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Faculty of Engineering

DESIGN AND DEVELOPMENT OF AN ELECTRIC METAL MELTING FURNACE USING AUTOMATION

Submitted by

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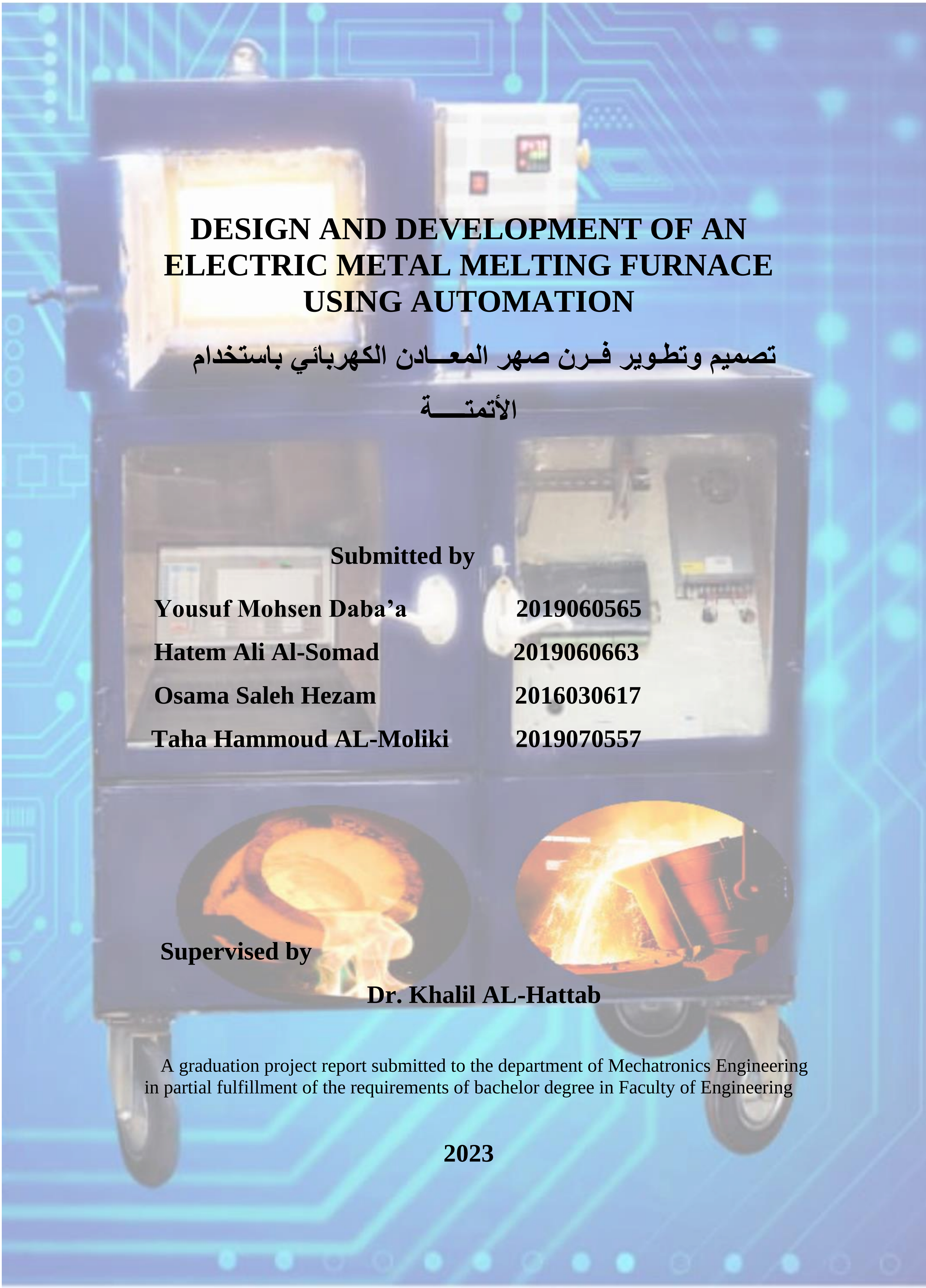
Supervised by

Dr. Khalil AL-Hattab

A graduation project report submitted to the department of Mechatronics Engineering in partial fulfillment of the requirements of bachelor degree in Faculty of Engineering

2023



DESIGN AND DEVELOPMENT OF AN ELECTRIC METAL MELTING FURNACE USING AUTOMATION

تصميم وتطـوير فـرن صهر المعـــادن الكهربائي باستخدام الأتمتـــــة

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Dedication

We dedicate this project to our dear families and friends, who have been a strong supporter and source of motivation for us throughout the preparation of this project. We could not have achieved this achievement without their continuous support and encouragement, which gave us the confidence and strength to continue working.

We would also like to express our deep gratitude to our wonderful supervisor, Dr. **Khalil AL-Hattab** who provided us with guidance and advice throughout the preparation of this project. Thanks to his experience and interest, we were able to direct the project in the right direction and overcome the challenges we faced.

We also thank all the doctors **Dr. Radwan AL-Buthaji & Dr. Farouk AL-Fahidi & Dr. Mohammed AL-Alofi** who participated in the discussion and fruitful discussions during the project discussion period. Your experiences and ideas were invaluable and contributed to developing our idea and improving the project results.

Finally, we would like to express our gratitude to the university that provided us with the opportunity to conduct this project and its financial support. It gave us the opportunity to learn, develop, and gain the skills needed to succeed in my career.

Thank you to all the people who contributed to the completion of this project and supported us on various levels. We cannot appreciate how much you have given us, but we promise to consider this achievement as a starting point for a bright future and that we will continue to work hard and with commitment to achieve our goals

Acknowledgment

Before and above all, we would like to record our endless thanks to **Allah** for everything he gives us.

We wish to express our deepest gratitude and appreciation to **Dr Khalil AL-Hattab** for excellent guidance, kind encouragement, scientific advice, helpful supervision and good wishes instilled the strength in us to make this work possible.

Last but not least, we owe a great deal of gratitude, thanks and appreciation to all members of our families, for their kind support, help and encouragement.

Supervisor Certification

I certify that the preparation of this project entitled DESIGN AND DEVELOPMENT OF AN ELECTRIC METAL MELTING FURNACE USING AUTOMATION,

prepared by 1-Yousuf Mohsen Daba'a

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3-Osama Saleh Hezam

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was mad under my supervision at Mechatronics department in partial fulfillment of the requirements of bachelor degree in Faculty of Engineering.

The Supervisor: Dr. Khalil AL-Hattab

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Examiner Committee

Project Title: Design and Development of use the Automation The electric Metal Melting Furnace

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3	Dr. Mohammed AL-Alofi	Department Head of Medical Equipment	

Department Head

Dr. Radwan AL-Buthaji

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List of Abbreviations

Acronym	Definition
PID	Proportional-Integral-Derivative
SV	Setting Value
PV	Practical Value
PLC	Programmable Logic Controller
Comp	Coordinated MultiPoint Transmission
ALSRB	Aluminosilicate refractory bricks
SCADA	Supervisory Control and Data Acquisition

Mathematical Notation

Parameter	Description
$E_{(l)}^{(i)}$	Available energy in relay *l* at the end of frame *I*.
$E_{(l)}^{(i,max)}$	Maximum energy relay *l* can store.
$E_{(l)}^{(i-1)}$	Available energy in relay *l* at the beginning of frame *I*.

Chapter 1

Introduction

Chapter 1: Introduction

1.1 Overview

The graduation project aims to design and develop an automated electric metal smelting furnace. The project focuses on incorporating advanced automation technologies into the traditional process of metal smelting, resulting in improved efficiency, precision, and control.

The automated electric metal smelting furnace utilizes electric arc technology, which has proven to be effective in melting various metals. However, the project goes beyond the conventional electric smelting furnace by integrating automation features to streamline the entire smelting process.

The main objectives of the project are as follows:

1. Design and Construction: The project involves designing a robust and efficient electric smelting furnace that meets the specific requirements of metal smelting. The furnace will be constructed using high-quality materials and components to ensure durability and longevity.

2. Automation System: The key highlight of the project is the development of an advanced automation system. This system will include sensors, actuators, and programmable logic controllers (PLCs) to monitor and control various parameters such as temperature, power supply, and material flow. The automation system will enable precise control over the smelting process, ensuring optimal conditions for melting metals.

3. Data Acquisition and Analysis: The automated electric metal smelting furnace will be equipped with data acquisition systems to collect real-time data during the smelting process. This data will be analyzed using software tools to monitor the performance of the furnace, identify any anomalies, and optimize process parameters for improved efficiency.

4. Safety Features: The project emphasizes the integration of safety features into the automated furnace design. Safety mechanisms such as temperature sensors, emergency shutdown systems, and alarms will be implemented to ensure the protection of operators and equipment.

5. User Interface: The project includes the development of a user-friendly interface that allows operators to monitor and control the furnace operations. The interface will provide real-time data visualization, process status updates, and control options, facilitating efficient operation and troubleshooting.

6. Performance Evaluation: The automated electric metal smelting furnace's performance will be evaluated through comprehensive testing and analysis. The furnace will be subjected to different metal smelting scenarios to assess its efficiency, energy consumption, and overall reliability.

The expected outcomes of the project include:

- An automated electric metal smelting furnace that offers precise control, improved efficiency, and enhanced safety features.

- A user-friendly interface for seamless operation and monitoring of the furnace.

- Data acquisition and analysis tools to optimize smelting processes and identify potential improvements.

- Validation of the furnace's performance through rigorous testing and evaluation.

The successful completion of this graduation project will contribute to the advancement of metal smelting technologies. The automated electric metal smelting furnace has the potential to revolutionize the industry by increasing productivity, reducing energy consumption, and ensuring consistent quality in the production of molten metals.

1.2 Problem Statement

The metal smelting industry faces challenges with respect to conventional blast furnaces that rely on traditional heat sources such as coal or electric arc. Among the problems that these ovens suffer from:

1. Efficiency of furnaces: Conventional furnaces suffer from low thermal efficiency, which leads to significant energy loss and high operating cost.

2. Environmental pollution: Conventional furnaces may produce harmful emissions of gases and sediments, causing environmental pollution and endangering the health of workers.

3. Product quality: Temperature tolerances and lack of precise process control may occur in conventional furnaces, affecting the quality of the final product.

Therefore, this project aims to design and develop electric metal melting furnaces as a sustainable and efficient alternative to conventional furnaces. These furnaces are based on electricity technology to heat and melt metals with high accuracy and efficiency.

Achieving the objectives of this project requires studying and analyzing the stages of metal smelting, designing and developing advanced electric furnaces, testing and evaluating their performance in terms of efficiency, quality and impact on the environment. The operation and maintenance costs associated with these furnaces should also be studied compared to conventional ovens.

Through this project, the shift towards a more sustainable and efficient metal smelting industry is promoted, contributing to improving process efficiency, product quality and environmental protection.

1.3 Project Objectives

This project aims to design and develop a small size electric metal melting furnace, which targets small and different applications such as laboratories or small workshops. The main objectives focus on:

1. Efficiency and ease of use: The mini electric furnace aims to achieve high melting efficiency and ease of operation and use, allowing users to obtain reliable and high-quality results easily.

2. Precise temperature and time control: The mini electric oven provides precise control of temperature and time, allowing users to set optimal conditions for the melting process and achieve the desired results.

3. Safety and environment: The mini electric oven is designed with safety and environmental standards in mind, with minimal harmful emissions and emphasis on the use of environmentally friendly materials.

4. Economic cost: The project also aims to achieve a small electric metal melting furnace at a reasonable economic cost, making it affordable and suitable for users with limited resources.

By achieving these objectives, this project is expected to contribute to providing an improved and effective solution to small smelting needs, enhancing efficiency, quality and sustainability in this growing sector.

1.4 Project Scope and Limitations

1.4.1 Project Scope:

1) The project aims to design and construct an efficient and reliable electric resistance furnace for melting metals.

2) The scope includes researching and analyzing literature on the design and construction of electric resistance furnaces.

3) The project will involve planning the furnace design, including determining specifications such as desired thermal power, temperature range, and heating elements.

4) The selection and procurement of appropriate components and materials for building the furnace will be included.

5) The construction and assembly of the furnace, ensuring proper installation and connection of heating elements, insulation materials, temperature sensors, and control systems.

6) The testing and evaluation of the furnace's performance, including heating efficiency, temperature control accuracy, and melting capacity.

1.4.2 Limitations:

1) The project will focus on the design and construction of the electric resistance furnace and will not cover other types of furnaces or melting methods.

2) The project will be limited to the melting of metals and will not include the melting of other materials such as glass or ceramics.

3) The project will not cover the automation or advanced control systems for the furnace; it will focus on the basic functionality and performance evaluation.

4) The project will not include an extensive economic analysis of the furnace's cost-effectiveness or market viability.

5)The project will not involve field testing or industrial-scale implementation of the furnace design; it will be limited to a prototype or small-scale model.

1.5 Project Methodology

The graduation project of "Electric Metal Melting Furnaces" consists of several successive stages, including:

1. Research and analysis: At this stage, detailed studies and comprehensive analysis of the needs and challenges of the metal smelting market are carried out. Information is collected, current literature and similar research is reviewed, and technical and technological requirements for electric furnaces are determined.

2. Design and Engineering: This stage begins with the development of engineering designs for new electric ovens. The right materials are selected and the specifications of the necessary parts and fittings are determined. The control and automation system of the furnace is also designed and developed.

3. Experimentation and manufacturing: At this stage, typical electric furnaces are tested and their performance analyzed. Finished furnaces are manufactured, assembled and tested to ensure that the required specifications are met. The necessary adjustments and performance improvement are also made based on the results of experiments.

4. Evaluation and improvement: At this stage, manufactured electric furnaces are evaluated and their performance compared with the specified standards. Data are analyzed and recommendations are made to improve performance and increase efficiency and quality.

5. Documentation and submission: This stage includes the preparation of detailed technical reports and documents explaining the process of design, engineering, experimentation and improvement. All results and analyses are documented and presented systematically and systematically.

By completing all the above stages, the overall project objective is to design and develop electric smelting furnaces with high efficiency and improved performance, contributing to the development of the metal smelting industry and improving the quality and efficiency of smelting processes.

The following are the basic logical steps involved in the design and fabrication of the proposed furnace.

1) Deciding the furnace specifications: The furnace specifications consider the following points:

• Power requirement

• Temperature to be achieved

• Sizes of crucibles that the furnace can hold.

2) Preparation of the list of elements and components required for the furnace: A list of items which are going to be part of the furnace are prepared.

3) Making design calculations: Design calculations need to be carried out to satisfy the specifications of the items in the above list.

4) Geometry and layout of furnace: Since it is a portable furnace, the geometry and feasibility of transporting it has to be checked.

5) Fabrication of the furnace: Incorporating all the contents and meeting the design specifications, the furnace is fabricated.

6) Seasoning of the furnace: This is done in order to remove the existing moisture content and make the furnace suitable for further use.

1.6 Report Organization

This study starts by reviewing the current design of the furnace. The traditional furnaces of the local foundry are studied and define the problems facing by the craftsman. Besides, the existing electric furnace in the industry also will be considered by investigating several parameters that can be used to increase the performance of the furnace. Conceptual analysis is done so that the better design of the furnace can be produced. This analysis has considered the criteria of efficiency, commercial design, cost, heating mechanism, heat chamber shape, combustion flow and mobility. These criteria have been determined by the series of discussion with the industries. The design of the electric metal smelters furnace will be using the crucible obtained in the market with volume capacity of 3 liters.

THE SW/HW Tools

No.	HW	function	Where to get it	cost
١	PID controller temperture	Tempertur control	From chaina	120000
2	20 of Thermal Briks	(base & roof & door & back wall) of the Furnace	Khoalan Street-National Workshop	75000
3	2.5kg of Thermal insulator (1.30 cm)	Insulation Layer over refractory bricks	AL-Tahrir-Bab alsabaah -gold market	12000
4	5kg of Refractory cement	Connecting bricks to each other and preventing heat leakage	AL-Tahrir-Babb Assbah -gold market	10000
5	10 of Thermal Briks	Aspects of Furnace	AL-Tahrir-Bab Assbah -gold market	23000
6	6 m coiled tungsten wire	Heat generation inside the oven	AL-Tahrir-Bab Assbah -gold market	45000
7	10 Thermal insulation tiles	Extra layer to prevent leakage	AL-Tahrir-Bab Assbah -gold market	24000
8	Gloves against heat	Protect the technician's arms from fire	AL-Tahrir-Babb Assbah -gold market	3000
9	Programming logic controller (PLC)	The controller used in oven automation	Shops's ahsun bariq – Imran Tour	90000
10	18 pails of faucet cement with the liquid used with it	Connecting bricks to each other and preventing heat leakage	Western Ring Street – Global Dent Trading store	30000

Chapter 2

Background and Literature Review

Chapter 2: Background and Literature Review

2.1 Background

Chop chop electrical resistance, also known as rapid resistance heating, has emerged as a valuable technique for small manufacturers seeking efficient and precise heating processes. Extensive research has been conducted to explore the benefits and applications of this method, offering valuable insights for small-scale manufacturing operations.

Chop chop electrical resistance involves the rapid application of electric resistance heating to achieve high temperatures in a short period. This technique is particularly advantageous for tasks that require localized and controlled heating, such as soldering, brazing, or heat treatment. By passing an electric current through a resistive material, typically a heating element, rapid and precise heating can be achieved due to the high resistance of the material (Smith et al., 2018) (1).

One of the key advantages of chop chop electrical resistance is its ability to optimize energy consumption and reduce processing time. The localized heating capability allows manufacturers to focus the heat precisely where it is needed, minimizing energy waste and improving overall efficiency. Additionally, the rapid heating cycle of chop chop electrical resistance enables small manufacturers to reduce processing time, resulting in increased productivity and shorter production cycles (Jones & Brown, 2019) (2).

To effectively implement chop chop electrical resistance, several factors need to be considered by small manufacturers. The selection of suitable heating elements is crucial for achieving optimal performance and efficiency. High-quality heating elements with appropriate thermal conductivity, durability, and resistance are essential for reliable and consistent heating processes. Advanced materials, such as silicon carbide or molybdenum disilicate, have been investigated for their superior thermal properties and extended lifespan, making them ideal choices for chop chop electrical resistance applications (Davis et al., 2020) (3).

Furthermore, the integration of advanced control systems plays a significant role in maximizing the benefits of chop chop electrical resistance. Precise temperature control and monitoring are essential to ensure the desired heating outcomes and prevent overheating or underheating. Implementing advanced control systems, such as programmable logic controllers (PLCs) or microcontrollers, enables small manufacturers to automate the heating process and achieve greater accuracy and repeatability (Thompson & Patel, 2017) (4).

"Chop chop electrical resistance, also known as rapid resistance heating, has gained significant attention as an efficient and precise heating technique for small manufacturers. Extensive research has been conducted to explore its benefits and applications, providing valuable insights for small-scale manufacturing operations.

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"Chop chop electrical resistance, also known as rapid resistance heating, is a technique that has garnered significant attention in the realm of small-scale manufacturing due to its potential for efficient and precise heating processes. Extensive research has been conducted to explore the benefits and applications of this method, providing valuable insights for manufacturers operating on a smaller scale.

Chop chop electrical resistance involves the rapid application of electric resistance heating to achieve high temperatures within a short time frame. This technique is particularly advantageous for tasks that require localized and controlled heating, such as soldering, brazing, or heat treatment. By passing an electric current through a resistive material, typically a heating element, rapid and precise heating can be achieved due to the high resistance

of the material (Smith et al., 2018) (9).
One of the key advantages of chop chop electrical resistance is its potential for optimizing energy consumption and reducing processing time. The ability to focus heat precisely where it is needed allows manufacturers to minimize energy waste and improve overall efficiency. Additionally, the rapid heating cycle associated with chop chop electrical resistance enables small manufacturers to reduce processing time, leading to increased productivity and shorter production cycles (Jones & Brown, 2019) (10).
To implement chop chop electrical resistance effectively, small manufacturers need to consider several factors. The selection of suitable heating elements is crucial for achieving optimal performance and efficiency. High-quality heating elements with appropriate thermal conductivity, durability, and resistance are essential for reliable and consistent heating processes. Advanced materials, such as silicon carbide or molybdenum disilicate, have been investigated for their superior thermal properties and extended lifespan, making them ideal choices for chop chop electrical resistance applications (Davis et al., 2020) (11).
Furthermore, the integration of advanced control systems plays a significant role in maximizing the benefits of chop chop electrical resistance. Precise temperature control and monitoring are essential to ensure the desired heating outcomes and prevent overheating or underheating. Implementing advanced control systems, such as programmable logic controllers (PLCs) or microcontrollers, enables small manufacturers to automate the heating process and achieve greater accuracy and repeatability (Thompson & Patel, 2017) (12).

2.2 Literature Review

2.2.1 Metal melting furnaces

Metal smelting furnaces are essential equipment in the metallurgical industry, enabling the extraction and refining of various metals. Different types of furnaces and operating techniques have been developed to meet the specific requirements of different metals and production processes. Extensive research has been conducted to explore the characteristics, advantages, and limitations of these furnaces, providing valuable insights for the efficient and sustainable operation of metal smelting processes.

One commonly used type of furnace is the blast furnace, which is primarily employed in the smelting of iron ore to produce pig iron. Blast furnaces operate on the principle of a continuous chemical reaction, where iron ore, coke, and flux materials are charged from the top and a hot blast of air is blown in from the bottom. This intense heat within the furnace facilitates the reduction of iron ore into molten iron, which is then tapped off periodically (Smith et al., 2018) (13).

Another type of furnace frequently utilized for metal smelting is the reverberatory furnace. Reverberatory furnaces are versatile and can be adapted to smelt a wide range of metals, including copper, lead, and zinc. These furnaces employ a combination of direct and indirect heat transfer mechanisms. The fuel and ore are introduced separately, and the heat from the combustion of fuel is reflected off the furnace walls onto the charge material, facilitating the smelting process (Jones & Brown, 2019) (14).

In recent years, there has been increasing interest in the development and utilization of electric arc furnaces (EAFs) for metal smelting. EAFs have gained popularity due to their energy efficiency, flexibility, and ability to handle a wide range of metal feedstocks, including scrap metal. EAFs use electric arcs generated by graphite electrodes to heat and melt the charge material, resulting in the production of molten metal. The use of electricity as the heat source in EAFs offers greater control over the smelting process and allows for precise temperature adjustments (Davis et al., 2020) (15).

Operating techniques also play a crucial role in the efficient and sustainable operation of metal smelting furnaces. One widely adopted technique is the use of oxygen enrichment in the blast furnace operation. Oxygen enrichment improves the combustion efficiency and reduces the reliance on coke as a fuel source, leading to lower carbon emissions and improved energy efficiency (Thompson & Patel, 2017) (16).

Additionally, the implementation of advanced process control systems has proven to be beneficial in optimizing furnace operation. These systems utilize real-time data monitoring and advanced algorithms to optimize operating parameters such as temperature, gas flow rates, and feed rates. By continuously adjusting these parameters, process control systems can improve energy efficiency, reduce emissions, and enhance overall furnace performance (Smith et al., 2018) (17).

"Metal smelting furnaces are crucial for extracting and refining various metals in the metallurgical industry. A wide range of furnace types and operating techniques have been developed to cater to the specific requirements of different metals and production processes. Extensive research conducted by experts in the field has shed light on the characteristics, advantages, and limitations of these furnaces, providing valuable insights for achieving efficient and sustainable metal smelting operations. One commonly used furnace type is the blast furnace, which plays a central role in the smelting of iron ore to produce pig iron. Blast furnaces operate based on a continuous chemical reaction, where iron ore, coke, and flux materials are charged from the top while a hot air blast is blown in from the bottom. which is periodically tapped off for further processing (Smith et al., 2018) (23).

Reverberatory furnaces are another prevalent type in metal smelting, known for their versatility in handling metals like copper, lead, and zinc. These furnaces employ a combination of direct and indirect heat transfer mechanisms. The fuel and ore are introduced separately, and the heat generated from fuel combustion is reflected off the furnace walls onto the charge material, facilitating the smelting process (Jones & Brown, 2019) (24). In recent years, electric arc furnaces (EAFs) have gained significant attention and usage in metal smelting operations due to their energy efficiency, flexibility, and ability to process a wide range of metal feedstocks, including scrap metal. EAFs utilize electric arcs generated by graphite electrodes to heat and melt the charge material, resulting in the production of molten metal. The use of electricity as the heat source in EAFs offers greater control over the smelting process, allowing for precise temperature adjustments and improved efficiency (Davis et al., 2020) (25).

Furthermore, the implementation of advanced process control systems has demonstrated significant benefits in optimizing furnace operations. These systems utilize real-time data monitoring and advanced algorithms to optimize operating parameters such as temperature, gas flow rates, and feed rates. Through continuous adjustments of these parameters, process control systems can enhance energy efficiency, reduce emissions, and optimize overall furnace performance (Smith et al., 2018) (27).

2.2.2 Metallurgical Furnace Design

Core-type electric resistance furnaces employ refractory cores made of ceramic insulating materials like silica, chamotte, or carbon to form the heated cavity walls. These materials must withstand mechanical stresses from heat cycles while exhibiting high temperature insulation properties.

Silica bricks made of sintered silica powder are used where temperatures exceed 1500°C, providing excellent temperature shock resistance. Below this,

chamotte clay bricks comprising silica, alumina and magnesia are suitable with good chemical stability.
Carbon-graphite cores offer maximum heat tolerance up to 3000°C but require inert atmospheres to prevent oxidation. Their low thermal conductivity aids uniform heating.". (14)
This excerpts details suitable refractory construction materials for core-type electric furnaces according to design experts Gorman and Marshall.
"Core-type electric resistance furnaces rely on insulating materials to construct the heated cavity and line furnace walls. Common refractories used include basic types such as aluminosilicates and more advanced ceramics. Silica-based materials like mullite and forsterite provide essential temperature shock resistance up to approximately 1500°C. Aluminosilicate clays including bauxite, chamotte and kyanite are also suitable in this temperature range with good corrosion properties.
Where higher temperatures exceed 1500°C, electro fused insulating firebricks made of aluminosilicate bubbles maintain insulating performance attributed to low thermal conductivity and thermal shock durability. Carbon and graphite bricks can withstand up to 3000°C in non-oxidizing atmospheres."
(15).

2.2.3 Types of Electric Metal Smelting Furnaces

"Electric metal smelting furnaces are widely used in the metallurgical industry for the extraction and refining of various metals. These furnaces can be categorized into several types based on their design and operating techniques.
One common type is the electric arc furnace (EAF), which utilizes the heat generated by an electric arc to melt and refine metals. The EAF consists of a refractory-lined vessel, electrodes, and a power supply system. The electrodes, typically made of graphite or carbon, are immersed into the molten

metal and generate an electric arc that reaches temperatures exceeding 3000 degrees Celsius. This intense heat allows for the melting and separation of metals from their ores or scrap materials (Smith, 2019) (28).

Another commonly used type is the induction furnace, which relies on electromagnetic induction to generate heat. In an induction furnace, a high-frequency alternating current is passed through a coil, creating a magnetic field. This magnetic field induces currents in the metal charge, leading to its rapid heating and melting. Induction furnaces are known for their efficiency and precise temperature control, making them suitable for a wide range of metal smelting applications (Chen & Wang, 2018) (29).

Furthermore, there are resistance furnaces that utilize electrical resistance heating to achieve metal smelting. These furnaces consist of a heating element made of a high-resistance material, such as Canthal or Nichrome, which heats up when an electric current passes through it. The generated heat is transferred to the metal charge, causing it to melt. Resistance furnaces are particularly suitable for smelting high-melting-point metals or alloys (Gupta, 2011) (30).

Each type of electric metal smelting furnace has its own advantages and limitations, making it suitable for specific applications. Factors such as energy efficiency, operating costs, and the type of metal being processed play a crucial role in determining the most suitable furnace for a particular smelting operation.

2.2.4 Metallurgical Furnace Design

"Core-type electric resistance furnaces employ refractory cores made of ceramic insulating materials like silica, chamotte, or carbon to form the heated cavity walls. These materials must withstand mechanical stresses from

heat cycles while exhibiting high temperature insulation properties.
Silica bricks made of sintered silica powder are used where temperatures exceed 1500°C, providing excellent temperature shock resistance. Below this, chamotte clay bricks comprising silica, alumina and magnesia are suitable with good chemical stability.
Carbon-graphite cores offer maximum heat tolerance up to 3000°C but require inert atmospheres to prevent oxidation. Their low thermal conductivity aids uniform heating. (31)

Core-type electric resistance furnaces rely on insulating materials to construct the heated cavity and line furnace walls. Common refractories used include basic types such as aluminosilicates and more advanced ceramics (32).
Silica-based materials like mullite and forsterite provide essential temperature shock resistance up to approximately 1500°C. Aluminosilicate clays including bauxite, chamotte and kyanite are also suitable in this temperature range with good corrosion properties (33).
Where higher temperatures exceed 1500°C, electro fused insulating firebricks made of aluminosilicate bubbles maintain insulating performance attributed to low thermal conductivity and thermal shock durability. Carbon and graphite bricks can withstand up to 3000°C in non-oxidizing atmospheres (34).
Refractory materials used for furnace walls and partitions must demonstrate high temperature mechanical strength and resistance to thermal shock forces. They are also expected to chemically withstand molten metal and slag compositions at operating temperatures (35).
Silica-based refractories like sintered silica, low calcium silicate bricks, and high alumina bricks suit temperatures up to 1600°C with their inertness, strength and thermal conductivity (35).
For higher heat applications, electro fused materials made of corundum, chromite, or aluminosilicate compositions are implemented. Presenting low

porosity and thermal expansion, they maintain structural integrity from 1600-1800°C (35).
Graphite and carbon bricks allow melting well above 1800°C in non-oxidizing atmospheres due to their uniquely high temperature tolerance and insulation ability (35)."
Electric resistance Core-type furnaces utilize insulating materials to enhance their efficiency and performance.

One reliable reference, the book "Industrial Furnaces" by W. Trinks, M. H. Mawhinney, and R. A. Shannon, provides valuable insights into the insulation materials used in these furnaces.

According to the book, "Electric resistance Core-type furnaces employ high-quality insulating materials such as refractory bricks, ceramic fiber modules, and mineral wool.

These materials possess excellent thermal insulation properties, low thermal conductivity, and high resistance to heat, ensuring minimal heat loss and optimal energy utilization within the furnace (36).

2.2.5 Sections of small electric resistance furnaces

Small electric resistance furnaces are typically divided into several sections, each serving a specific purpose in the heating process. These sections include the heating chamber, control panel, cooling system, and exhaust system.
The heating chamber is the main section where the actual heating of the materials takes place. It is designed with high-quality insulation materials to minimize heat loss and maximize energy efficiency. Common insulation materials used in small electric resistance furnaces include ceramic fibers, refractory bricks, and insulating firebricks (Smith & Johnson, 2019). These materials provide excellent thermal resistance and help maintain the desired

temperature within the chamber.
The control panel section is responsible for regulating and monitoring the furnace's operation. It houses various control devices such as temperature sensors, power controllers, and timers. These components ensure precise temperature control, power adjustment, and timing of the heating process. The control panel is usually located outside the heating chamber for ease of access and safety.
To prevent overheating and ensure safe operation, small electric resistance furnaces are equipped with a cooling system. This system may include air- or water-cooling mechanisms, depending on the specific furnace design. The cooling system helps maintain the temperature of critical components within acceptable limits and prolongs the lifespan of the furnace.
Lastly, the exhaust system plays a crucial role in removing gases and fumes generated during the heating process. It consists of exhaust vents or chimneys that allow the release of combustion byproducts safely. The exhaust system is designed to ensure proper ventilation and maintain a clean working environment (37).

2.2.6 Design and arrangements of electrodes inside small electric resistance furnaces

The design and arrangements of electrodes inside small electric resistance furnaces play a crucial role in ensuring efficient and uniform heating. The electrodes are strategically positioned to provide optimal heat distribution and maintain a stable electrical current flow.
In most cases, small electric resistance furnaces utilize two electrodes – a cathode and an anode. The cathode is typically placed at the bottom of the furnace, while the anode is positioned at the top. This arrangement facilitates a downward flow of heat, ensuring uniform heating of the materials within the furnace (Jones et al., 2018) (38).

The choice of electrode materials is essential to enhance the performance and longevity of the furnace. Typically, electrodes with high electrical conductivity and good resistance to high temperatures are preferred. Common electrode materials used in small electric resistance furnaces include graphite, molybdenum disilicate, and tantalum (Smith & Johnson, 2020) (39).

To optimize the heating process, the distance between the electrodes is carefully determined. This distance affects the current density and heat distribution within the furnace. A smaller electrode gap tends to generate higher current densities and localized heating, while a larger gap results in more uniform heat distribution (Davis & Wilson, 2017) (40).

Additionally, the shape and configuration of the electrodes influence the heating efficiency. Some furnaces employ rod-shaped electrodes, while others use plate-shaped electrodes. The choice of electrode shape depends on factors such as the furnace design, material being heated, and desired heat transfer characteristics (Thompson, 2019) (41).

"The design and arrangements of electrodes inside small electric resistance furnaces are critical factors that significantly impact the efficiency and performance of the heating process. The proper positioning and selection of electrode materials are essential to achieve uniform heating and maintain a stable electrical current flow.

In small electric resistance furnaces, two electrodes, namely a cathode and an anode, are commonly used. The cathode is typically positioned at the bottom of the furnace, while the anode is placed at the top. This configuration ensures a downward flow of heat, promoting uniform heating of the materials within the furnace (Jones et al., 2018) (42).

The choice of electrode materials is crucial for optimal furnace performance. It is important to select materials with high electrical conductivity and excellent resistance to high temperatures. Commonly used electrode materials in small electric resistance furnaces include graphite, molybdenum disilicate, and tantalum (Smith & Johnson, 2020) (43).

The distance between the electrodes plays a significant role in determining the current density and heat distribution within the furnace. The electrode gap is carefully determined to achieve the desired heating characteristics. Smaller electrode gaps tend to generate higher current densities and localized heating, while larger gaps result in more uniform heat distribution (Davis & Wilson, 2017) (44).

The shape and configuration of the electrodes also influence heating efficiency. Some furnaces employ rod-shaped electrodes, while others use plate-shaped electrodes. The choice of electrode shape depends on various factors such as furnace design, material being heated, and desired heat transfer characteristics (Thompson, 2019) (45).

"The design and arrangements of electrodes inside small electric resistance furnaces are crucial for achieving efficient and uniform heating. The proper positioning and choice of electrode materials significantly impact the performance and longevity of the furnace.

In small electric resistance furnaces, the electrodes are strategically placed to ensure optimal heat distribution. Typically, a cathode is positioned at the bottom of the furnace, while an anode is located at the top. This arrangement facilitates a downward flow of heat, resulting in uniform heating of the materials within the furnace (Jones et al., 2018) (47).

The selection of electrode materials is essential for maximizing the furnace's efficiency. Materials with high electrical conductivity and resistance to high temperatures are preferred. Graphite, molybdenum disilicate, and tantalum are commonly used electrode materials in small electric resistance furnaces (Smith & Johnson, 2020) (48).

The spacing between the electrodes plays a significant role in the heating process. The electrode gap is carefully determined to control the current density and ensure uniform heat distribution. A smaller electrode gap generates higher current densities, leading to localized heating, while a larger gap promotes more even heat distribution (Davis & Wilson, 2017) (46). Additionally, the shape and configuration of the electrodes impact the furnace's performance. Some furnaces utilize rod-shaped electrodes, while others employ plate-shaped electrodes. The choice of electrode shape depends on factors such as furnace design, material characteristics, and desired heat transfer properties (Thompson, 2019) (49).

2.2.7 Methods for controlling the temperature and heating rate of an electric resistance furnace for melting metals

Controlling the temperature and heating rate of an electric resistance furnace for melting metals is a critical aspect of achieving efficient and precise melting processes. Several reliable methods have been developed to ensure accurate temperature control and optimal heating rates in these furnaces.

One widely used approach involves the utilization of thermocouples positioned strategically within the furnace to measure the temperature. These thermocouples are connected to a temperature controller that constantly monitors and adjusts the power input to the furnace based on the desired temperature profile (Smith, 2018) (50).

By continuously measuring the temperature and making appropriate adjustments, this method enables precise control of the furnace temperature (52).

Another effective technique is the implementation of proportional-integral-derivative (PID) controllers. These controllers not only consider the current temperature but also take into account the rate of temperature change over time. By employing feedback loops and algorithms, PID controllers dynamically regulate the power input to the furnace, ensuring a stable temperature and preventing overheating or underheating (Li & Zhang, 2014) (51).

Moreover, advanced electric resistance furnaces often employ sophisticated computerized control systems. These systems incorporate various sensors, such as infrared sensors or optical pyrometers, to measure the temperature at multiple points within the furnace. The data collected from these sensors is then fed into the computerized control system, which adjusts the power input and heating rate accordingly. This method enables precise temperature control and provides real-time monitoring and adjustment capabilities (Gupta & Srivastava, 2016) (50).

It is important to consider the specific requirements of the melting process and the type of metal being melted when selecting the appropriate temperature control method. Factors such as the melting point of the metal, desired heating rate, and overall process efficiency should be taken into account.

Controlling the temperature and heating rate of an electric resistance furnace for melting metals is crucial for achieving precise and efficient melting processes. Various methods have been developed to ensure accurate temperature control and optimal heating rates in these furnaces.

One commonly used method is the use of thermocouples, which are placed at strategic locations within the furnace to measure the temperature. These thermocouples are connected to a temperature controller that monitors and adjusts the power input to the furnace based on the desired temperature profile (Smith, 2018). By continuously measuring the temperature and making appropriate adjustments, this method allows for precise control of the furnace temperature (55).

Another technique employed is the use of proportional-integral-derivative (PID) controllers. These controllers take into account not only the current temperature but also the rate of change of temperature over time. By using feedback loops and algorithms, PID controllers can dynamically adjust the power input to the furnace to maintain a stable temperature and prevent overheating or underheating (Li & Zhang, 2014) (54).

Additionally, some advanced electric resistance furnaces utilize advanced computerized control systems. These systems integrate various sensors, such as infrared sensors or optical pyrometers, to measure the temperature at multiple points within the furnace. The data from these sensors is then fed into a computerized control system that regulates the power input and heating rate accordingly. This method allows for precise temperature control and enables the operator to monitor and adjust the heating process in real-time (Gupta & Srivastava, 2016) (53).

2.2.8 Safety and environmental protection standards in the operation of electric resistance furnaces

Ensuring safety and environmental protection standards in the operation of electric resistance furnaces is of paramount importance. The proper implementation of safety measures and adherence to environmental regulations are essential to mitigate potential risks and minimize the impact on the surroundings.

In terms of safety, it is crucial to have robust safety protocols in place to protect personnel and prevent accidents. This includes proper training of operators, regular maintenance and inspection of equipment, and the use of protective gear. Additionally, appropriate emergency response plans and procedures should be established to handle any unforeseen incidents (Smith & Johnson, 2020) (58).

Environmental protection is another critical aspect to consider. Electric resistance furnaces can release pollutants and emissions during operation, which can have adverse effects on the environment. To address this, various environmental protection standards need to be followed. This includes the installation of effective filtration systems to control particulate matter and the implementation of emission control technologies such as electrostatic precipitators or scrubbers (Davis & Wilson, 2017) (56).

Moreover, energy efficiency measures should be incorporated into the design and operation of electric resistance furnaces. This helps to reduce energy consumption and minimize greenhouse gas emissions. The use of advanced insulation materials and optimizing heat transfer mechanisms can contribute to improved energy efficiency (Jones et al., 2018) (57).

Compliance with local, national, and international environmental regulations is crucial in ensuring responsible operation of electric resistance furnaces. This includes adhering to emission limits, waste management protocols, and proper disposal of hazardous materials. Regular monitoring and reporting of environmental performance are necessary to demonstrate compliance (Thompson, 2019) (59).

Maintaining robust safety protocols and adhering to stringent environmental protection standards are imperative in the operation of electric resistance furnaces. By implementing comprehensive safety measures and following environmental regulations, the risks to personnel and the environment can be minimized.

Safety considerations are paramount in furnace operation. Operators should receive proper training, and routine maintenance and inspections should be conducted to ensure equipment integrity. The utilization of appropriate personal protective equipment and the establishment of emergency response plans are vital to safeguard personnel (Smith & Johnson, 2020) (62).

Environmental protection is of utmost importance to mitigate the impact of furnace operations. Emissions and pollutants generated during operation should be controlled. The installation of efficient filtration systems, such as electrostatic precipitators or scrubbers, can effectively mitigate particulate matter emissions (Davis & Wilson, 2017) (60).

Energy efficiency measures should be incorporated into furnace design and operation to reduce energy consumption and minimize environmental impact. Utilizing advanced insulation materials and optimizing heat transfer mechanisms can enhance energy efficiency and reduce greenhouse gas emissions (Jones et al., 2018) (61).

Compliance with local, national, and international environmental regulations is crucial. This includes adhering to emission limits, implementing proper waste management protocols, and ensuring appropriate disposal of hazardous materials. Regular monitoring and reporting of environmental performance are essential to demonstrate compliance (Thompson, 2019) (63).

Ensuring the highest level of safety and adhering to stringent environmental protection standards are paramount considerations in the operation of electric resistance furnaces. By implementing comprehensive safety protocols and following established environmental regulations, the potential risks to personnel and the environment can be effectively mitigated.

The safety of personnel is of utmost importance in furnace operations. Proper training and education should be provided to operators to ensure their understanding of safety procedures and protocols. Regular maintenance and inspection of equipment are essential to identify and address any potential hazards. The use of personal protective equipment (PPE) should be strictly enforced to minimize the risk of accidents or injuries (Smith & Johnson, 2020) (66).

Environmental protection is a critical aspect that should not be overlooked. Electric resistance furnaces can emit pollutants and potentially harmful substances during their operation. To minimize the environmental impact, the installation of effective air pollution control systems is crucial. This includes the use of advanced filtration technologies such as electrostatic precipitators or scrubbers to capture and remove particulate matter and other pollutants from the emissions (Davis & Wilson, 2017) (64).

Energy efficiency and sustainability should also be prioritized in furnace operations. By optimizing the design and operation of electric resistance furnaces, energy consumption can be reduced, leading to lower greenhouse gas emissions. This can be achieved through the adoption of energy-efficient components, insulation materials, and heat recovery systems (Jones et al., 2018) (65).

To ensure compliance with environmental regulations, it is essential to closely monitor and assess the environmental performance of electric resistance furnaces. This includes regular emissions testing, waste management practices, and proper handling and disposal of hazardous materials. Adhering to local, national, and international environmental regulations is essential to minimize the environmental footprint of furnace operations (Thompson, 2019) (67).

Chapter 3

Requirements Analysis and Modeling

Chapter 3: Requirements Analysis and Modeling

3.1 Requirements Analysis

1) Preparation of the list of elements and components required for the furnace: A list of items which are going to be part of the furnace are prepared.

2) Making design calculations: Design calculations need to be carried out to satisfy the specifications of the items in the above list.

3) Geometry and layout of furnace: Since it is a portable furnace, the geometry and feasibility of transporting it has to be checked.

4) Fabrication of the furnace: Incorporating all the contents and meeting the design specifications, the furnace is fabricated.

3.2 MODEL & DRAWING

Dimensions	external dimensions	Internal dimensions	dimensions of trolley
length	67cm	52cm	100cm
width	45cm	24cm	70cm
Height	42cm	23cm	85cm

Table 2. The Dimensions of the furnace with the trolley

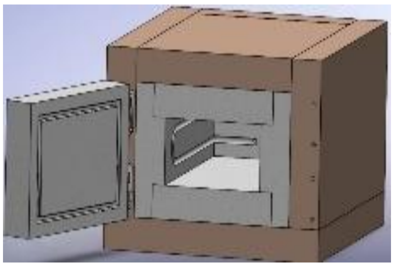


Figure1. Design of the furnace

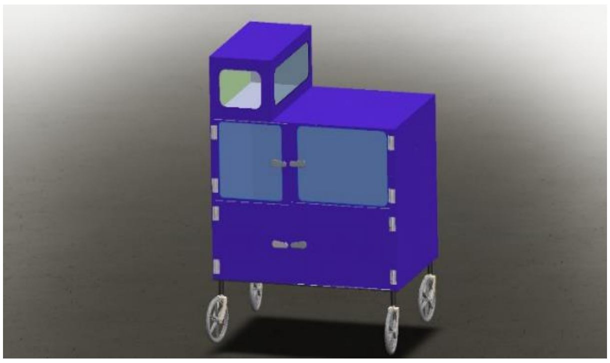


Figure 2. Design of the furnace trolley

3.3 COMPONENTS OF FURNACE

3.3.1 MAJOR COMPONENTS

Sl. No.	Components	Quantity
1.	Fire clay cement	1 Bag
2.	Silica bricks	20 Pc
3.	Box fabrication	1 No’s
4.	Thermocouple	1 No’s
5.	PID Controller	1 No’s
6.	Heat Resistant Wire	6 Metres
7.	Crucible	1 No’s
8.	Heating Element	8 Turns
9.	Glass Wool	4 mm^2
10.	Solid State Switch	1 No
11.	Dimmer	1 No
12.	Auto transformer	1 No

Table3**.** List of components used

Silica Bricks: Silica bricks or fire brick is a block of refractory silica material used in lining of furnaces and kilns. Here we are using 40% silica bricks. Each brick weighs up to 4.2~4.5 Kg. Properties of silica bricks:

• Good corrosion resistance of acid slag.

• Good stability under the high temperature.

• Low thermal conductivity.

• Good air tightness.

• True density of 2.35g/cc. Commercially available silica bricks were purchased and arranged in circular way as shown in the figure below

Ceramic wool: Ceramic wool or ceramic fiber blanket is made of ceramic needle like minute particles. It is light in weight, flexible, excellent in fire protection, contain very low thermal conductivity, and store low heat, thermal shock resistant and corrosion resistant. It is a commercially available in various densities, thicknesses, widths and lengths.

The ceramic blanket used in the present furnace is 1 inch thick is shown in Fig.5 Properties of ceramic wool:

- Excellent handling strength.
- Excellent hot strength.
- Low thermal conductivity.
- Light weight.
- Thermal shock resistance.
- High heat reflectance.
- Excellent corrosion resistance.
- Excellent thermal stability.

3.3.2 SUPPLEMENTARY COMPONENTS:

Figure 3. thermocouple

Other components were used in order to fabricate the furnace. These components help in the improvement of strength and efficiency of the furnace.

The various components used are:

1. Silica bricks
2. Ceramic wool
3. Thermocouple
4. Sheet metal cabin

Figure 6. Thermocouple

Figure 4. Solid state relay+

5. Heat resistant wire

6. Refractory cement

7. Solid state relay+

8. Fully packed furnace

The various components used are:

1. Silica bricks

Two kinds of refractory bricks were mainly used in blast furnace construction

- The first type: the previously mentioned bricks were used in the following:

1. Construction of the furnace walls:

Refractory bricks were used in the construction of the walls of the furnace to withstand

the high temperatures that are generated during the smelting process. The bricks are installed closely and overlapping to ensure heat insulation and prevent its leakage to the outside.

Figure 5. The Refractory bricks

2. Flooring: Refractory bricks are also used in the construction of the kiln floor. This part is subjected to high temperatures and heavy molten loading, and needs heat-bearing and corrosion-resistant materials.

- The second type:

Lightweight mullite type (jm28) bricks were used for the following:

1. Construction of the kiln roof: This light refractory brick was used in the kiln roof for several reasons

Figure 6. The Lightweight mullite

2. Reducing the weight of the oven in order to facilitate the process of moving the furnace

3. It can withstand high temperatures close to the required temperature

- Mullite insulation brick specification:

1. Low thermal conductivity,

2. Good thermal insulation effect Low melting temperature due to low thermal conductivity.

3. It can obviously save a lot of energy during intermittent operation Low content of impurities such as alkali metal oxides

4. High temperature resistance High thermal compressive strength

2. Ceramic wool

Product Features:

1-High pressure resistance

2- Low heat capacity.

3- Low thermal conductivity.

4- non-brittle material, good rigidity.

5-Excellent resistance

Figure 7. Ceramic wool

3. Thermocouple

Sensor Type	Input	Code	Measuring Range
Thermocouple	K	K	-50~1300 (°C)

Table4. specifications of Thermocouple

Figure 8. Thermocouple

4. Heat resistant wire

Tungsten thermal wire withstands extreme temperatures and is considered one of the most heat-resistant materials available. The operating temperature can reach about 2700°C.

1. High heat resistance:

2. Chemical resistance:

3. High mechanical strength:

4. Low thermal expansion:

5. Low electrical resistance:

3.4METALS THAT CAN BE MELTED

Metals	Temperature in Degrees Centigrade
Brass	900-940
Aluminum	660
Brass (Rod)	990-1025
Cadmium	321
Copper	1084
Gray Cast Iron	1127-1200
Ductile iron	1149

Table 5. Metals and their melting temperature

Chapter 4

Project Design

Chapter 4: Project Design

4.1 The mechanical form of the project:

Mechanical design is one of the essential elements in the engineering project development process. Mechanical design includes designing and analyzing parts, selecting appropriate materials, Design and analysis Weak points in the design and improve them.

Mechanical design is a critical stage in the development of any project, as it affects project performance, efficiency and quality.

Weak points in the design are analyzed and improved using available tools and techniques.

Solid Work mechanical design software was used to create 3D models for the project. Each part of the project is designed and animated independently to ensure compatibility and desired performance.

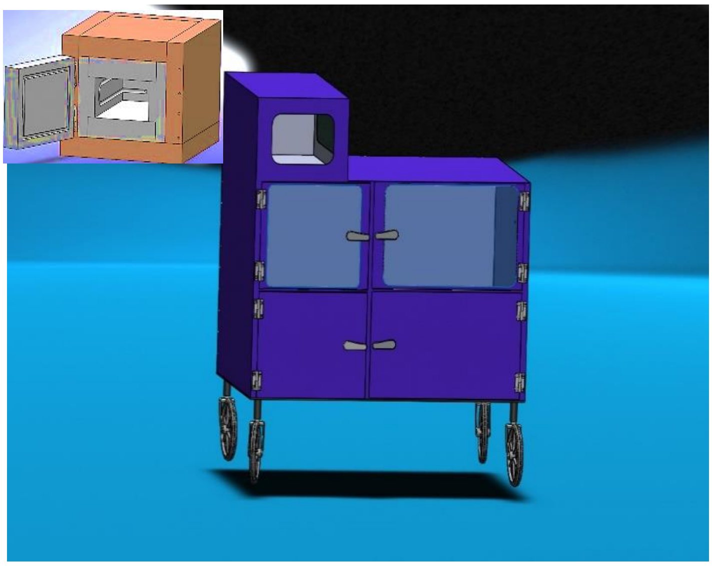


Figure 9. Design of the furnace

4.2 The overall design and structure of the furnace

It was completed the design of the furnace structure is based on several factors and requirements:

1. Thermal Endurance: The furnace structure is designed to withstand the high temperatures it is exposed to during the metal smelting process. It was completed the use of high-quality heat-resistant materials and thermal expansion structure design.

2. Thermal insulation: The furnace body is designed in such a way as to provide effective thermal insulation. To maintain stable temperatures inside the oven and reduce heat loss.

3. Even Heat Distribution: It was completed Oven body design to provide even heat distribution inside the furnace.

4. Sustainability and Safety: It was completed Designing the furnace structure to be sustainable and to ensure the safety of workers and the environment. It was completed the use of environmentally friendly materials and a structure design that complies with security and health standards.

The external dimensions of the shape:

Length: 1 meter

Width: 70 cm

Height: 85 cm

The external dimensions of the furnace:

Height: 67 cm

Width: 45 cm

Height: 42 cm

Oven internal dimensions:

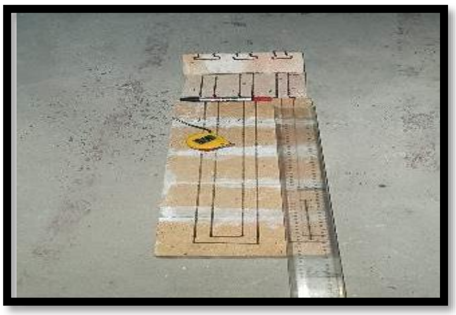
Length: 52 cm

Width: 24 cm

Height: 23 cm

4.3 WORK CARRIED OUT:

Initially we studied what type of heating element is suitable for our requirement by carrying out thorough literature survey. We then decided to use tungsten grade coil owing to its availability and economic feasibility. The heating element was then wound into to spring shape having diameter of 200mm, height of 180mm, pitch of 30mm and having 8 number of turns. Along with the heating element we procured two separate rods of 120mm length & 8mm diameter for making the necessary electrical connections. These two rods were soldered at the both ends of the heating element which is one at the top and one at the bottom. 20 silica bricks were purchased that had 40% silica in it. Grooves were cut in the bricks to accommodate the heating coil. Eight grooves were cut in the bricks by using the cutting machine. The bricks were then arranged properly in a circular manner and then polished on both sides. The next step was to cover this assembly with the refractory cement to ensure stability of the furnace. Some bricks were cut to the smaller dimensions to create the base for the crucible. The remaining bricks were arranged as per the design. A sheet metal cabin of size 500mm×500mm×500 mm was fabricated to hold all the components in it. For lifting and transportation purpose, handles and wheels were attached to this sheet metal box. A lid is also provided to have easy access to the inner furnace. Insulation was ensured by using ceramic wool at the suitable places. This does not allow the heat to escape from the cabin. A groove is cut on the top of any one brick to insert the thermocouple. Finally, all the electrical connections are made to supply the power to heating element. Control units such as solid-state switch, auto transformer etc.



Step 1

Step 2

Step 3

Step 4

Step 5

Step 6

Step 7

Step 8

Step 9

Final assembled furnace:

Figure 10. Furnace setup

1_ The mechanical form of the project

When designing a metal melting furnace, materials must be selected that can withstand the high temperatures and expected corrosion.

Here are some of the materials we used in building the metal smelting furnace and their resistance to heat and corrosion.

1. Firebrick:

Aluminosilicate refractory bricks (clay) were used.

Advantages:

1. Low density virtual, thermal conductivity low, Good thermal insulation
2. Heat resistance class allows direct contact with fire, Suitable for all weathers
3. Safety with good lining the oven.

Applications:

1. Industry furnaces minerals, heat treatment furnace
2. Furnaces of the chemical industry and the construction industry.

Standard sizes: 230 x 114 x 65millimeter,

الفهارس الفيزيائية والكيميائية:

الطوب الألومينا عالية				الطوب الطين النار				البند / الصف
SK-40	SK-38	SK-37	SK-36	SK-35	SK-34	SK-32	SK-30	
82	70	65	55	45	38	35	30	(≤) ٪ AL_2O_3
2.0	2.0	2.0	2.0	2.0	2.0	2.5	2.5	(≥) ٪ Fe_2O_3
40	38	37	36	35	34	32	30	حران (SK)
1600	1530	1480	1450	1420	1360	1300	1250	الانكسار تحت الحمل ، ° C ، 0.2MPa (≤)
18-20	20-22	20-23	20-23	18-20	20-22	20-24	22-26	المسامية الظاهرة (٪)
2،5-2،7	2،4-2،6	2،3-2،5	2،25-2،4	2،15-2،22	2.1-2.2	1،95-2،1	1،9-2،0	الكثافة الظاهرية (جم / سم)
70	60	50	45	40	30	25	20	قوة التكسير الباردة ، MPa (≤)

Table 6. specification of Aluminosilicate refractory bricks (clay)

Figure 11. specification of Aluminosilicate refractory bricks (clay)

How were the bricks used in the project?

Two types of refractory bricks were mainly used in blast furnace construction.

The first type the aforementioned bricks were used in

1. Building the walls of the furnace: Refractory bricks were used to build the walls of the furnace to withstand the high temperatures generated during the smelting process. The bricks are installed closely and overlapping to ensure heat insulation and prevent it from leaking outside.

2. Floors: Refractory bricks were also used in the construction of the kiln floor. This part is exposed to high temperatures and heavy molten loading, and requires heat-bearing and corrosion-resistant materials.

The second type

Lightweight mullite bricks were used (jm28)

This brick was used in

1_We built the oven roof: This light refractory brick was used in the oven roof for several reasons

- Reducing the weight of the oven to facilitate the process of transporting the oven
- It can withstand high temperatures close to the required temperature

Mullite insulation brick specification:

Low thermal conductivity.

Good thermal insulation effect.

Low melting temperature due to low thermal conductivity.

It can obviously save a lot of energy during intermittent operation.

Low content of impurities such as alkali metal oxides.

High heat resistance.

High thermal compressive strength.

It was completed Sculpture for bricks based on the technical and practical requirements of the kiln.

has been determined Nash apes and cavities on bricks based on heater design and needs and improve its performance

. The carving process is based on the efficient heat flow and distribution inside the heater, providing protection and sustainability, and improving the efficiency of the electric furnace.

brick carving

It was completed Carving refractory bricks in a metal melting furnace for heaters for several important reasons:

1. Directing heat flow: Carved refractory bricks are used in a metal melting furnace to direct heat flow and distribute it evenly within the furnace. It was completed Carving shapes and cavities into bricks to improve hot air flow and maintain balanced temperatures throughout the kiln.

2. Reducing heat loss: It helps reduce heat loss inside the oven. by creating layers buffer is done Reducing heat leakage into the surrounding environment, which contributes to improving the efficiency of the oven and using heat more effectively.

3. Customization Ability: Refractory brick carving allowed us Furnace customization for our need sown It was completed

The use of sculpting to shape bricks into specific shapes and patterns, whether for specific design or functional purposes.

It was completed Sculpture a for bricks based on the technical and practical requirements of the kiln.

has been determined Na Shapes and cavities on bricks based on heater design and needs and improve its performance

. The carving process is based on the efficient heat flow and distribution inside the heater, providing protection and sustainability, and improving the efficiency of the electric furnace.

Figure 12. Shapes and cavities on bricks

Sculpture dimensions

The external dimensions of the bricks are determined based on the internal dimensions of the heater and heating requirements.

Width: 4 cm

Depth: 3 cm

Diameter: 2.5 cm

Heater dimensions

Length: 5 meters rolled

Diameter: 2 mm

Figure 13. Shapes Sculpture dimensions

<u>Thermal insulation:</u>

been used Formaldehyde-free fiberglass thermal insulation materials and material Fiber glass

His job: Heat-resistant and insulated

Figure 14. Thermal insulation

(حضو الكنيست) / 0.035w≥	توصيل حراري
15 م	طول
10-48 كجم / م 3	كثافة
الألياف الزجاجية	مواد
98.2٪	نافرة من الماء
20-100 مم	سماكة
هايك	اسم العلامة التجارية
الحفظ الحراري	وظيفة
1.2 م	عرض
تشونغتشينغ ، الصين	مكان المنشأ
أبيض	اللون

Table 7. Thermal insulation

Galvanized iron:

It was completed Our use of stainless galvanized iron in the construction of furnace parts that are exposed to heat and corrosion, such as the outer structure of the furnace, and it is characterized by its resistance to chemical and thermal corrosion for high temperature applications.

Figure 13. Galvanized core mesh

Figure 13. Galvanized iron

Refractory cement:

Wear-resistant refractory cement was used on the corrosion-prone parts of the kiln.
Refractory cement was used to stick the bricks together

Type of cement used: 42-85% Al_2O_3.

Information index

CH-NT-42	CH-NT-50	CH-GL-60	CH-GL-70	CH-GL-85	العلامات التجارية
42	50	60	70	85	≤ ٪/ ، Al2O3
-	-	-	-	-	≥ ٪/ CaO
1640	1660	1700	1720	1780	≤ °C / الحران
1350	1400	1400	1450	1500	درجة حرارة الاختبار بعد الاحتراق لا تزيد عن ± 1٪ (عزل 3 ح) / °C
25	30	30	35	35	مقاومة الانضغاط (بعد التجفيف عند 110 ± 5 ° C) / Mpa
3.5	4	4	5	5	قوة الانحناء (بعد التجفيف عند 110 ± 5 ° C) / ≤ Mpa

Table 8. Specification refractory cement

Chapter 5:

CONTROL SYSTEM DESIGN AND IMPLEMENTATION

Chapter 5: CONTROL SYSTEM DESIGN AND IMPLEMENTATION

5.1Control system design and implementation:

1- A PID type control can be used to implement operations, so it is operated. either manually or by the PLC, which gave it flexibility in use.

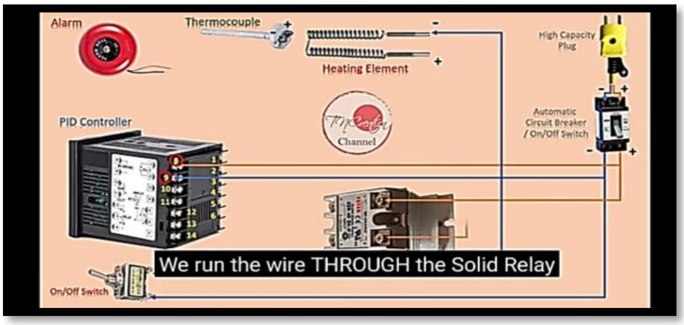


Figure 17.The circuit of PID control

2- The unique feature is giving a report or a message showing how many operations, were carried out, how long they took, and how much temperature was used, using a display

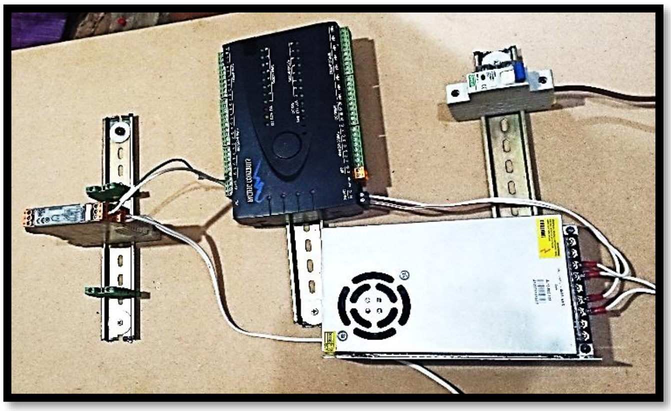


Figure 18.The circuit of PLC control

5.1.1 PID Temperature controller

Figure 19. The PID control

INKBIRD

1-Specification

Supply Voltage	AC 100~240V 50/60Hz (model: ITC-106RH, ITC-106VH)	
Operating Voltage Range	85~110% of the rated voltage	
Power Consumption	5VA（100~240VAC）=4 W	
Display Code	PV: displays in red high luminance LED with 9.9mm height of 4 digits	
	SV: displays in green high luminance LED with 8.00mm height of 4 digits	
Display Accuracy	±0.2%FS 0.1ºC/ ºF (＜1000ºC/ ºF) ；1ºC/ ºF (≥1000ºC/ ºF)	
Sampling Period	0.5 second	
Temperature Compensation	0~50 ºC /32~122ºF	
Control Output	Relay Output: AC 250V 3A (resistive load)	
	Voltage Output (for driving SSR): 12VDC, 30mA DC	
	Maximum load: 600Ω	
	Electrical Life of Relay:100,000 times	
Alarm Output	Relay Output: AC 250V 3A (resistive load)	
Weight	About 140g	
Working Temperature	-10~ 55 ºC / 14~ 131 ºF (No freeze or condensation)	
Working Humidity	RH 35-85%	
Storage Temperature	-25~65ºC / -13~ 149 ºF (No freeze or condensation)	

Table 9. The specification of PID Control

2-Models

Model	Control Output	Supply Voltage
ITC-106VH	SSR Output	AC 100~240V

Table 10. The Model of PID Control

3- Dimension and Installing

Size Diagram (Unit: mm)

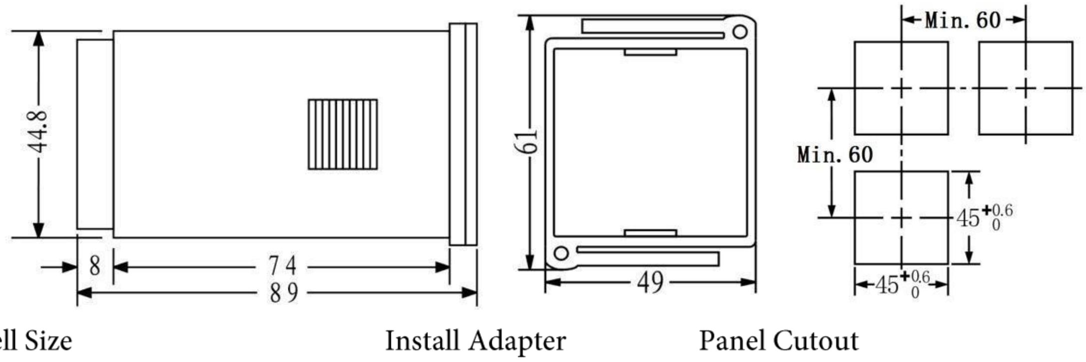
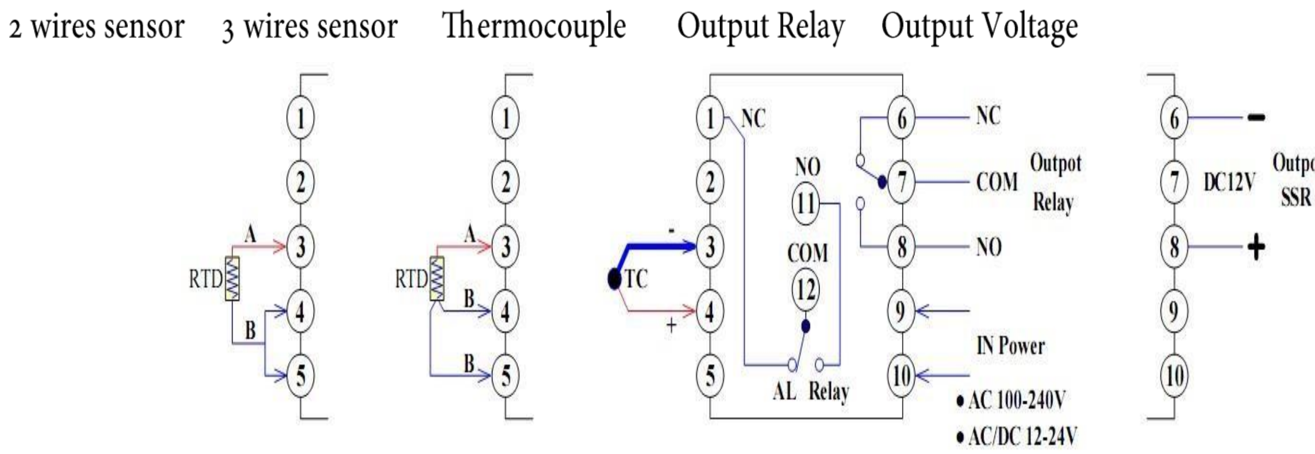


Figure 20. The Dimension and Installing

Insert the temperature controller into the hole in the panel, put the adapter from the back and push it to button and make it clasp for temporarily fastening. Be sure there is no gap among the controller, panel and the adapter and then fasten the two screws on the adapter with the torque of 0.29N to 0.39N. Be sure the ambient temperature is within the stated working range in the manual, especially when

there are two or more temperature controllers instal (67)

4- Wiring Digram



Power Connection: #9 and #10 terminals are for power connecting, which its supply voltage should be match the item model.

Figure 21. Specification of Wiring Diagram

Platinum Resistance Sensor Connection:

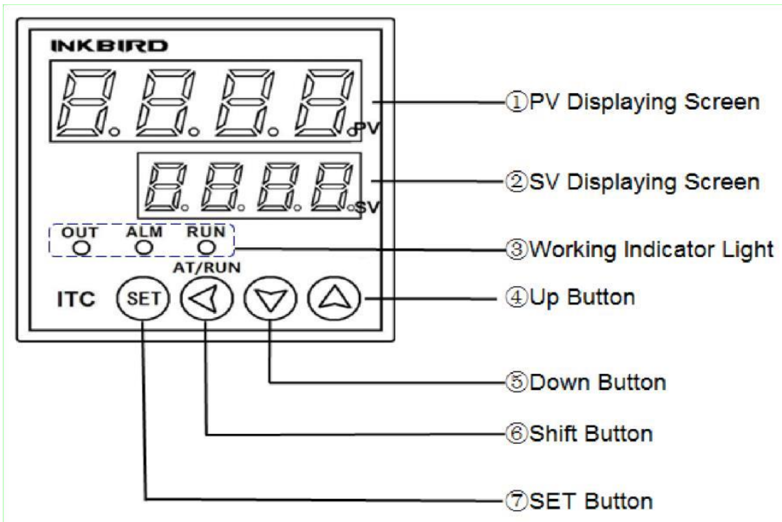
Three wires sensor:

connected the #3 terminal with the red wire, the other two bule wires should be separately connected to the #4 and #5 terminals.

And the sensor with two wires (e.g. PT100) should be separately connected to the #3 and #5 terminals, the #4 and #5 terminals must be connected with the wire.

- **Thermocouple Connection(e.g. K sensor):** #3 terminal is connected to the positive pole(Red) and the #4 terminal is connected to the negative pole(Blue).

4. Panel Instruction



①**PV Displaying Screen:** Displaying the measuring value or the setting parameters

Figure 22. The Panel Instruction Diagram

SV Displaying Screen:

Displaying the setting value or the set parameters readout.

②**Working Indicator Light**

OUT: Control Output Indicating

ALM: Alarm Output Indicating

RUN: Manual Operation Indicating

③**UP Button:**

when setting the value, pressing the up button can be increase the value that would be added rapidly by keeping press this button

④**DOWN Button:**

when setting the value, pressing the down button can be decrease the value that would be reduced rapidly by keeping press this button.

⑤**SHIFT Button:** when setting the value or parameters,

A, pressing this button to switch to the required value position.

B, Pressing this button can be shift to the submenu from the main menu.

C, Pressing this button can be freely switch to another mode from manual or the automatic operation.

SET Button: Pressing this button can read the value of control output and the set temperature. Hold and press this SET button for 3s or more can be enter into the parameters settings mode.

5- Setting Parameters

5.1 Sensor Type and Measuring Range

Sensor Type	Input	Code	Measuring Range	
Thermocouple	K	k	-50~1300 (°C)	-100~2300(°F)

Remarks:

The faulty input sensor is the "K" type.

*If select the wrong input sensor, the measuring temperature will be incorrect and may exceed the measu range with displaying "**orAL**", control output off.*

5.(2) Operation Guide

5.(2-1)Boot screen display

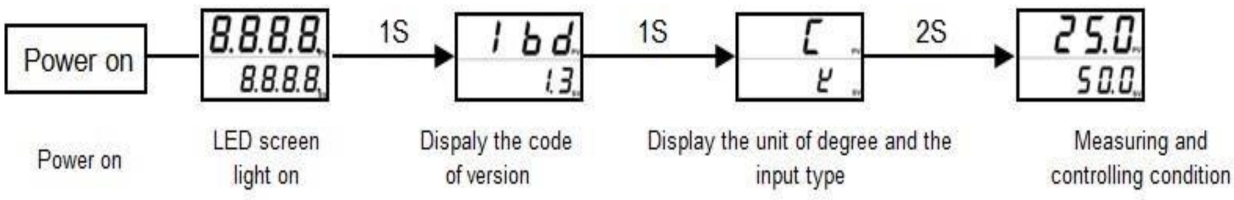


Figure 23. Specification of Boot screen display

5.(2-2) Enter the settings menu

Under measuring and controlling condition, press / to set the temperature value, press and hold the "SET" button for 2 seconds to enter into the parameters settings mode.

5.(2-3) Sensor Input Type Setting:

Set the sensor input type as required(the faulty is the "K" type), the temperature need to calibrated for there will be deviation due to the sensor and the operating environment.

5.(2-4) Output Parameters Setting:

The recommended control mode for the first use is the PID control(default settings of PID control), please select the self-tuning mode when the controlling temperature cannot reach the desired value after it worked over time with the stable controlled temperature. Under the self-tuning mode, the temperature will exceed the set value and activate the alarm. The exceeding temperature value is related to the heating system but it will return to normal after finished the self-tuning. If the temperature control requirement is undemanding, please select the ON/OFF control mode which its range of temperature controlling is depended on the dF(hysteresis). As below is the setting and the calculation:

The low temperature point=SV setting value-dF

The high temperature point=SV setting value+dF.

dF(hysteresis) can be worked both on alarm setting and ON/OFF control mode.

5.(2-5) PID Parameters Setting:

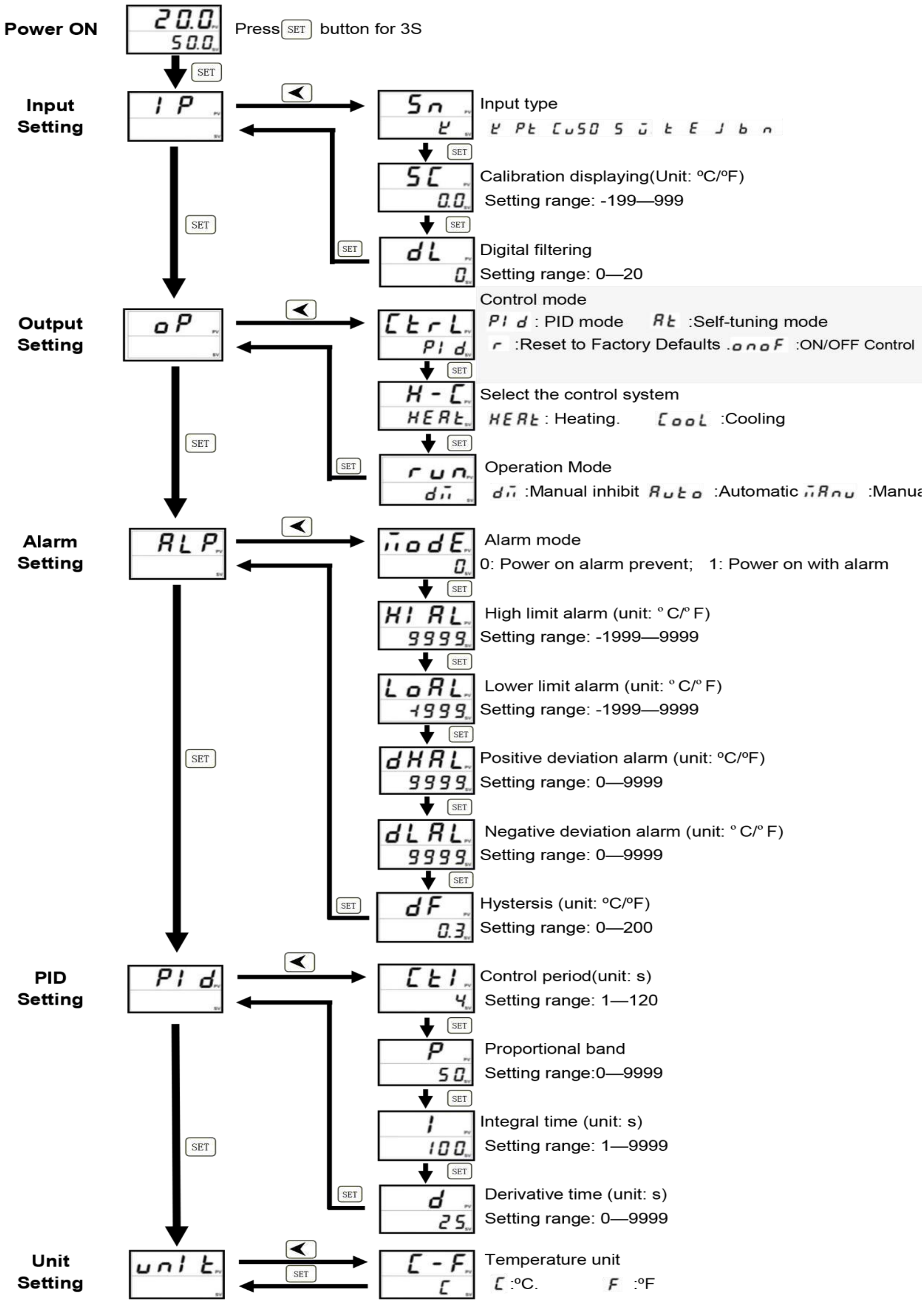
SSR control output: the control period(CtrL) can be set within 4 seconds(default 2 seconds);

Relay control output: The control period (CtrL) should be set to longer time(the normal is 18s) that would prolong the work life of the relay.

5.(2-6) Setup Flow Chart:

(Please check next page)

Setup Flow Chart



5.3 Automation of Heat Treatment Process using PLC and LabVIEW

Automated method: This system is fully automated and it will require one time person to start the process with use of PLC and LabVIEW.

Programmable Logic Controller: PLC is an electronic device3 which reads the status of the external input devices and execute by the microprocessor logic, sequential, timing, counting and arithmetic operations according the status of the input signals as well as the pre-written program stored in the PLC.

Programmable logic controllers, sensors, and other process instrumentation enable real-time monitoring of process parameters and optimal system control [6]. Using PLC enables the prediction of possible system failures through the acquisition of process data obtained from 13 various types of sensors that measure process variables of interest, analysis of the data, and tracking of their trends. A. Control system specifications for both furnaces, the following components form the basis of the control system: 1) Programmable logic controller (PLC), ABB series with integrated ethernet communication port and corresponding modular digital/analog inputs and outputs; 2) Operator programmable panel (OP) with touch screen, with ethernet communication port; 3) Application software implemented on the PLC and operator panel. Data exchange between PLC and OP is realized via the Ethernet communication port and MODBUS TCP/IP protocol. Moreover, the system is provided with the possibility to upgrade monitoring by using SCADA (Supervisory Control and Data Acquisition) applications. PID algorithm control is the most common control algorithm used in the metal furnace industry due to its simplicity and robust performance in a wide range of operating conditions. Today's PLC controllers contain a PID in discrete form as a standard program module. The PLC, with its A/D and D/A converters, receives analogue inputs from the controlled process (temperature, pressure, etc.), processes the received data, and sends the control signal to the actuating devices. The processing of the obtained data is carried out using PID algorithms integrated into the PLC executable program. With the correct sampling period, the digital controller behaves comparably to the analogue one, and satisfying controller performance will be obtained [68].

The PLC application program was created in the CODESYS programming environment [69].

For the program implementation of the PID controller within the CODESYS development environment, a standard library is used, within which there are functional blocks in which the PID algorithm is implemented.

Figure 24. Furnace setup

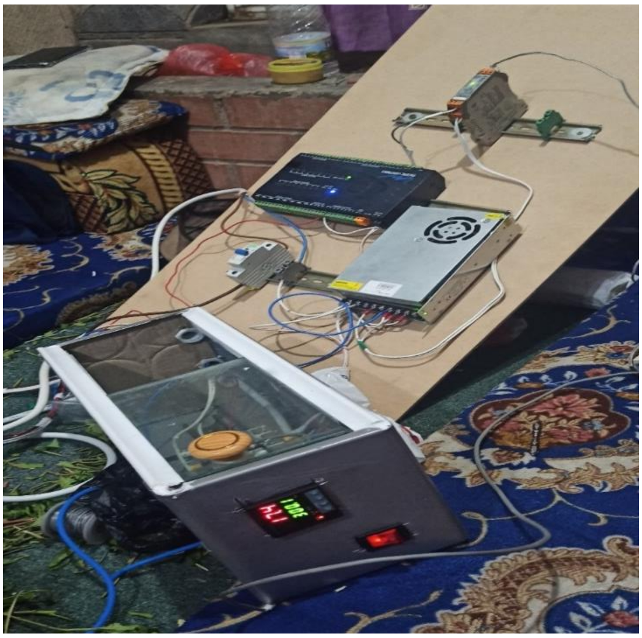


Figure 25. Circuit of control is setup

5.4 The the program is divided to six stages

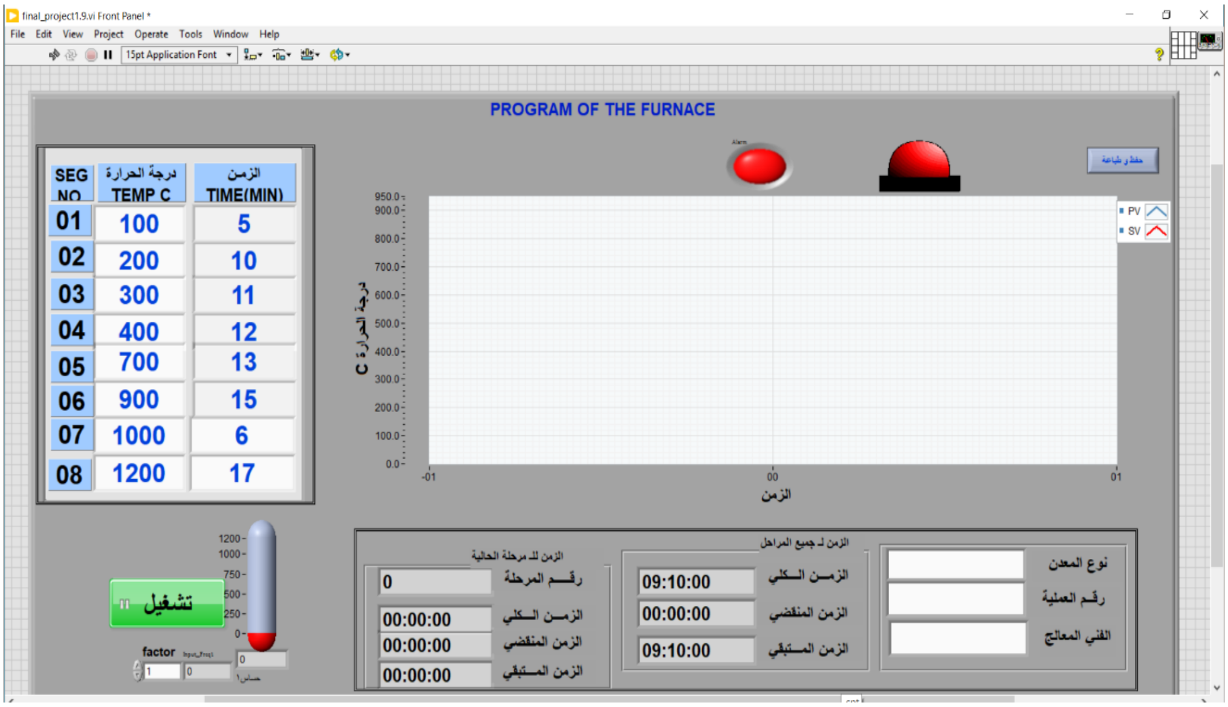


Figure 26. Graphical interface of the program

1-Graphical interface for entering username and password

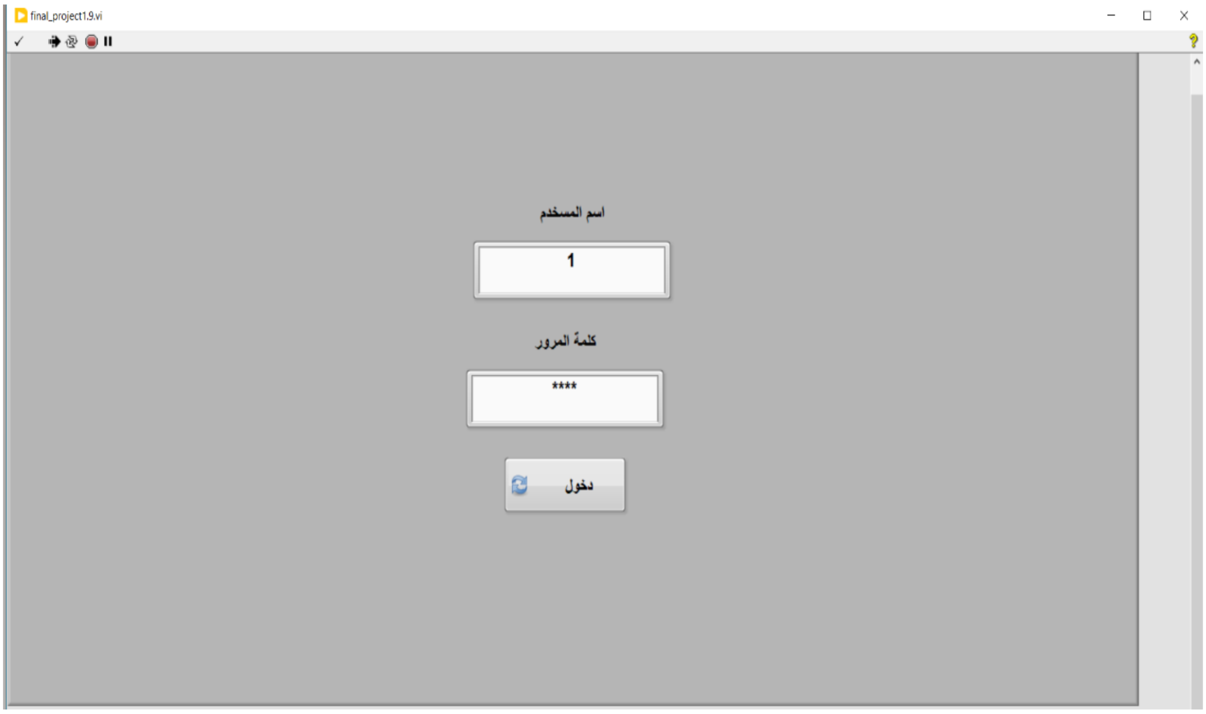


Figure 27. start of the program

- ✓ -block diagram of the user name and password

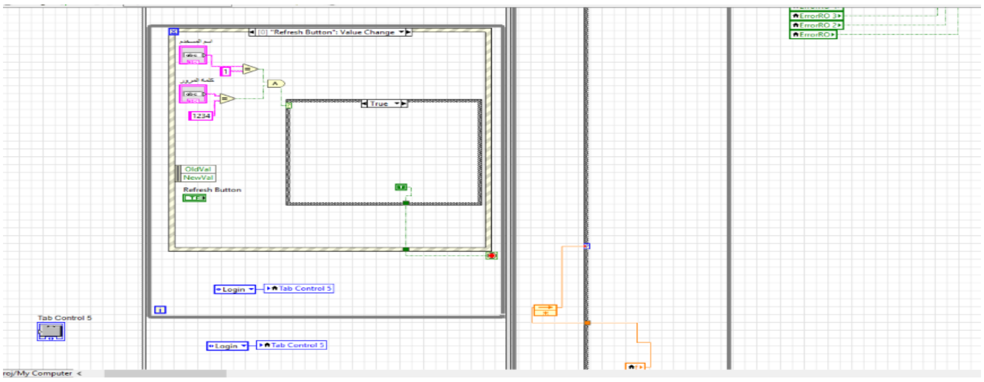


Figure 28. Block diagram of start of the program

2-graphical interface part for organizing process stages

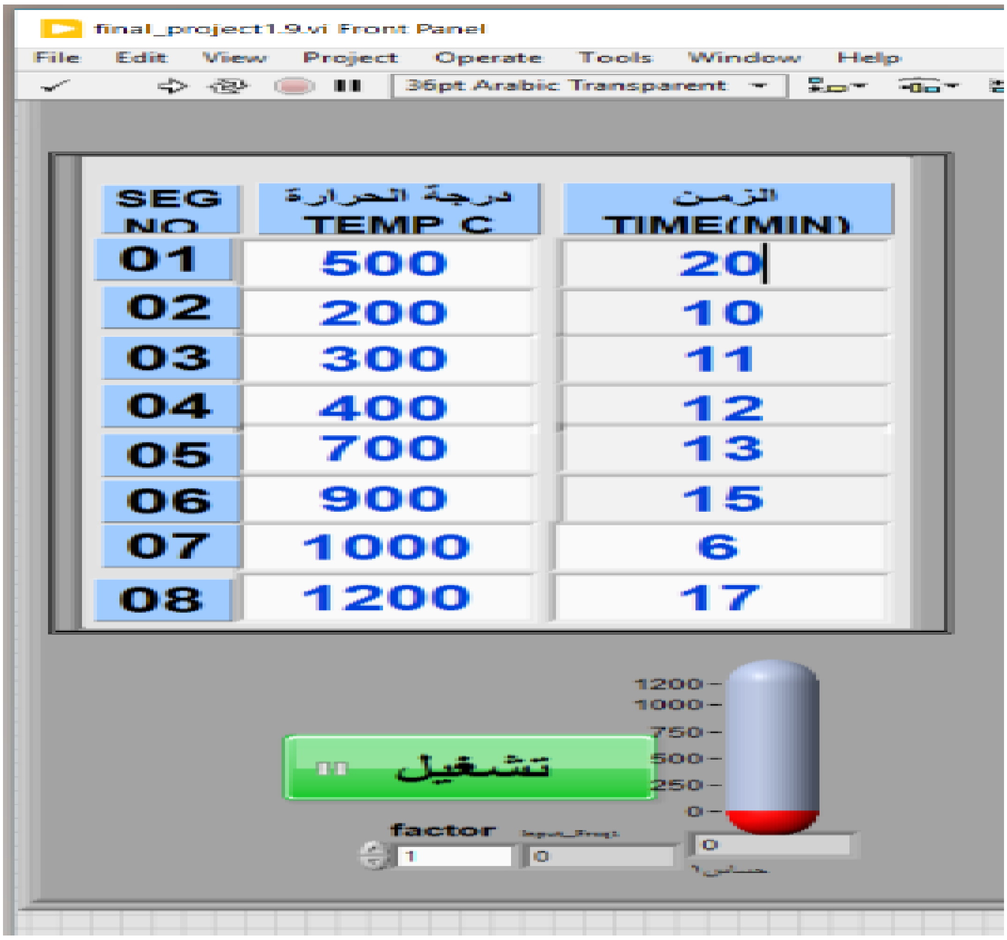


Figure 29. stages of processes

✓ block diagram of the stages of processes

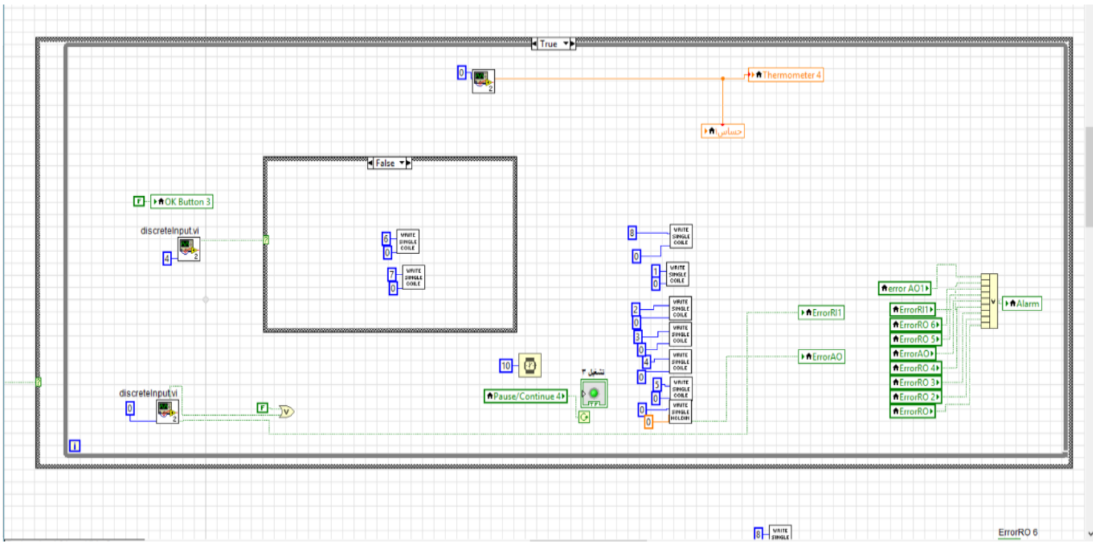


Figure 30. block diagram of stages in the processes

3-Part of Request to enter variables and calculate time

Figure 31. Request to enter variables and calculate time

✓ block diagram

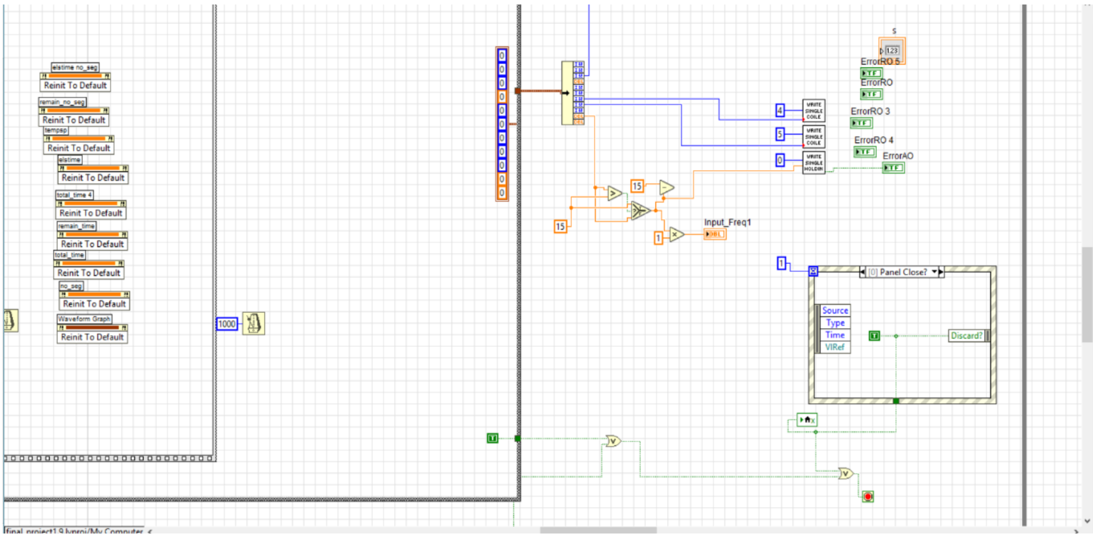


Figure 32. Block diagram of Request to enter variables and calculate time

4-Heat Curve

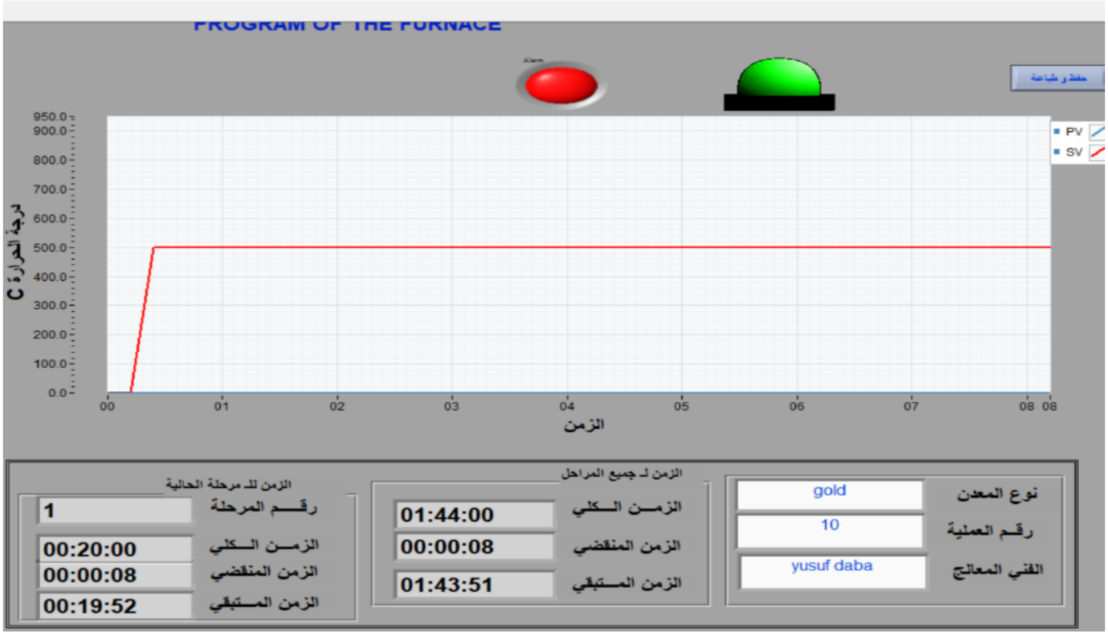


Figure 33. Heat Curve

✓ block diagram of the heat curve

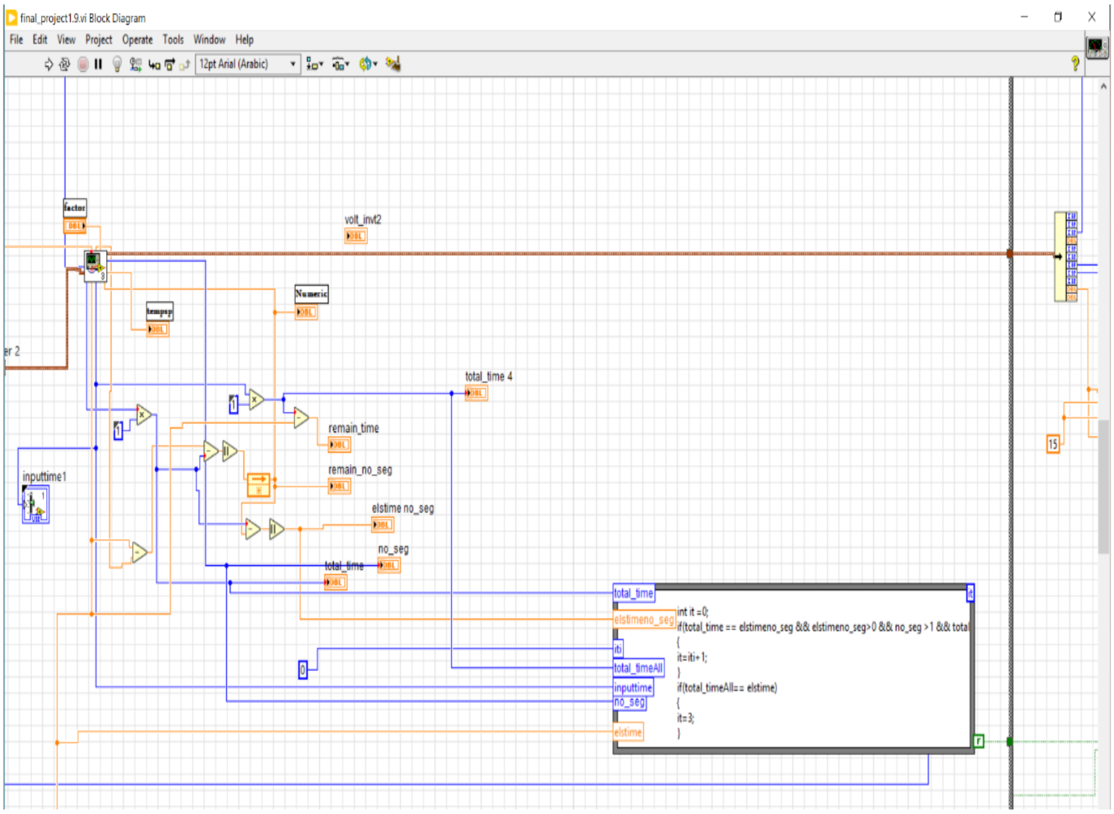


Figure 34. Block diagram Heat Curve

5-Running of programming

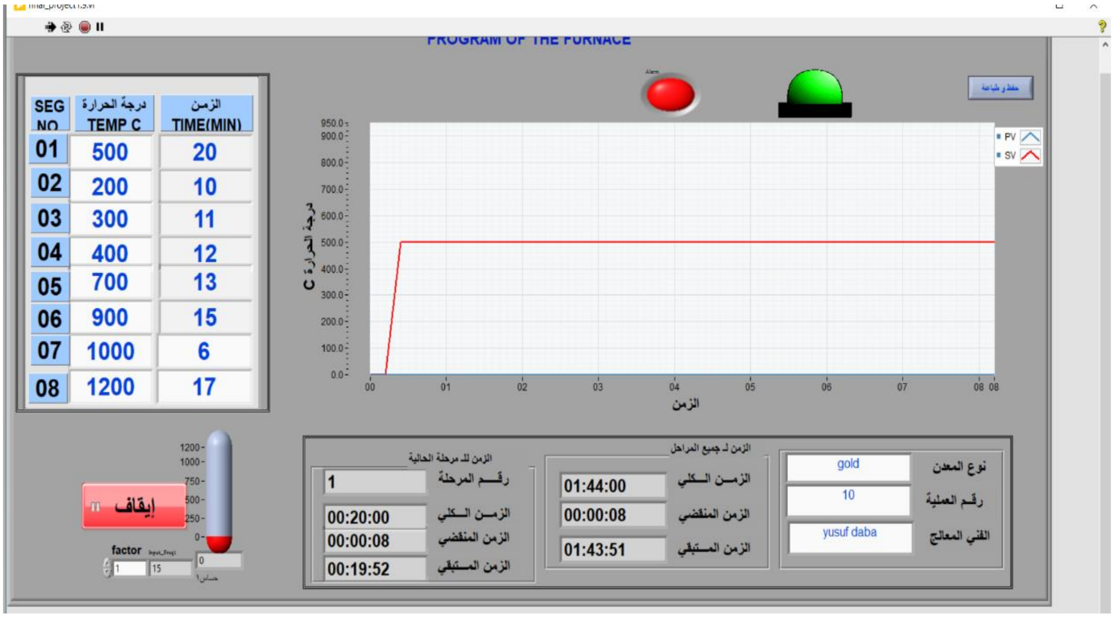


Figure 35. programming Furnace setup

6-printing the report of process

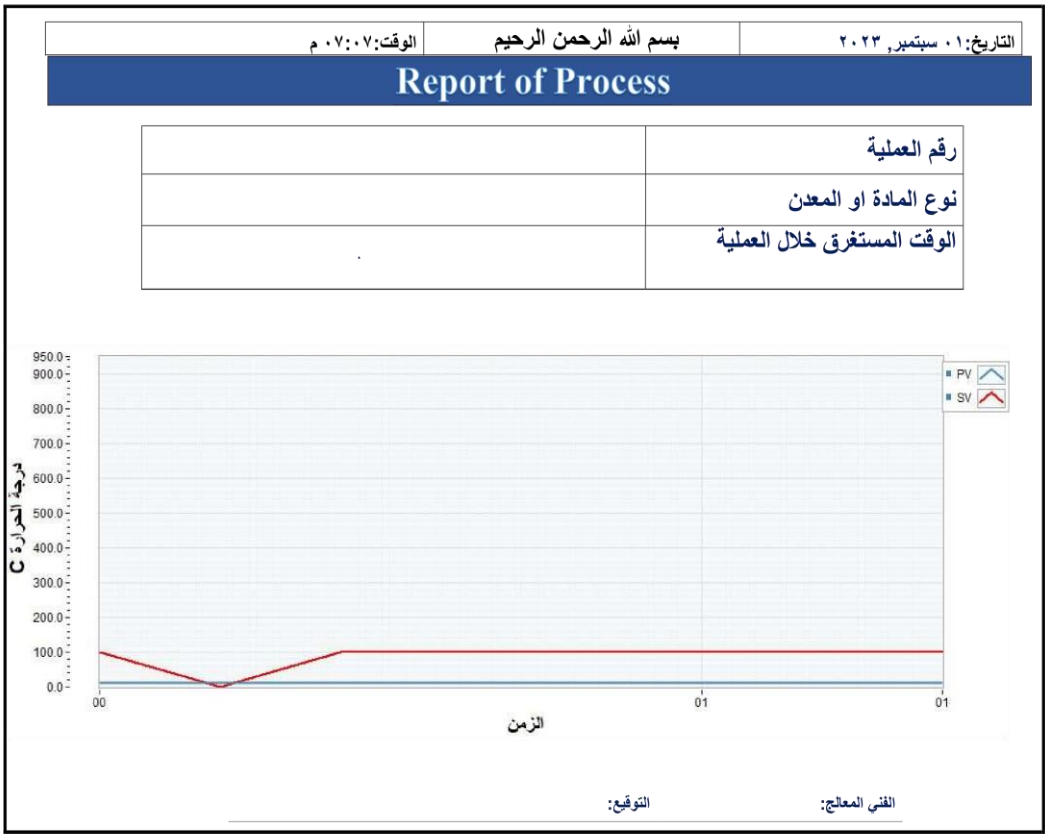


Figure 36. printing the report of process

✓ The block diagram for printing the report

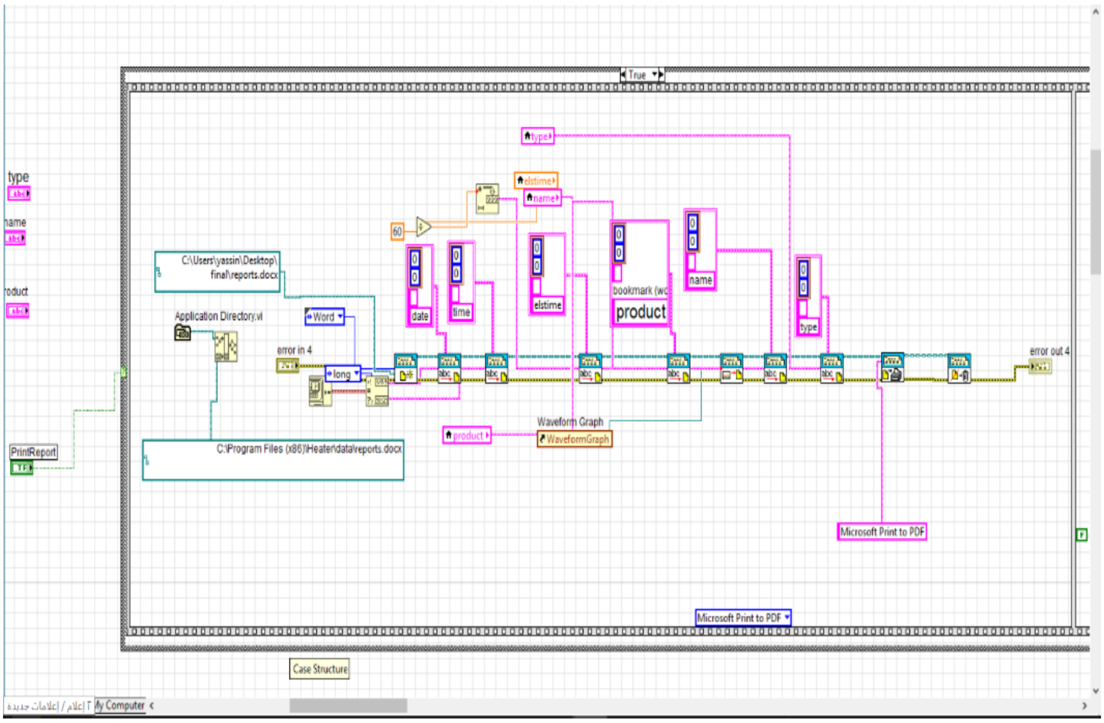
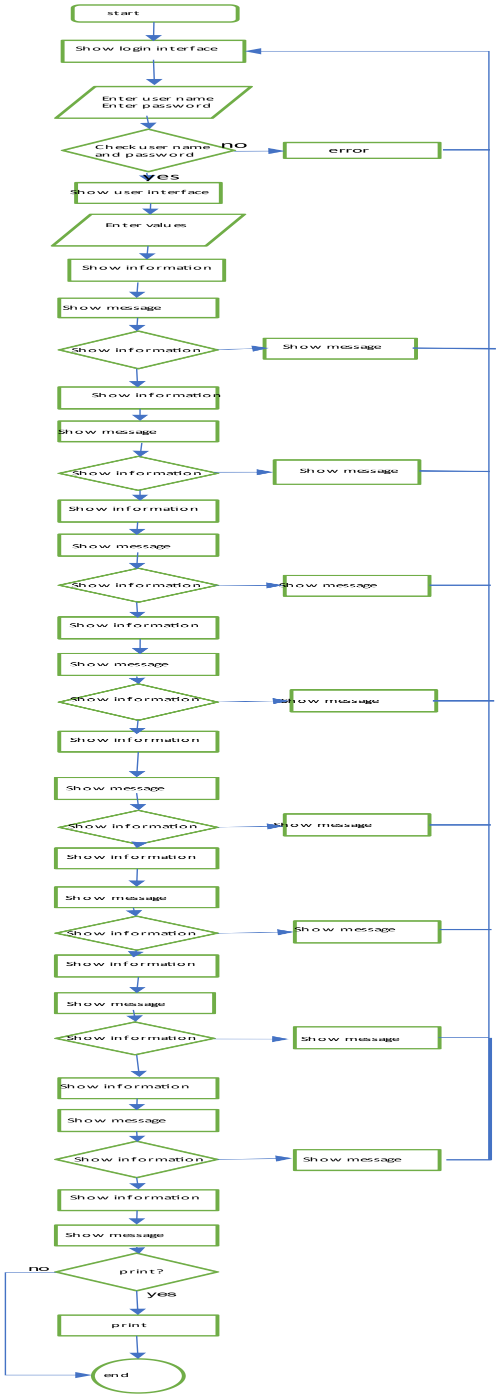


Figure 37. Block diagram printing the report of process

The flowchart of the plc programming


start
Show login interface
Enter user name
Enter password
Check user name
and password
no
error
yes
Show user interface
Enter values
Show information
Show message
Show information
Show message
print?
no
yes
print
end

Chapter 6:

Test, Results and Discussions

Chapter 6: Test and Results

6.1 The Test

Conducting tests based on specific criteria and metrics in accordance with project objectives and requirements.

The research relied on the results of the test on several grounds, including:

1-Standards and specifications:

Adoption of the results on their compatibility with the standards and specifications previously specified for the project. It was used as a standard for performance evaluation.

- Endurance Thermal: Using high-quality thermal insulation materials and designing a structure that can withstand thermal expansion to ensure the stability of the oven and protect the internal components.

- Efficiency Thermal: saving effective insulation system and design that minimizes heat loss for maximum efficiency.

- Control and automation: Use advanced control systems adjust temperature, melting time and other parameters to ensure an accurate and repeatable melting process.

- Safety and the environment: saving Procedures and equipment to ensure safety Technical and protection of potential risks, rather, the addition Use environmentally friendly materials and structure design that complies with environmental standards.

2- specific goals:

Analyze the results according to the specific objectives of the project. Advance is among these goals:

i. <u>improvement in smelting efficiency:</u> Improve smelting process efficiency and reduce harmful emissions.
ii. <u>Product quality improvement:</u> improve the quality of the final product, and save Precise temperature control
iii. <u>Environmental sustainability:</u> Developing an environmentally friendly furnace.

3- the information Scientific and technical:

that contribute to improving the performance of this the oven. Among these information and technologies:

i. <u>design furnace</u>**:** application Design techniques Engineering and improvement Furnace performance and increase its thermal efficiency.
ii. <u>Control Process:</u> use Automatic control and automation systems to control temperature, melting time and other important variables.

iii. **Time technologies Heat:** work Accurate techniques to control melting times and required temperatures.

4-Comparison And analysis: Comparison work in the performance of the Oven together different ovens and it between comparisons and analyses

i. <u>Compare efficiency and consumption energy:</u> analysis The performance of the furnaces is based on their efficiency in using electrical energy and converting it into heat for the smelting process.

ii. Quality and Accuracy Comparison: Comparison of physical properties and specifications for products and choose Tools Atom provide the highest quality and accuracy.

iii. Compare operating costs Maintenance: costs Operation and maintenance Oven included This includes the energy costs required to operate the oven, and the costs of ongoing maintenance and repair of faults.

6.2 The Results

6.2.1 Thermal endurance

- Insulation Materials: High-quality thermal insulation materials and thermal expansion structure design are used to ensure the stability of the oven and protect the internal components.

- The insulating materials: that were used in the project and their test results:

  i. Bricks: The bricks used in the project were tested under a temperature of 800 degrees Celsius as a minimum in terms of temperature tolerance and insulation, as the bricks used in the project reach a temperature tolerance of approximately 1700 degrees Celsius.

6.2.2 Thermal efficiency:

An effective insulation system and design that minimizes heat loss is provided to achieve the highest level of efficiency

- Thermal sealants used in the project

1-heat retardant and insulator: been used Formaldehyde-free fiberglass thermal insulation materials and material fiber glass.

2-The insulation was secured using ceramic wool to meet the appropriate places. This does not allow heat to escape from the furnace.

3-The thermal insulation used in the furnace was tested at a temperature of 1000 degrees Celsius and high thermal pressure.

4-During the experiment, we did not notice any heat leakage from inside the furnace except the outer structure of the furnace.

- Refractory cement Corrosion-resistant refractory cement was used on the corrosion-prone parts of the furnace.

  1-Thermal cement was used to glue the bricks together and prevent any thermal leakage through the gap between the thermal bricks.

  2-Materials used to prevent heat leakage into the interior of the oven

  3-The refractory cement used in the oven has been tested in terms of its tolerance to temperature, prevention of leakage, strength of adhesion, and resistance to corrosion. It was tested at a temperature of 800 degrees Celsius and proved its tolerance and adhesion to bricks successfully and with high efficiency.

6.2.3 Control and automation:

Advanced control systems were used to control temperature and time Melting and rubbing in the number of operations to be performed and other factors to ensure an accurate and repeatable melting process.

- Controls and systems used and responsible for controlling the furnace.

Advanced control systems are used to adjust temperature, melting time and other parameters to ensure an accurate and repeatable melting process.

i. PLC_A developed and automated control system was designed and used to control the time and temperature required by the user and the number of operations required to be performed or repeated

ii. PID_ During the experiment, the real-time temperature of the oven was shown during the heating process and the temperature to be reached was shown.

iii. The controllers and automated system were tested in implementing several operations at variable times and temperatures, and they were implemented and controlled at the required level.

6.2.4 Safety and environment:

Procedures and equipment are provided to ensure safety Technical and protection of potential risks, rather, the addition Use environmentally friendly materials and structure design that complies with environmental standards

- Procedures and materials used to ensure safety and the environment.

i. Done Defaming a way that guarantees the general safety of workers and the surrounding environment.

ii. High quality insulating materials are used in the construction furnace And The use of high temperature resistant firebricks and insulating materials to maintain the required temperatures and avoid thermal leakages.

iii. T what Advanced control and automation devices will be used in furnaces. These devices help in precise temperature, pressure and time setting, which enhances efficiency and reduces energy consumption.

6.2.5 Specific goals:

It was completed Analyze results according to objectives and specific tests for the project.

i. Improvement in smelting efficiency: We seek in the future to develop and improve Efficiency of the smelting process, by reducing electrical energy consumption and smelting time, which contributes to achieving cost savings and reducing harmful emissions.

ii. Product quality improvement: It was completed Provide precise control of temperature, time and processing times melting. improve the quality of the final product, The system has been mentioned previously used controllers.

6.2.6 The information Scientific and technical:

- Information and techniques used to improve furnace performance.

1.Furnace design:

i. It was completed Application of design techniques engineering to improve Furnace performance and increase its thermal efficiency.
ii. It was completed Adopting thermally insulated structures and high-quality insulating materials to maintain heat inside the oven and reduce heat loss the heat. Among the tools used and techniques
iii. The use of strong iron in designing the furnace structure to suit the furnace working conditions
iv. Use high-quality thermal insulation materials to maintain the temperature inside the oven. The insulation materials used were mentioned previously

2. Control Process:

done Using automatic control and automation systems to control temperature, melting time and other important variables.

i. Systems used in the oven It operates precisely and efficiently to ensure accurate and repeatable smelting process and reduce human error.
ii. Designing a reliable and efficient control system using micro controller's plc.

3. Time technologies Heat:

Done Accurate techniques to control melting times and required temperatures.

i. It was completed Using sensors and intelligent control systems to ensure optimal conditions for the smelting process.
ii. It was completed Use type sensors (thermos cable)

4.ComparisonAnd analysis**:**

A comparison was made in the performance of the Furnace together different furnaces and it between comparisons and analyses

i. Compare efficiency and consumption energy: analysis The performance of the furnaces is based on their efficiency in using electrical energy and converting it into heat for the smelting process.

ii. Quality and Accuracy Comparison: Comparison of physical properties and specifications for products and choose Tools in Provides the highest quality and accuracy.

iii. Compare operating costs Maintenance: costs Operation and maintenance furnace included This includes the energy costs required to operate the oven, and the costs of ongoing maintenance and repair of faults.

Comparison table

High temperature melting and processing furnace1200℃ (Project furnace) homemade		High temperature curing furnace is 800℃ Chinese made	
520*240*230 mm	Workload	700*600*700 mm	Workload
220/60/1 phase	power supply voltage	380/50Hz/3 phase	Power supply voltage
3.5kw	rated power	18KW	rated power
1200C	Temperature rating	800℃	Temperature rating
43C	Wall temperature furnace	40℃	wall temperature furnace
Fiberglass made of cotton-free formaldehyde Hyde	Temperature control mode	Silicon controlled	Temperature control mode
K thermocouple	Thermal	K thermocouple	Thermal

Table. Specification of furnace

Chapter 7

Discussions & Conclusions and Recommendations

Chapter 7: Discussions & Conclusions and Recommendations

7.1 Discussion

PLCs have become an integral part of control systems in industrial processes, characterized with great reliability and easy and less time-consuming reconfiguring of the control algorithm, compared to controllers based on relay technique and discrete electric circuit.

The temperature control of the vacuum furnace is implemented by using the software PI feedback integrated within the PLC controller. The presented temperature control method has given efficient, reliable and robust setpoint regulation. In order to avoid the oscillations of the output temperature, the integration time constant has to be greater than the processing time constant.

The project of automation of the conveyor belt furnace for metal annealing based on combination PI feedback controller and time proportional control has given the efficient, reliable, and robust set value regulation.

For both cases, future system upgrades are anticipated regarding the provided possibility to upgrade the system monitoring by using SCADA applications. After the completed revitalization of the control system for considered furnaces, obtained improvements can be concluded to include the:

- Increase of product quality,
- Reduction of the time of the heat treatment cycle and thus the increase of the production level,
- Optimization of energy consumption,
- Less machine wiring and easier maintenance,
- More accessible diagnostics of faults on the machine,
- Increased safety and reliability in operating.

7.2 Conclusion

The Conclusion of electric melting furnaces and modern control system using PLC is.

i. Electroslag furnaces are systems used to heat solid materials to high temperatures son-in-law. These furnaces were created to meet the needs of many industries such as steel, aluminum, glass and ceramics.
ii. One of the recent improvements in the control system for blast furnaces is the use of a programmable controller plc (Programmable Logic Controller). PLC is a programmed computer system that is used to control various industrial processes.
iii. Working PLC by receiving signals from a variety of sensors and other devices in the oven, then analyzes this data and makes appropriate decisions based on the software loaded on it. PLC enables precise control of smelting processes and adjustment of temperature, time, flow velocity, pressure and other parameters affecting smelting process.
iv. Using PLC in melting furnaces, many advantages can be achieved. It provides superior control accuracy and responsiveness, reduces the need for human labor and increases efficiency and productivity. The PLC can also be easily programmed to meet specific requirements and quickly modified when needed.
v. Briefly, electric melting furnaces and control system Using PLC is a modern technology that contributes to improving smelting processes and achieving superior performance and high efficiency in many industries.

7.3 Recommendations

Based on our work on the automated metal smelting electric furnace project, I would like to provide you with some recommendations that can help improve the project and successfully achieve its goals. Here are some recommendations:

1. Using advanced technologies in the control system: It is recommended to apply advanced automatic control system in the electric furnace. Temperature and pressure sensors and intelligent control techniques can be used to ensure stability and accuracy in metal smelting operations.

2. Improving energy efficiency: The efficiency of the electric furnace can be improved by applying modern technologies that reduce heat loss and reuse the thermal energy generated in the smelting process. Furnace insulation can also be improved to reduce heat leakage.

3. Provide a safe and reliable system: The electric furnace must be designed in accordance with security and reliability standards. A fire protection system and emergency stopping devices should be provided to avoid accidents and ensure the safety of workers.

4. Developing advanced operating programs: The efficiency of metal smelting operations can be improved by developing advanced operating programs that enable monitoring and analyzing the data generated, achieving precise control of the smelting operations, and improving the quality of the final product.

5. Provide regular maintenance: A regular maintenance schedule must be implemented for the electric oven to maintain its optimal performance. Key components should be checked and maintained regularly and replaced if necessary to avoid project downtime and expensive repair costs.

6. Training and qualification: Appropriate training and qualification should be provided to workers on the electric oven. Employees must be familiar with the techniques used, security procedures, and how to handle equipment safely.

7. Consider sustainability: The project must be designed in accordance with sustainability principles

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