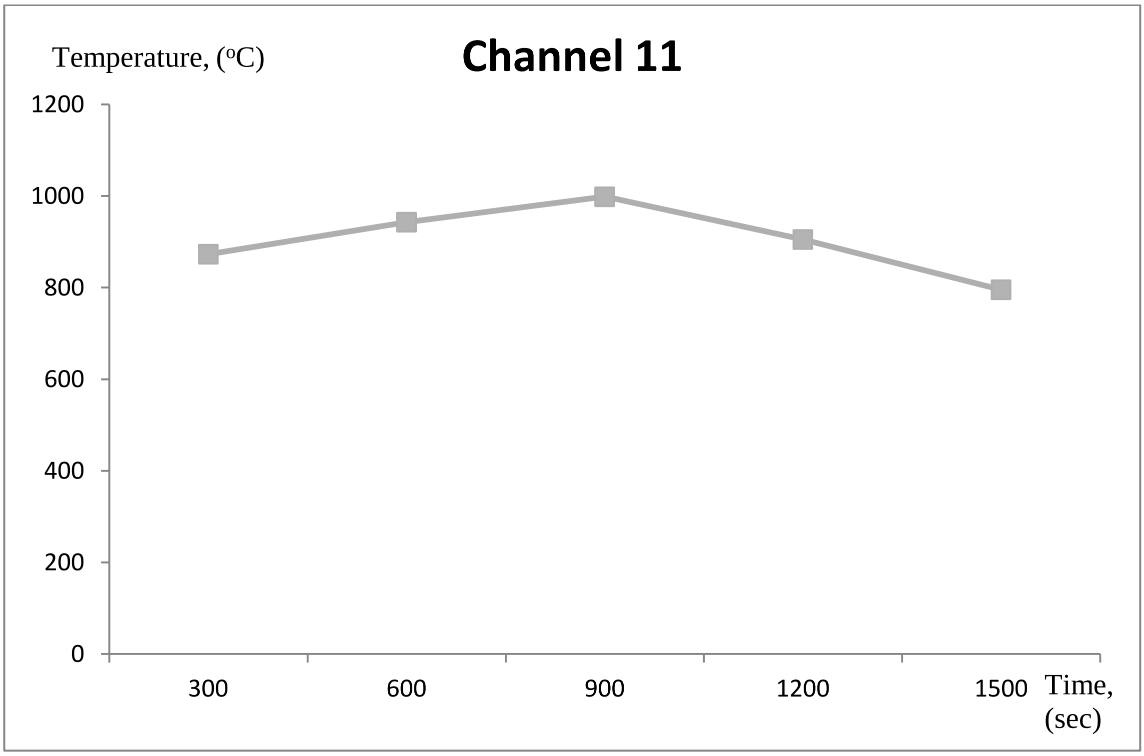


Figure 4.11: Temperature profile of channel 11

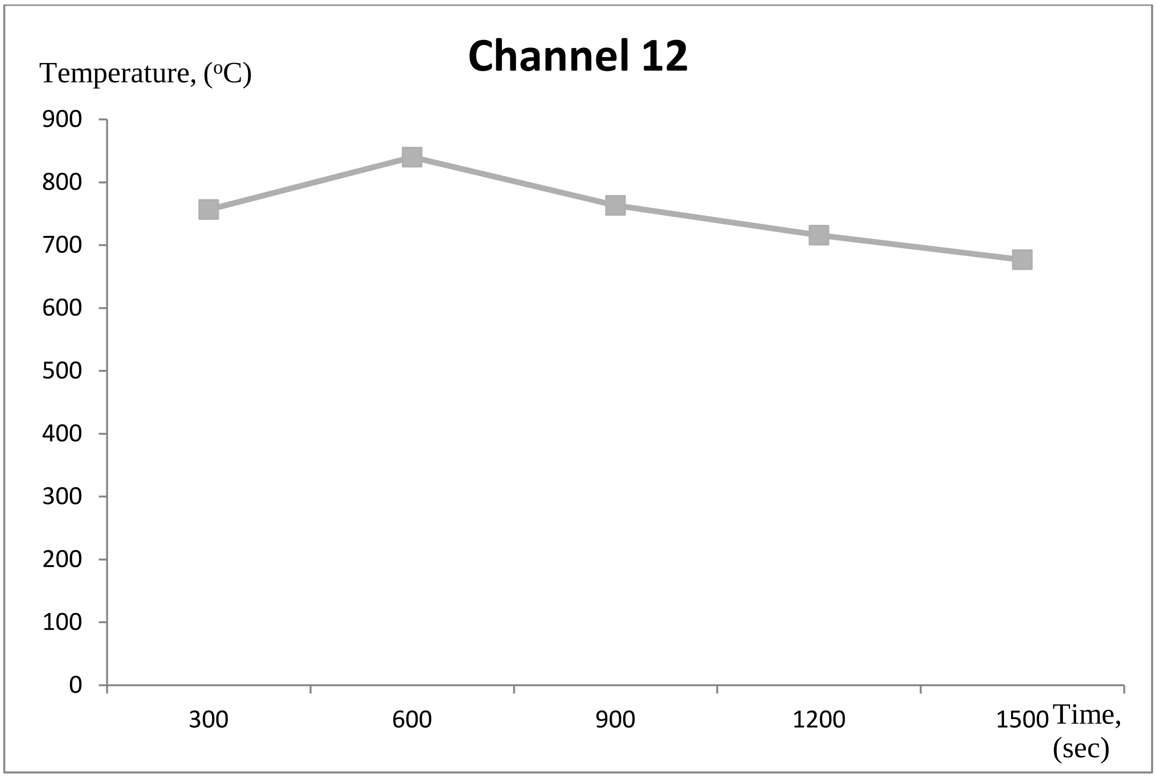


Figure 4.12: Temperature profile of channel 12

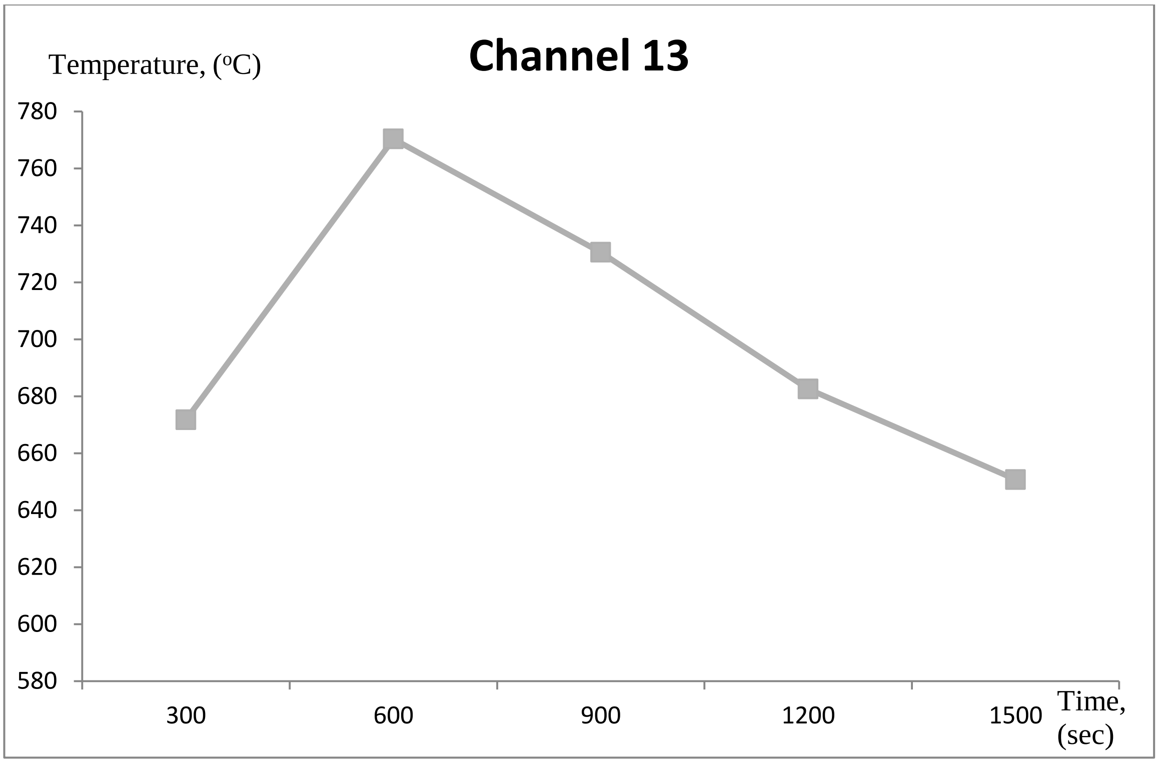


Figure 4.13: Temperature profile of channel 13

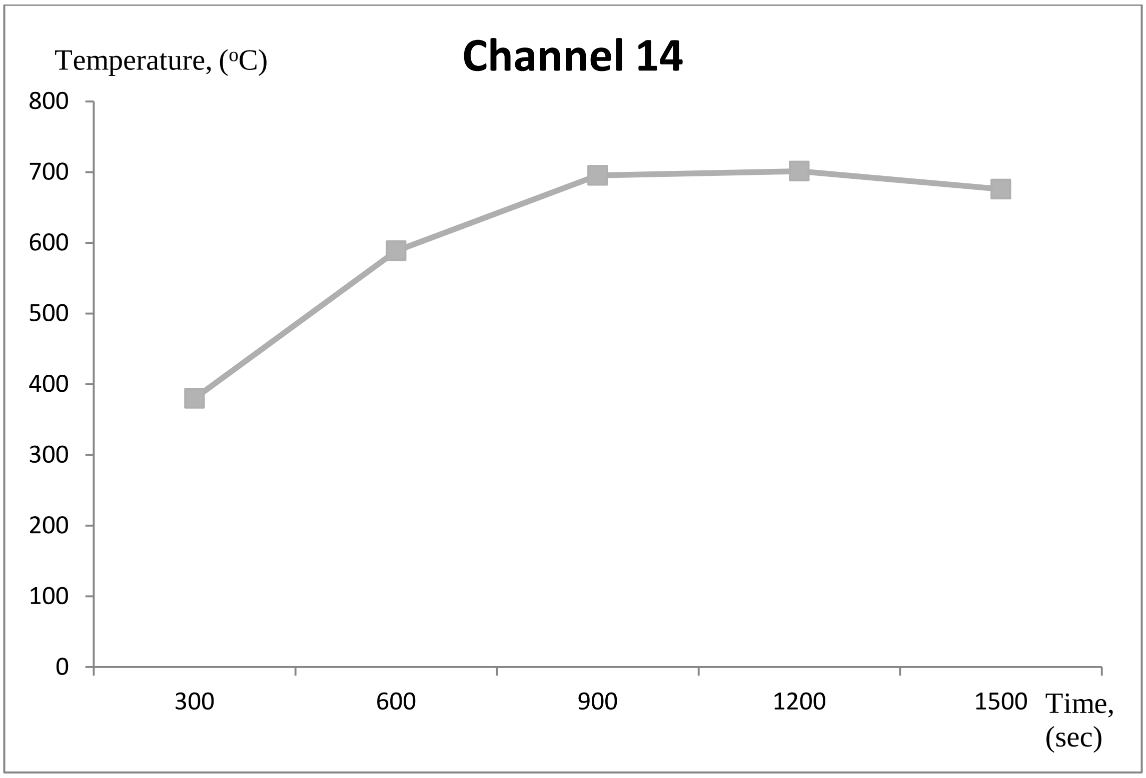


Figure 4.14: Temperature profile of channel 14

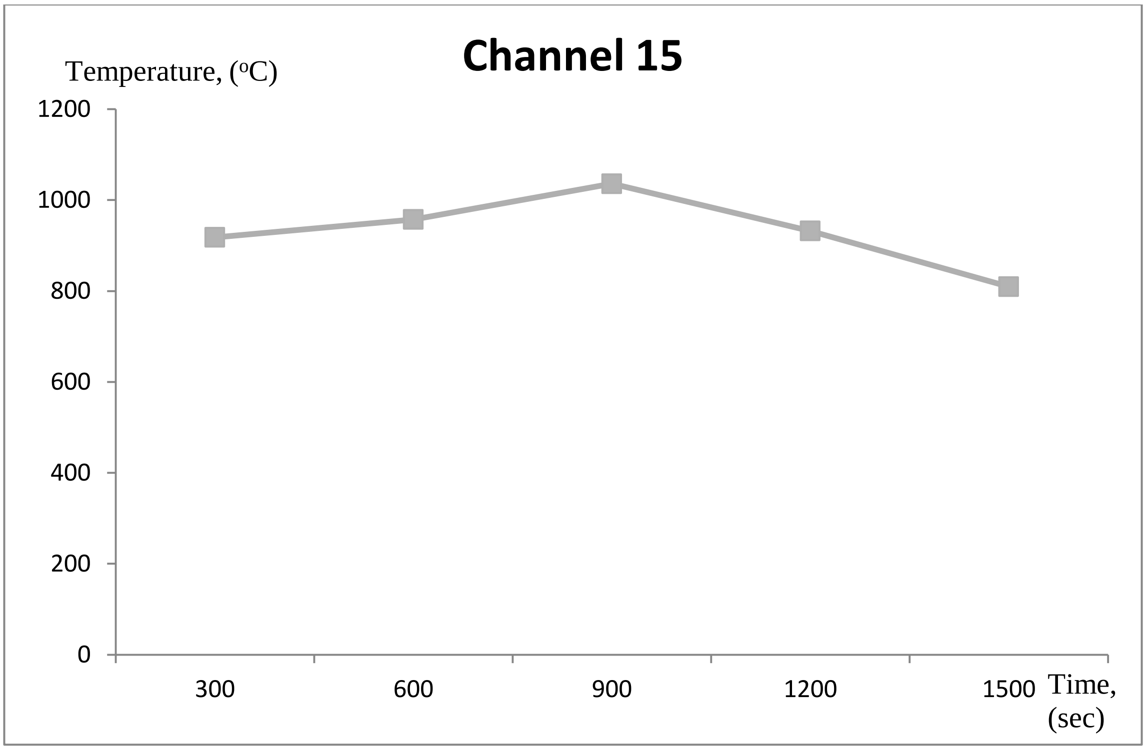


Figure 4.15: Temperature profile of channel 15

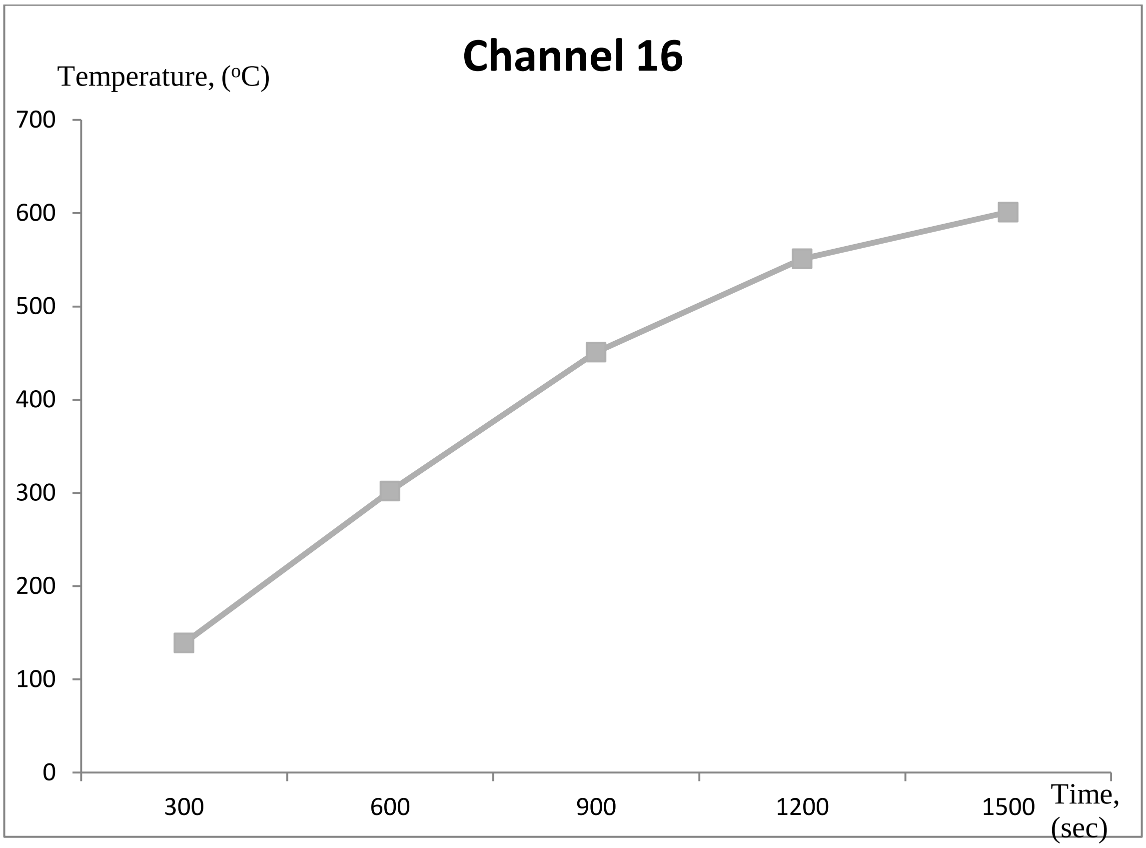


Figure 4.16: Temperature profile of channel 16

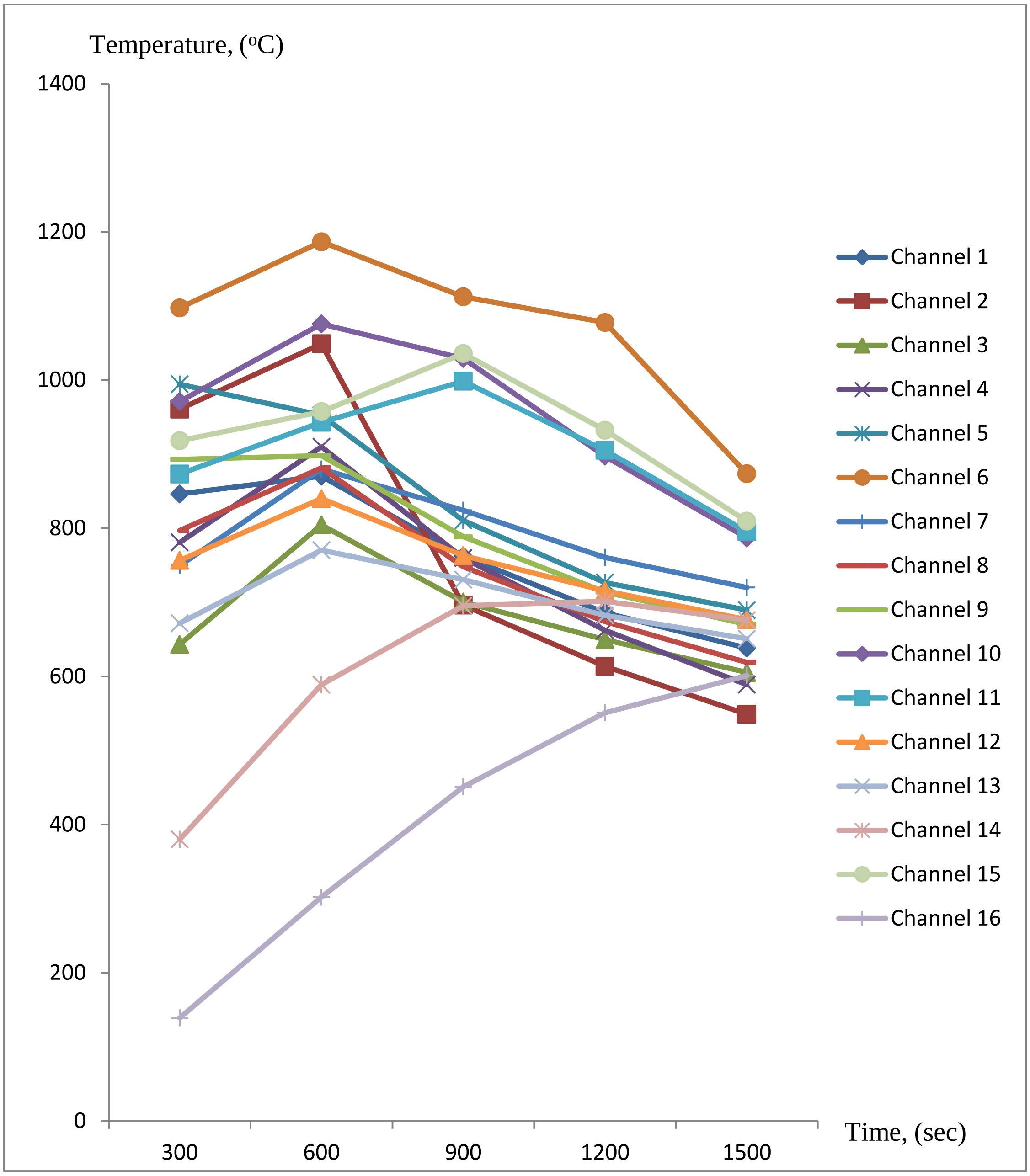


Figure 4.17: Temperature profile of the furnace

From Figure 4.1 until Figure 4.16, all the figures show the temperature profile of each channel or point along the furnace. Every channel show different temperature profile. Most of the channels are having temperature increasing from 300 until 600 second. After 600 second it is started to drop.

Figure 4.17 shows the comparison of the channel from the furnace. All the temperature is started to fall except for channel 14 and 16. This happened because the temperature after 600 seconds is going to stabilize. Channel 14 and 16 also started to stabilize after 600 seconds.

4.3 ZINC OXIDE SYNTHESIS

When the zinc is heated by using furnace, it has to wait 30 minutes until it can turn over to gaseous phase. It has to be at high temperature to make sure that the product will be in nano size. There are three samples that be taken in this research. Every sample gives different sample color and sizes that can be found in each sample.

Figure 4.18: Sample A

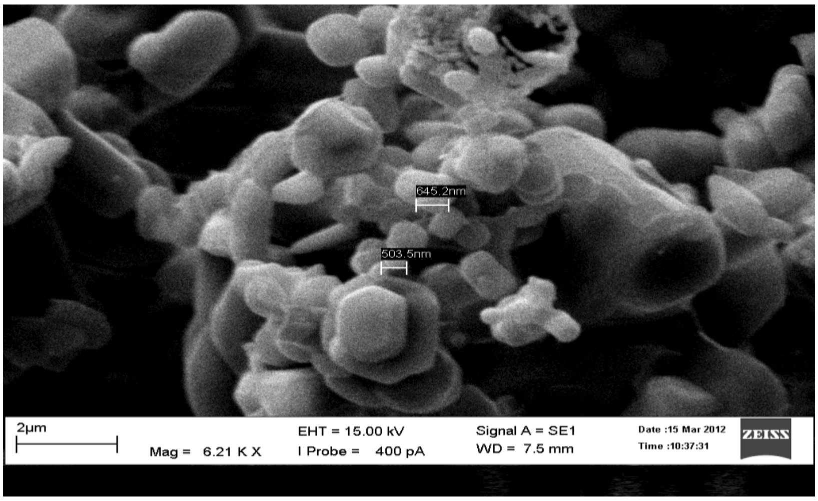


Figure 4.19: SEM image of sample A

Figure 4.18 shows sample A. The sizes that can be seen in this sample are 645 and 503.5 ηm. These sizes still cannot be noted as nanoparticle because the size is more than 100 ηm. Those sizes can be proved at figure 4.19.

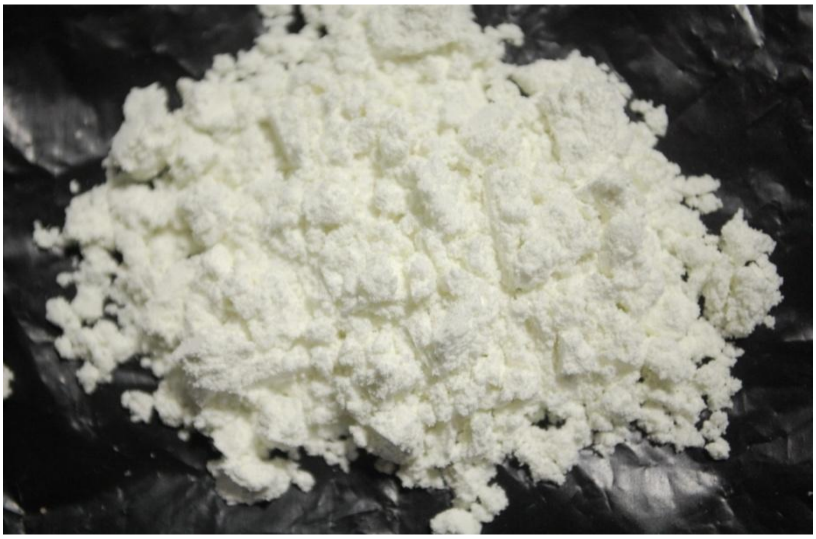


Figure 4.20: Sample B

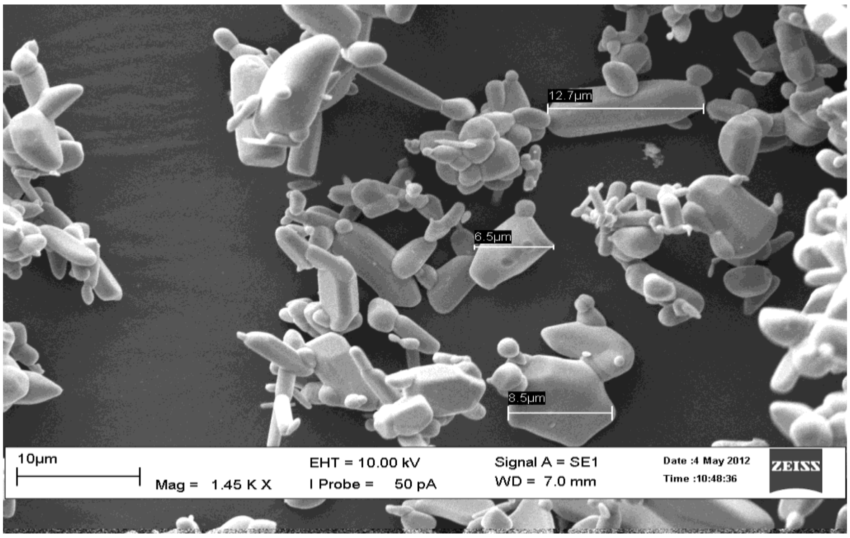


Figure 4.21: SEM image for sample B

From figure 4.21, sample B have yellowish colour. It is very different from sample A. The various sizes in sample B are different from sample A. It is smaller than the sizes in sample B which are 12.7, 6.5 and 8.5 µm.

While in sample C, the particles are smaller than sample B. The sizes that can be found in sample C are 2.1. 5.6 and 3.4 µm. but it physical color much more like sample A. Figure 4.23 shows sample C that be taken from the experimental work.

Figure 4.22: Sample C

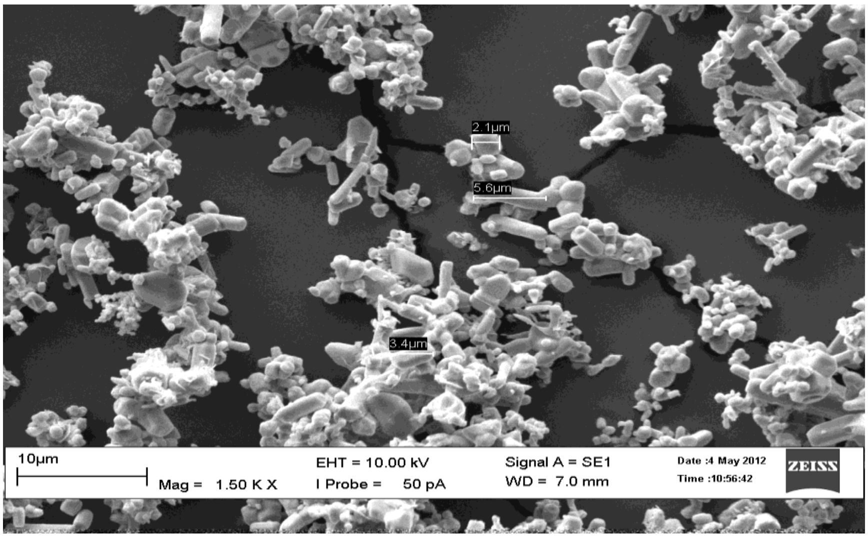


Figure 4.23: SEM image of sample C

From the result gained, all samples give different sizes. But sample A have smallest sizes compared to the sample B and C. It is because it nano size, sample A give the smallest value of nano size.

For the physical look, sample B have yellowish colour compared to the other two samples which are sample A and C. Sample B do not have black impurity. It is occurs when the product of the combustion is go through the nanoparticle collector system. The black particle might be from the coating paint from the system. Sample B is taken from inside the furnace so it not has any impurity.

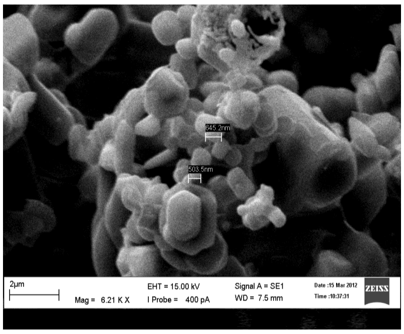
The mass flow rate of the system can be calculated as follow:

$$\dot{m} = \frac{mass\ of\ \ the\ product}{completing\ time}$$

$$\dot{m} = \frac{323.27 \times 10^{-3} kilograms}{120 \times 60\ second}$$

$$= 4.48 \times 10^{-3} \text{ kg per second}$$

Table 4.3: Summary of ZnO produced

<table>
<tr><th>Sample</th><th>Image</th><th>SEM image</th></tr>
<tr><td>Sample A</td><td></td><td>
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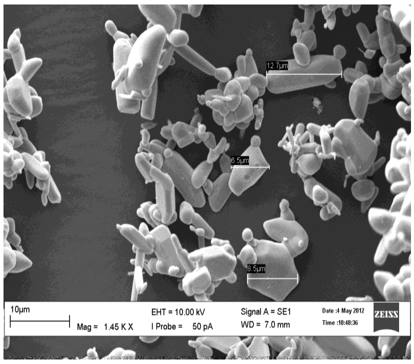
<tr><td>Sample B</td><td></td><td>
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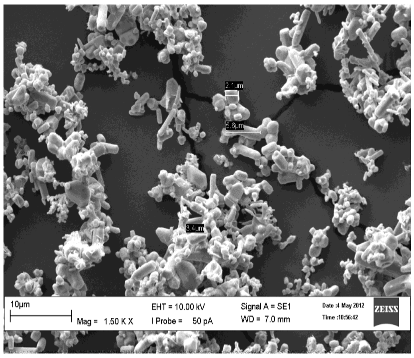
<tr><td>Sample C</td><td></td><td>
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Table 4.3 shows the all the samples taken from the experiment and it SEM image.

4.3.1 NANOPARTICLE COLLECTOR SYSTEM

The system known as nanoparticle collector system is being used in this experimental work also gives factor that can be considered to gain the result. There are some reasons this system can affected in production of ZnO.

Regarding subtopic 4.2, there are samples that contain black impurity. This black impurity can be considered produced by nanoparticle collector system. This can be sure because the sample B which is taken from inside the furnace does not have this black impurity. Besides that, there are two samples which are sample A and C were taken from this collector system. So it can be prove that this system is the reason where the black particles come from. When the coating paint is gone through high temperature combustion, it will react and turned into black. Then, it mixed with the sprue gas from the combustion and yet stops at collector tank and mix with the ZnO produced.

Moreover, the fuel that be used by this collector system is quite high. The diesel burner can transfer 15 L diesel in 45 minutes. This experimental work is conducted about two hours. It is about 40 L of diesel is used in 120 minutes of experiment.

After the experiment, there are some places of collector system were identified is being leak. The coil inside the cooling tower is leaking and most of the ZnO were released to the air. This case can be sure when the exhaust fan of the cooling tower is covered with the ZnO powder. Figure 4.25 shows the ZnO that released from the leaking part.

Figure 4.24: ZnO stuck at the exhaust fan

When this case happened, there are losses of ZnO powder. This system cannot consider it is efficient because it cannot collect all the products from the combustion. If the coil does not leak, this system can collect more ZnO.

4.3 CONCLUSION

The temperature distribution of the furnace can be assisting factor to produce nanoparticle because it help it term of high temperature combustion. All the samples taken have different sizes and physical looked.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The temperature distribution of a furnace is shown that the furnace can stand for the high temperature combustion. A furnace played a big role in assist to carry out the combustion system. It can be seen that with the high temperature which is 852 °C, it can helped to produce nanoparticle.

Furthermore, a new combustor system is proposed for industrial furnace. The new combustion system will give a new way in nanoparticle research. After all the experiments were conducted, this new combustion system gives successful in order to produce ZnO but this product is not in the nano size range.

The products of ZnO give nine several size of particle. The sizes of ZnO powder can be seen in range of 645 ηm to 12.7 μm. It can be said that this new combustion system is not gives the product in nano size. The physical looked for ZnO is same but it particle do not achieve nano size.

As the conclusion, the overall process of combustion system for industrial furnace can be concluded that the performance of combustion system is studied and it is analyzed from the result gained but the range of nano size particle is not achieved. The objectives is successfully achieved which are to study the performance of combustion system and to analyze also propose a new design of combustor system for industrial furnace.

5.2 RECOMMENDATION

In order to get more precision result during this study, recommendation and adjustment needed to be arranged especially when the combustor system has to be provided with the nano size filter to make sure the product in nano size.

Then, the product of combustor should be test to validate it properties. The sample can be used as nanocoolent to make sure it small enough to use for nanocoolent. It is also can be test to other experiment that use nanoparticle such as coating.

Furthermore, the combustor system material should be change to other material with higher heat resistance material. The combustor system cannot be tested on aluminium because aluminium has high melting temperature. If the experiment is conduct with aluminium it can affect the part of the system.

Other than that, the coating paint for the furnace and combustor system should be materials that resist high temperature. So the paint will not react when gained heat from the furnace and do not mix with the product.

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APPENDIX A

APPENDIX A

DATA SHEET OF DIESEL BURNER

Models	Output max		Output min		Flow rate max	Flow rate min	Power supply	Motor	Operation
	kW	kcal / hx1000	kW	kcal / hx1000	kg/h	kg/h	V	W	
MAX 1	41,4	35,7	17,6	15,3	3,5	1,5	230	75	P
MAX 1 Low NOx	35,5	30,6	17,6	15,3	3	1,5	230	75	P
MAX 4	59	51	20	17,34	5	1,7	230	75	PAB/PR
MAX 4 Low NOx	47,3	40,8	17,6	15,3	4	1,5	230	75	P
MAX 8	105	90,78	47	40,8	8,9	4	230	100	PAB/PR
MAX 12	130	112,2	60	52	11	5,1	230	130	P
MAX 15	190	163,8	73,4	63,24	16	6,2	230	130	ON-OFF
MAX 20	237	204	86,4	74,46	20	7,3	230	200	ON-OFF
MAX 30	319	275,4	110	94,86	27	9,3	230	200	ON-OFF
MAX P15 / P15AB HS	190	163,8	77	66,3	16	6,5	230	130	P - AB
MAX P25 / P25AB HS	300	259,08	102	87,72	25,4	8,6	230	200	P - AB

- Fuel : Light oil (L.C.V. 10.200 kcal/kg max. visc 1,5°E at 20°C)

APPENDIX A2

FEATURES OF DIESEL BURNER

Main features

<- Back to product list

- Completely sealed aluminum casing with a new modern design cover.
- New high efficiency fan ventilation system (HPV) allowing easy matching with boilers having high combustion chamber back pressure.
- Compact burner dimension with low noise levels.
- New air damper with progressive micrometric air regulation adjustable in 3 positions.
- Air damper with 60 or 80 mm snorkel adaptor (optional).
- New electrical wiring simple to disassemble for easy maintenance.
- Combustion head easy to assemble and adjust for fine set up.
- Single bolt burner fixing and the possibility to firmly secure it to the flange in three different positions for easier maintenance.
- Ease of installation with adjustable flange (optional only for TL from Max 1 to Max 12).
- Monoblock electrodes for easy and steady installation into the nozzle even after maintenance.
- Hi - Low version available with compact hydraulic system (Max AB HS).
- Low NOx version with yellow flame developed by Ecoflam.
- Max range available with "D" pump for light oil with viscosity up to 200 cTs.

Depliant download

Source; www.ecoflam-burners.com

APPENDIX B

APPENDIX B

ZINC OXIDE PROPERTIES

Approfit Zinc Oxide Mfg Sdn Bhd (223363-P)

ZINC OXIDE SPECIFICATION

CHARACTERISTIC	METHOD	INDIVIDUAL GRADES REQUIREMENTS (%)		
		RED SEAL	WHITE SEAL	PHARMA
Zinc Oxide Purity	QAM 011	99.50 min	99.70 min	99.70 min
Lead (Pb)	QAM 061	0.0500 max	0.0050 max	0.0050 max
Iron (Fe)	QAM 061	0.0100 max	0.0010 max	0.00075 max
Cadmium (Cd)	QAM 061	0.0150 max	0.0010 max	0.00075 max
Copper (Cu)	QAM 061	0.0005 max	0.0001 max	0.0001 max
Manganese (Mn)	QAM 061	0.0002 max	0.0001 max	0.0001 max
Chloride content (Cl)	QAM 031	0.0150 max	0.0075 max	0.0075 max
Mineral Acidity (H_2SO_4)	QAM 021	0.0500 max	Trace	Trace
Moisture content @ 105^{0}C	QAM 041	0.2000 max	0.1500 max	0.1500 max
Ignition Loss @ 950^{0}C (on dried sample)	QAM 051	0.5000 max	0.1400 max	0.1200 max
HCL Insoluble	QAM 101	0.0500 max	0.0050 max	Nil
Appearance	Visual	Fine white powder	Fine white powder	Superfine white powder with yellowish glow
Fineness thru 325 Mesh	QAM 071	99.90 min	99.90 min	99.90 min
Surface Area (B.E.T)	QAM 111	4-6 m^2/g	4-6 m^2/g	5-8 m^2/g
Standard Packaging	Polywoven bag with inner liner (25kg per bag; 40 bags per pallet)			
Customers special requirements	We also cater for specialized Customer requirements. Kindly contact us with your requirements.			

Rev: E

Eff: 25.10.2002

APPENDIX C

APPENDIX C

PROPERTIES OF FUEL

Properties of Fuels (a)

Property	Gasoline	No.2 Diesel Fuel	Methanol	Ethanol	MTBE	Propane	Compressed Natural Gas	Hydrogen	Biodiesel
Chemical Formula	C4 to C12	C8 to C25	CH3OH	C2H5OH	(CH3)3COCH3	C3H8	CH4 (83-99%), C2H6 (1-13%)	H2	C12-C22 FAME
Molecular Weight	100–105	~200	32.04	46.07	88.15	44.1	16.04	2.02	~292(g)
Composition, Weight %									
>Carbon	85–88(b)	87(g)	37.5	52.2	68.1	82	75	0	77(g)
>Hydrogen	12–15(b)	13(g)	12.6	13.1	13.7	18	25	100	12(g)
>Oxygen	0	0(g)	49.9	34.7	18.2	–	–	0	11(g)
Specific gravity, 60° F/60° F	0.72–0.78(b)	0.85(g)	0.796(h)	0.794(h)	0.744(k)	0.508(m)	0.424	0.07(o)	0.88(g)
Density, lb/gal @ 60° F	6.0–6.5(b)	7.079(g)	6.63(b)	6.61(b)	6.19(k)	4.22	1.07(n)	–	7.328(g)
Boiling temperature, °F	80–437(b)	356-644(g)	149(h)	172(h)	131(h)	-44(m)	-263.2 to -126.4(m)	-423(m)	599-662(g)
Reid vapor pressure (100° F), psi	8–15(c)	<0.2	4.6(i)	2.3(i)	7.8(l)	208	2400	–	<0.04(r)
Heating value (2)									
>Lower (Btu/gal) (d)	116,090	128,450	57,250	76,330	93,540	84,250	–	–	119,550
>Lower (Btu/lb) (d)	18,676	18,394	8,637	11,585	15,091	19,900	20,263	52,217	16,131
>Higher (Btu/gal) (d)	124,340	137,380	65,200	84,530	101,130	91,420	–	–	127,960
>Higher (Btu/lb) (d)	20,004	19,673	9,837	12,830	16,316	21,594	22,449	59,806	17,266
Octane no.(1)									
>Research octane no.	88–98(c)	–	–	–	–	112	–	130+	–
>Motor octane no.	80–88(c)	–	–	–	–	97	–	–	–
Cetane no.(1)	–	40-55(g)	–	0-54(f)	–	–	–	–	48-65(g)
Freezing point, °F	-40(e)	-40–30(4)	-143.5	-173.2	-164(h)	-305.8(m)	-296	-435(p)	26-66(g)(7)
Viscosity, mm²/s									
>@104 °F	–	1.3-4.1(g)	–	–	–	–	–	–	4.0-6.0(g)
>@68 °F	0.5-0.6(f)	2.8-5.0(f)	0.74(f)	1.50(f)	0.47(f)	–	–	–	–
>@-4 °F	0.8-1.0(f)	9.0-24.0(f)	1.345(f)	3.435(f)	0.77(f)	–	–	–	–
Flash point, closed cup, °F	-45(b)	140-176(g)	52(i)	55(i)	-14(c)	-156(m)	-300	–	212-338(g)
Autoignition temperature, °F	495(b)	~600	867(b)	793(b)	815	842(m)	900-1170(m)	932(m)	–
Water solubility, @ 70° F									–
>Fuel in water, volume %	Negligible	Negligible	100(h)	100(h)	4.8(f)	–	–	–	–
>Water in fuel, volume %	Negligible	Negligible	100(h)	100(h)	1.5(f)	–	–	–	–
Flammability limits, volume%									
>Lower	1.4(b)	1.0	7.3(i)	4.3(i)	1.6(c,e)	2.2	5.3	4.1(o)	–
>Higher	7.6(b)	6.0	36.0(i)	19.0(i)	8.4(c,e)	9.5	15	74(o)	–
Latent heat of vaporization									
>Btu/gal @ 60° F	~900(b)	~710	3,340(b)	2,378(b)	863(5)	775	–	–	–
>Btu/lb @ 60° F	~150	~100	506(b)	396(b)	138(5)	193.1	219	192.1(p)	–
Specific heat, Btu/lb °F	0.48(e)	0.43	0.60(j)	0.57(j)	0.50(j)	–	–	–	
Stoichiometric air/fuel, weight	14.7	14.7	6.45	9.00	11.7	15.7	17.2	34.3(o)	13.8(g)
Volume % fuel in vaporized stoichiometric mixture	2.0 (b)	–	12.3(b)	6.5(b)	2.7(l)	–	–	–	–

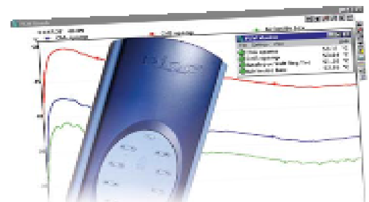
APPENDIX D

APPENDIX D

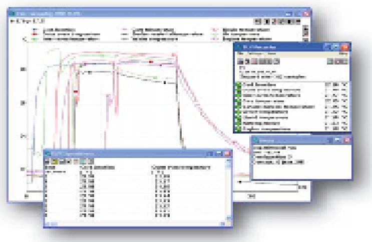
SPECIFICATION OF THERMOCOUPLES

TC-08 THERMOCOUPLE DATA LOGGER

The TC-08 thermocouple data logger offers industry-leading performance and a cost-effective temperature measurement solution. With 8 direct thermocouple inputs, the TC-08 can take accurate, rapid readings. In addition, up to 20 units can be used simultaneously on one PC. The logger can measure and record temperatures ranging from −270°C to +1820°C using the appropriate thermocouple type (B,E,J,K,N,R,S,T). It draws power from the USB port, so no external power supply is needed.



PicoLog



In addition to the monitor view, PicoLog can also display a graph, a spreadsheet and user notes. It can display them all at once, as shown here, or individually in any combination.

PicoLog is a powerful but flexible data acquisition program designed for collecting, analyzing and displaying data over long or short periods of time. Data can be viewed both during and after data collection in spreadsheet or graphical format. If required, the data can also be easily exported to other applications.

SOFTWARE DRIVERS

For users who wish to write their own software or use our products with third party software, we provide, free of charge, a range of software drivers and examples. Drivers are included for Windows XP (SP2), Vista and Windows 7 (32 and 64 bit). Programming examples are supplied for C, Delphi and Visual Basic, LabVIEW, Agilent VEE 6.1 and Excel.

THERMOCOUPLES

Pico Technology offers both off the shelf and built to order thermocouples for use with our data logging products. The TC-08 is compatible with all popular thermocouples offering high accuracy without compromising acquisition speed. Thermocouple types and temperature ranges are shown in the table below.

Type	Overall Range °C	0.1°C Resolution	0.025°C Resolution
B	20 to 1820	150 to 1820	600 to 1820
E	-270 to 910	-270 to 910	-260 to 910
J	-210 to 1200	-210 to 1200	-210 to 1200
K	-270 to 1370	-270 to 1370	-250 to 1370
N	-270 to 1300	-260 to 1300	-230 to 1300
R	-50 to 1760	-50 to 1760	20 to 1760
S	-50 to 1760	-50 to 1760	20 to 1760
T	-270 to 400	-270 to 400	-250 to 400

TC-08 SPECIFICATIONS

Number of channels	8
Temperature accuracy	The sum of ±0.2% and ±0.5% C
Voltage accuracy	The sum of ±0.2% and ±10 μV
Overload protection	±30 V
Voltage input	±70 mV
Reading rate	Up to 10 per second
Input connectors	Miniature thermocouple
PC connection	USB
Dimensions	201 x 104 x 34 mm

ORDER CODES and PRICES

ORDER CODE	DESCRIPTION	£	$*	€*
PP222	TC-08	249	411	302
PP624	Terminal Board	18	30	22

* US dollar and euro prices are subject to exchange rate variations. For latest prices see our website or contact us at the address below.

The PP624 is an optional terminal board for the TC-08. The screw terminals allow wires to be attached to the data logger without soldering and enable the TC-08 to measure voltages from 0 to +5 V, or 4-20 mA loop current.

Pico Technology James House Colmworth Business Park Eaton Socon St Neots PE19 8YP
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www.picotech.com

APPENDIX E

APPENDIX E

SPECIFICATION OF INFRARED THERMOMETER

- Max, Min and Diff. Avg. temperature displays
- Fahrenheit/Celsius selectable
- High and low alarm setpoints
- Built-in laser pointer
- Large LCD with backlight and display hold
- Includes battery and carrying case

Specifications:

Temperature Range: -58.0 to 1832°F (-50.0 to 1000°C)

Resolution: 0.1° up to 200°; 1° over 200°

Accuracy: ±2% of reading

Optical Resolution: 50:1

Emissivity: Adjustable, 0.10 to 1.0

Response Time: < 1 second

Power Supply: Single 9V battery

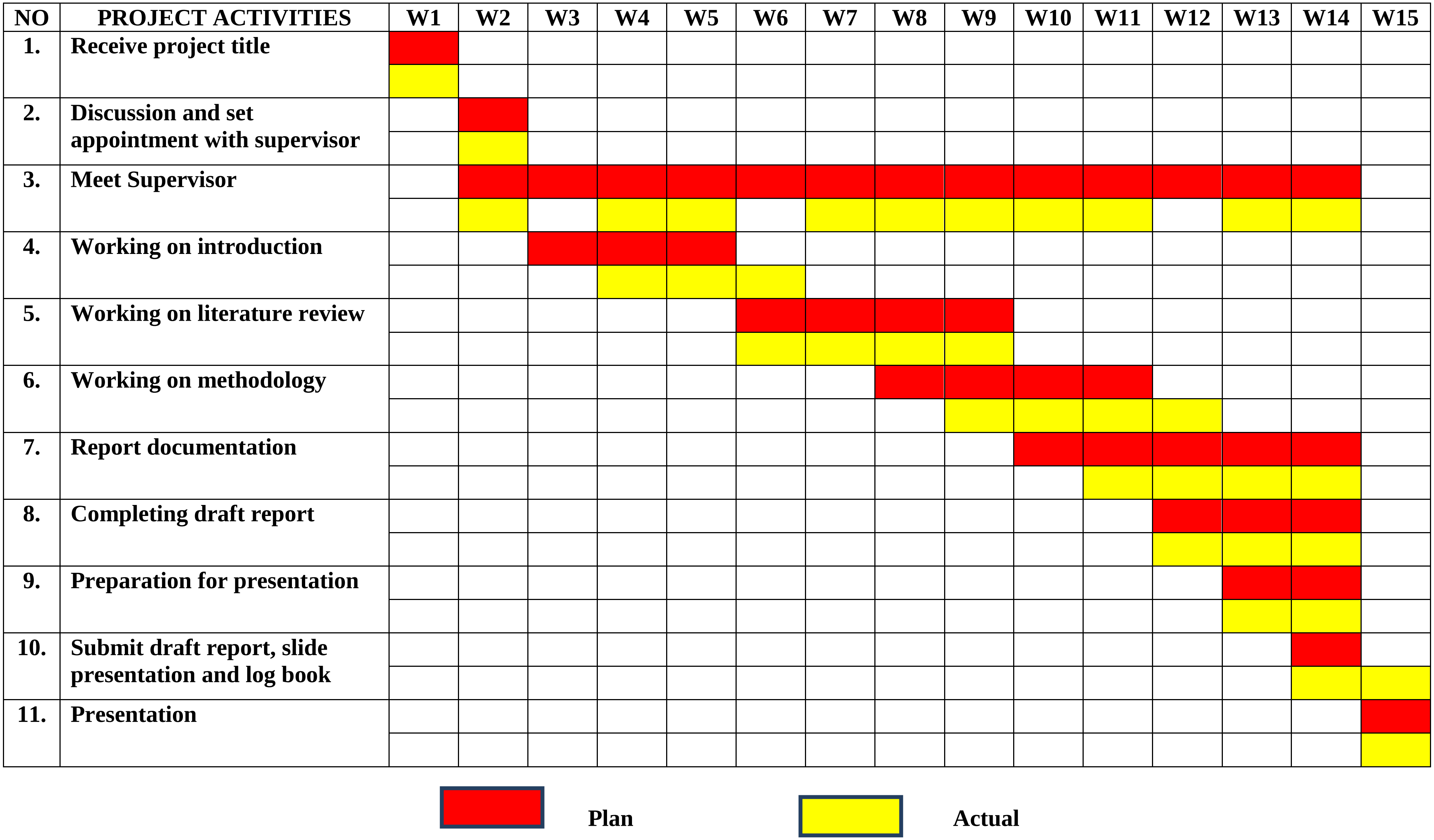
Dimensions: 9 x 3.9 x 2.2" (230 x 100 x 56mm)

Weight: 10.2 oz (290g)

APPENDIX F

APPENDIX F1

PSM 1 GANTT CHART



APPENDIX F2

PSM 2GANTT CHART

NO	PROJECT ACTIVITIES	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18
1.	Discussion and set appointment with supervisor																		
2.	Meet Supervisor																		
3.	Working on experiments																		
4.	Preparation for presentation																		
5.	Presentation																		
6.	Report writing																		
7.	Submit report 1																		
8.	Submit report 2																		
9.	Submit report																		

Plan **Actual**