

Preparation of Arc Furnace for Powdered Products

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1.1 ABSTRACT

Electric arc furnaces (EAFs) are extensively employed in steel production and nonferrous metal smelting. Typical electric arc furnaces have a power range of 10MW to 100MW. Laboratory electric arc furnace is a minimized AC electric arc furnace which consumes around 5KW of power. The aim of remodeling a minimized EAF is to refine some types of metals to have much better electrical and thermal conductivity, the way of getting these characteristics in laboratory with a cost-effective method is by melting the material using the minimized EAF, then rapidly cooling the molten metal with crushed ice put around the crucible. Using this type of EAF in combination with this cooling method will give smallest grain size possible after the material reforms in a mold (amorphous crystal shape), which is the best in terms thermal and electrical conductivity. Stainless steel is an example for the materials that could be refined in that way, which can be used in variety of applications in the biomedical field and prosthetics inside the human body.

1.2 Introduction:

An electric arc furnace (EAF) is a type of industrial furnace that is used to produce steel and other vital materials (e.g) The quantity of energy required in an electric arc furnace is determined by the quality and condition of the charge materials (scrap, direct reduced iron DRI , and others), as well as the amount of slag and the entire heat time [1]. Electric arc furnaces are responsible for a significant amount of the world's steel production (about 31%). In current facilities, electric arc furnaces work with very huge electrical loads ranging from several megavolt amperes (MVA) to 250 MVA, which means that even tiny efficiency gains result in significant electrical energy savings [2]. When melting scrap in an Electric Arc Furnace (EAF), electrical energy is the primary source of power. The EAF must be thoroughly understood in order to optimize power usage. Also, because electric arcs are the primary source of power, their electrical and thermal properties must be investigated. The length of the arc determines its power, which can be modified by moving the electrodes [3]. The high temperature created by the electrode arc is used to smelt ores and metals in an electric arc furnace. The energy is greatly concentrated when a gas discharge creates an arc, and the arc zone temperature is above 3000 °C. Electric arc furnaces are more versatile than conventional steelmaking furnaces for smelting metals, can efficiently eliminate impurities such as sulfur and phosphorus, furnace temperature is easy to manage, and the equipment occupies a small footprint, making them ideal for smelting high-quality alloy steel [4]. Electric arc furnaces are industrial furnaces that use metal or non-metal electrodes to produce electric arc heating. According to the arc form, electric arc furnaces are classified as three-phase EAF, consumable EAF , single-phase EAF , and resistance EAF [5]. The furnace cover, furnace door, tapping tank, and furnace body make up the electric arc furnace body. Basic

or acid refractory is used to construct the furnace's bottom and walls. Electric arc furnace can be classified into three types based on the transformer capacity per ton of capacity: ordinary power EAF, high power EAF, and ultra-high power EAF. Electric arc furnace steelmaking involves feeding electric energy into the EAF via a graphite electrode and using the arc between the electrode end and the charge as a heat source. The environment in EAF may be modified, which is extremely useful for the smelting of steel grades with more oxidizable constituents. Electric energy is used as the heat source in EAF, and the atmosphere in EAF can be adjusted. Electric arc furnace steelmaking was first employed to smelt alloy steel shortly after its creation, and it quickly advanced [6].

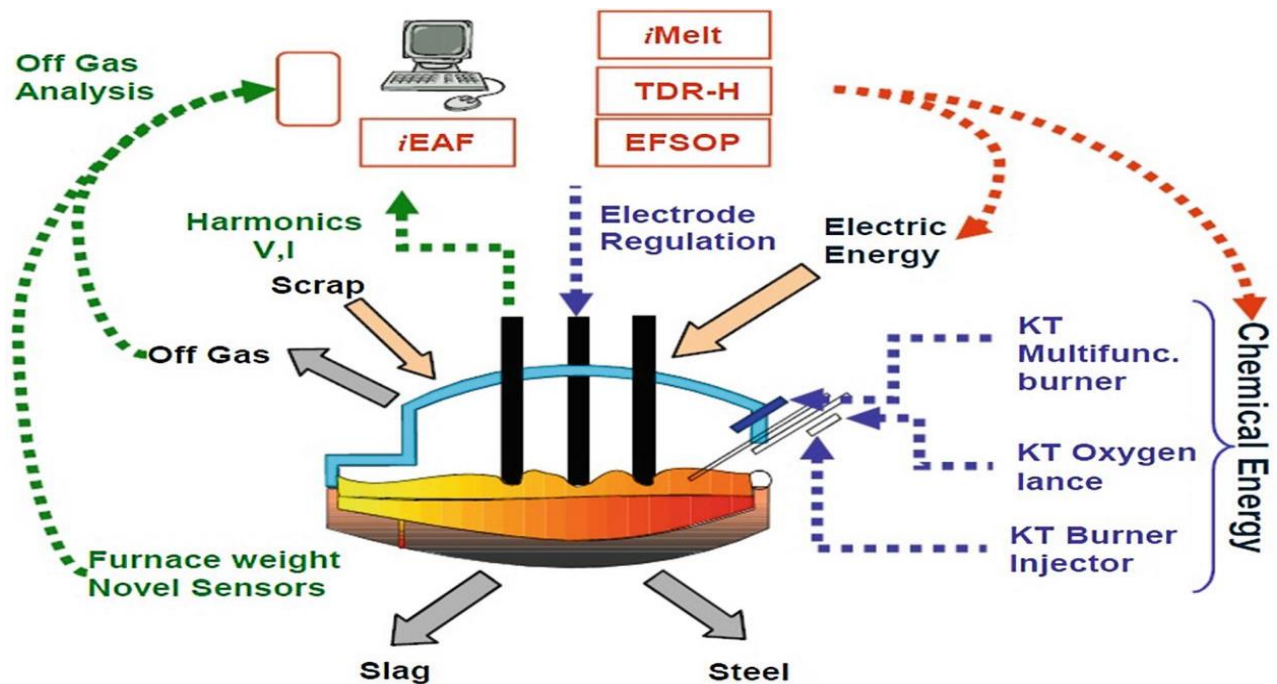


Figure 1.1 The Electric of Arc Furnace (EAF) [6].

1.3 Objective:

- The object of the laboratory electric arc furnace is to melt a specific metallic material and instantly cool it with the crushed ice, to obtain smallest grain size possible, which has optimal electric and thermal conductivity. In other words, closer to the single-crystalline structure. As mentioned earlier, these types of materials have the best electrical and thermal conductivity among others. The melted sample would have amorphous crystals (crystals with no identifiable characteristics shape).
- The object of the classic electric arc furnace in the biomedical engineering fields is to manufacture metals which are used in the biomedical field. For example, stainless steel, which has several applications in this field (cardiovascular implants, stents, artificial valves, orthopedic implants, bone fixation, artificial joints, dentistry, orthodontics, fillings and artificial ear drum).

1.4 Types of Arc Furnace:

There are types of Arc Furnace namely:

1.4.1 Direct Arc Furnace: A direct arc furnace uses the charge as one of the electrodes and heats it by creating an arc between the electrodes and the charge. The furnace's chamber is walled with refractory material. Between the electrode and the charge, an arc is formed. Three electrodes made of carbon or graphite are projected from the top of the furnace, and three-phase supply is given. The direct arc furnace is very commonly used for the production of steel [7].

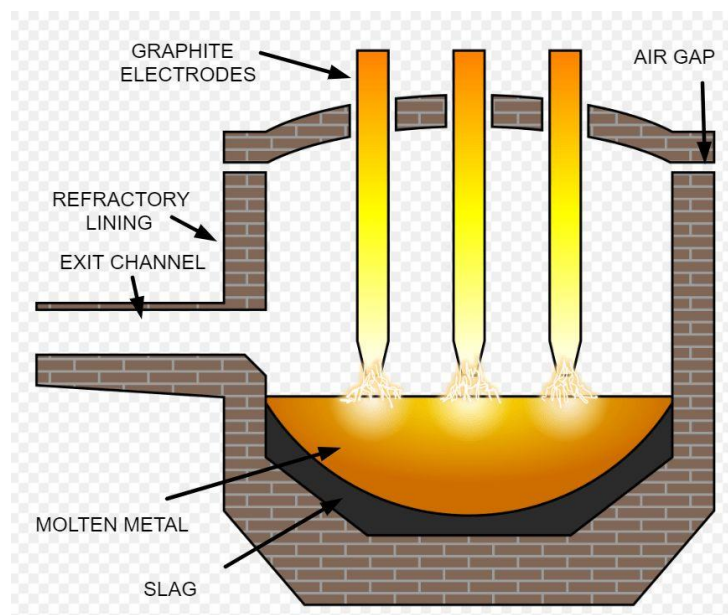


Figure 1.2 Direct arc Furnace [7].

1.4.2 Submerged Arc Furnace: are a specific heating systems used to make a range of ferroalloys via the use of electrical power. Some selected advantages of the SAF are simple, safe maintenance and high process efficiency. This furnace is used for the manufacture of ferrochrome and ferromanganese. In submerged arc furnace, the electrodes project down into the charge remains immersed in it [8].

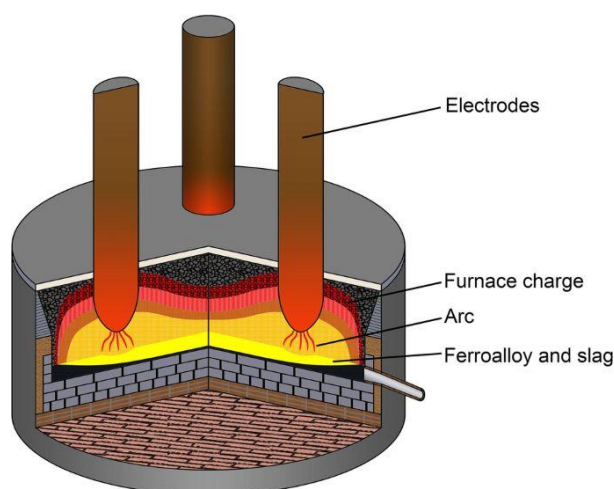


Figure 1.3 submerged Arc Furnace [8].

1.4.3 Indirect Arc Furnace: In this situation, an arc is generated between two electrodes above the charge, and heat is transferred entirely through radiation to the charge. As a result, the temperature of the charge in this case is lower than in a direct arc furnace. Because there is no current flowing through the charge in this furnace, there is no stirring motion, and the furnace must be rocked mechanically. As a result, the furnace is shaped like a cylinder, with electrodes protruding into the chamber from each end and along the horizontal axis. As a result, indirect arc furnaces are ideal for melting metals with lower melting points, such as brass, copper, zinc, and other non-ferrous metals [9].

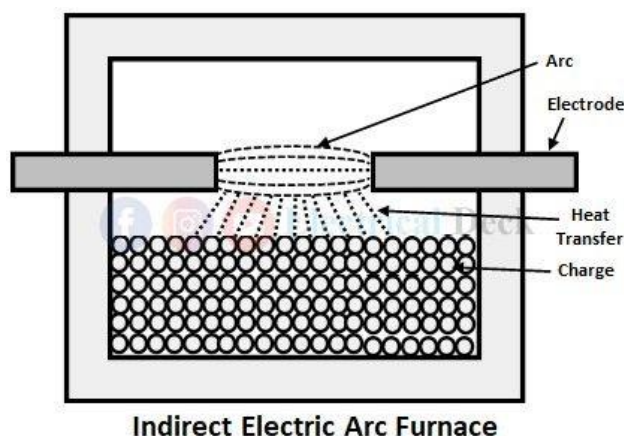


Figure 1.4 Indirect Arc Furnace [9].

1.5 Structure of Electric Arc Furnace:

1.5.1 Lower Bottom Shell:

The shape of a typical EAF is cylindrical. It's made up of the bottom, which is shaped like a dish and has a spherical shape. It's attached to a cradle arm that sits on a rocker rail and features a curved segment with geared teeth. This system is required to tilt the furnace on one side for tapping (spout or EBT system) and removing slag on the other side (slag door). A refractory lining covers the bottom and is usually made up of a safety lining (usually bricks) and a working lining at the top (normally ramming mass). The tapping mechanism (eccentric bottom) and, in some cases, gas stirring devices (well blocks purging plugs) are located at the bottom of the EBT EAF furnace [10].

1.5.2 Upper Sidewall Shell:

The upper part is composed by a cylindrical shell. In most of the EAF this part can be easily removed from the bottom. Once the shell is removed, the furnace bottom can also be changed out. The upper sidewall shell is also covered by a refractory lining (bricks) [11].

1.5.3 Water Cooled Side wall Panels:

Above the slag line, the furnace sidewall is commonly made up of water-cooled panels that must bear strong thermal and mechanical loads [12].

1.5.4 Roof:

The furnace's upper component, referred to as the roof, is a flattened spherical. The outside perimeter of the roof is formed by a water-cooled roof ring. This is a cage in which water-cooled panels are put into the center to make a cylindrical entrance. To fill this gap, a refractory deltasection is placed. This delta portion has the smallest opening possible around the electrodes to avoid arcing between the electrodes and the water-cooled panels. Roof and electrode supports can be relocated jointly or separately in most cases [13].

1.5.5 Areas Available for opening:

The Delta refractory roof has three opening regions via which the graphite electrode columns can enter the furnace. Another hole (dubbed the "fourth hole") is utilized to extract furnace gases (suction system). Other processes, such as continuous feeding of DRI and HBI or coal and lime injections, may require an extra hole (dubbed the fifth hole). A slag door is installed on the furnace's sidewall for slag removal as well as extra activities such as the use of manual oxygen lances. A tapping spout is installed on the sidewall of the furnace in the side tapping EAF, whereas an EBT system (tap hole) is provided on the bottom tapping EAF. A number of ports could be added around the furnace shell to house burners. Low on the furnace sidewall, opening regions for oxygen, lime, or carbon injection may be provided [14].

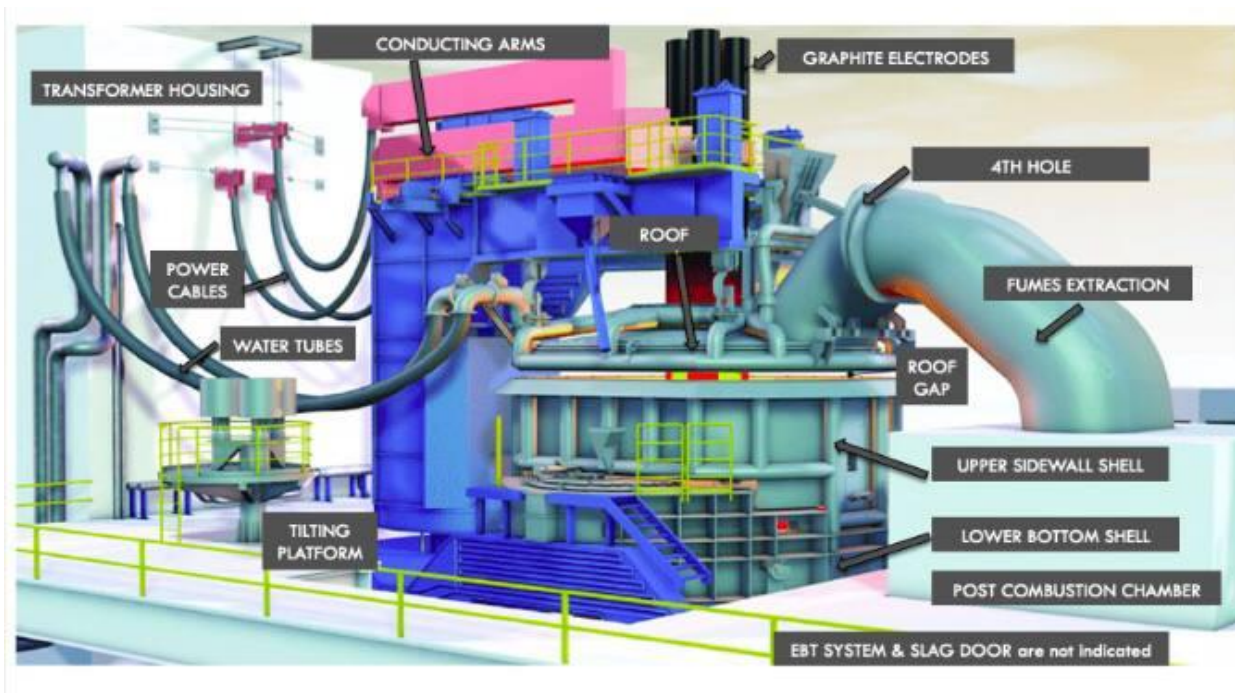


Figure 1.5 Structure of Electric Arc Furnace [14].

1.6. Dc Arc Furnace Components

An electric arc furnace used for steelmaking consists of a refractory-lined vessel, usually water-cooled in larger sizes, covered with a retractable roof, and through which one or more graphite electrodes enter the furnace. The furnace is primarily split into three sections in other words The main parts of the electric furnace are the roof, hearth (lower part of a furnace, where molten metal is collected), electrodes, and sidewalls [15].

- the-shell ,which consists of the side walls and lower steel" bowl" The lower part of the submerged electric arc furnace is composed of a cylindrical steel shell with a flat bottom or hearth. The interior of the shell is lined with two or more layers of carbon blocks. The furnace shell may be water cooled to protect it from the heat of the process.
- the hearth, which consists of the refractory that lines the lower bowl The hearth includes metal and slag.
- the-roof, which maybe refractory-lined or water-cooled,and can be shaped as a section of a sphere, or as a frustum (conical section). The roof also supports the refractory delta in its centre, through which one or more graphite electrodes enter, The roof consists of three holes through which the electrodes are inserted.
- The tilting mechanism is used to pour the slag from the container before the pure form of iron is to be taken out [16].
- The incinerator mainly consists of the grate frame, the grate, feeding hopper and chute, pusher, slag machine, furnace shell and burners, hydraulic systems of the incinerators, and other equipment and parts.

Waste is fed into the hopper by a grab crane, and slips onto the pusher platform through the chute, and is then pushed into the furnace by a hydraulic pusher for incineration. The grate is moved by hydraulic devices. Waste is stirred and turned over through the reciprocating movements of the active grate and the fixed grate, and is brought into full contact with air. In addition, according to the properties of waste and rate and temperature of burning, the speed of each grate can be adjusted by hydraulic drive machines, and the primary air volume of each grate

area is adjusted to ensure full combustion of waste. The slag block formed after incineration is sent into the slag pit by slag machines [17].

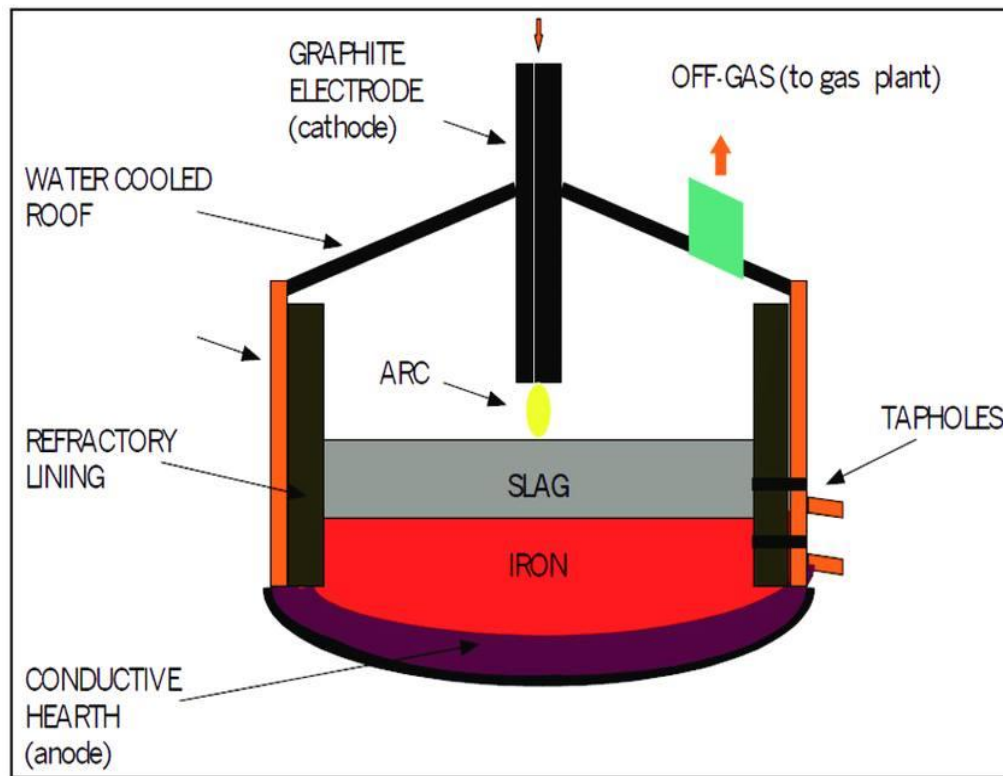


Figure (1.6-a) DC Electric Arc Furnace [17].

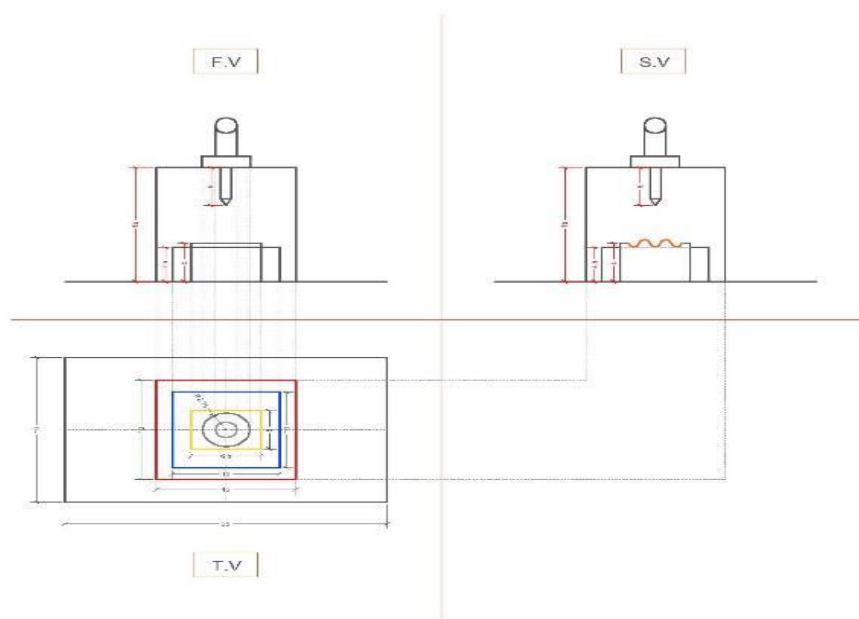


Figure (1.6-b) Engineering drawing for the electric arc furnace [34].

1.7 AC Electric Arc furnace:

- The electrodes are three in number and are in circular cross-section. Graphite is used as electrodes because of its high electrical conductivity.
- The electrodes positioning system helps to raise and lower the electrodes automatically. The electrodes get highly oxidized when the current density is high.

- Electric arc furnaces (EAFs) used in steel production use high current and low voltage electric energy to melt and purify the charge materials. EAF is a batch furnace that consists of a refractory-lined tank with a retractable roof through which electrodes are introduced into the furnace. The body of EAF is formed like a big bowl, with a dish-shaped hearth. Inside the shell is a refractory lining. A removable roof formed of refractory bricks and held in place by a roof ring covers the reaction chamber of the furnace from above. It comprises three graphite electrodes connected by flexible cables and water-cooled copper tubes and is powered by three phase alternating current (AC) [18].

1.8 Advantage of Electric Arc Furnace :

The following are some of the benefits of using an electric arc furnace:

1. The use of an Electric Arc Furnace is superior than the traditional method of producing steel from ores. We can get a pure type of steel from scrap by using this procedure
2. capable of generating the entire range of steel grades without requiring a specific type of charge (scrap, sponge, iron, pig iron, hot metal),
3. minimal initial investment, programmable and automated melting process, high efficiency and flexibility
4. Steel may be manufactured entirely from scrap metal thanks to the usage of EAFs. When compared to primary steelmaking from ores, this significantly reduces the energy required to produce steel.
5. Another advantage is flexibility: whereas blast furnaces cannot vary their output considerably and can operate for years at a time, EAFs can be started and stopped quickly, allowing the steel mill to adjust production in response to demand [19].
6. Although steelmaking arc furnaces generally use scrap steel as their primary feedstock, if hot metal from a blast furnace or direct-reduced iron is available economically, these can also be used as furnace feed.
7. Because EAFs consume a lot of electricity, many businesses plan their operations to take advantage of cheaper electricity during off-peak hours.
8. A typical steelmaking arc furnace is the source of steel for a mini-mill, which may make bars or strip product. Mini-mills can be sited relatively near to the markets for steel products, and the transport requirements are less than for an integrated mill, which would commonly be sited near a harbour for access to shipping.
9. The supply and price of electricity became constant, allowing the arc furnace to be widely used;
10. Arc furnaces are often larger and more powerful.
11. Low initial investment, quick construction, and quick cost payback;
12. The temperature and the component of the molten steel can be controlled with accuracy. The arc furnace can also smelt various kinds of different steels. Compared with others, the arc furnace also has several obvious.
13. The arc can heat the furnace and the steel up to 4000-6000°C directly and smelt special steels that contain refractory elements like W and Mo.
14. The arc furnace could remove the toxic gases and the inclusions while deoxidizing and desulfurating.
15. Currently, owing to the development of related technologies, the electric arc furnaces could be well -integrated with traditional steel-making processes .[20]

1.9 Disadvantage of Electric Arc Furnace :

1. Only point-like heating sources may be generated by the arc, resulting in unequal heat distribution in the furnace.
2. The arc will react with the furnace gases and vapor, releasing significant amounts of H₂ and N₂ into the atmosphere.
3. Slag production, The electric arc furnace produces slag, the Slag is the glass-like by-product left over after a desired metal has been separated (i.e., smelted) from its raw ore so Slag production will increase in this procedure.
4. Scrap handling necessitates the use of four large vehicles.
5. Because the arc furnace load has a dynamic nature, power systems may require technical steps to preserve power quality. [21]
6. Although the modern electric arc furnace is a highly efficient recycler of steel scrap, operation of an arc furnace shop can have adverse environmental effects. Much of the capital cost of a new installation will be devoted to systems intended to reduce these effects, which include:
 - Enclosures to reduce high sound levels
 - Dust collector for furnace off-gas
 - Cooling water demand
 - Heavy truck traffic for scrap, materials handling, and product
 - Environmental effects of electricity generation
7. Because of the very dynamic quality of the arc furnace load, power systems may require technical measures to maintain the quality of power for other customers, flicker and harmonic distortion are common power system side-effects of arc furnace operation [22].

Chapter Two

Theoretical Procedure

2.1 The Principle Work of Electric Arc Furnace.

2.1.1 Pre- melting process:

The working **principle** of the arc furnace includes charging the electrode, meltdown period (melting the metal) and refining. The heavy and light scrap in the large basket is **preheated** with the help of exhaust gas. For speeding up the slag formation, burnt lime and spar are added to it. The charging of furnace takes place by swinging the roof of the furnace. As per requirement, the hot metal charging also takes place. Next is the **meltdown** period. The electrodes are moved **down** onto the scrap in this period. Then the arc is produced between the electrode and metal. By considering the **protection** aspect, low voltage is selected for this. After the arc is shielded by electrodes, the voltage is increased for speeding up the melting process. In this process, carbon, silicon, and manganese get **oxidized**. The lower current is required for large arc production. The heat loss is also less in this. Melting down process can be fastening by **deep** bathing of electrodes. Refining process starts during melting. The **removal** of sulfur is not essential for single oxidizing slag practice. Only phosphorous removal is required in this. But in double slag practice, both (S and P) are to be removed. After the deoxidizing; in double slag practice, the removal of oxidizing slag is performed. Next, with the help of aluminum or ferromanganese or ferrosilicon, it gets deoxidized. When the bathing chemistry and required temperature is reached, the heat will get deoxidized. Then, the molten metal is ready for tapping. For the cooling of the furnace, tubular pressure panels or hollow annulus spraying can be used [23].

Electric arc furnaces work on the **principle** of the electrode forming an arc between itself and the top layer of metal to be melted. The operation begins with a delivery of steel scrap to the scrap bay, located at one end of the EAF building. The scrap comes in many **forms**, from shredded crushed cars to kitchen white goods, steel sections, and plates. These are loaded onto a scrap container known as a basket, which has bottom-opening doors, along with some pig iron (an iron ingot product of the blast furnace) as required for the finished grade of steel.

The basket is loaded to ensure that the topmost layer is of light scrap, then a layer of heavy scrap, alternating until the basket contains the correct mix and weight of scrap. On its way to the furnace, the basket may **pass** through a large pre-heat system, which uses electric arc furnace industrial heat in the form of exhaust gasses to heat the scrap, thereby increasing efficiency using waste heat.

Next the basket of scrap is **transported** on its steel wheeled trolley to the furnace where the furnace roof is retracted and ready for the charge.

Anyway, once the charge is in the furnace, the lid is replaced on the furnace and the electrodes **lowered** onto the top layer of light scrap. An arc is struck and the electrodes start sinking into the scrap, their rate of advance and voltage are controlled automatically, the oxygen burners are energized, and melting commences.

The electric arc furnace temperature of the molten metal is around 2970F, but alarmingly the temperature of the arc is something in the region of 11000F!

A **normal** melt of 100T would take just over an hour to complete, using about 400kWh of power.

Scrap metal is delivered to a scrap bay, located next to the melt shop. Scrap generally comes in two main grades: shred (whitegoods, cars and other objects made of similar light-gauge steel) and heavy melt (large slabs and beams), along with some direct reduced iron (DRI) or pig iron for chemical balance. Some furnaces melt almost 100% DRI.

The scrap is loaded into large buckets called baskets, with "clamshell" doors for a base. Care is taken to layer the scrap in the basket to ensure good furnace operation; heavy melt is placed on top of a light layer of protective shred, on top of which is placed more shred. These layers should be present in the furnace after charging. After loading, the basket may pass to a scrap pre-heater, which uses hot furnace off-gases to heat the scrap and recover energy, increasing plant efficiency.

The scrap basket is then taken to the melt shop, the roof is swung off the furnace, and the furnace is charged with scrap from the basket. Charging is one of the more dangerous operations for the EAF operators. A lot of potential energy is released by the tonnes of falling metal; any liquid metal in the furnace is often displaced upwards and outwards by the solid scrap, and the grease and dust on the scrap is ignited if the furnace is hot, resulting in a fireball erupting. In some twin-shell furnaces, the scrap is charged into the second shell while the first is being melted down, and pre-heated with off-gas from the active shell. Other operations are continuous charging—pre-heating scrap on a conveyor belt, which then discharges the scrap into the furnace proper, or charging the scrap from a shaft set above the furnace, with off-gases directed through the shaft. Other furnaces can be charged with hot (molten) metal from other operations.

After charging, the roof is swung back over the furnace and meltdown commences. The electrodes are lowered onto the scrap, an arc is struck and the electrodes are then set to bore into the layer of shred at the top of the furnace. Lower voltages are selected for this first part of the operation to protect the roof and walls from excessive heat and damage from the arcs. Once the electrodes have reached the heavy melt at the base of the furnace and the arcs are shielded by the scrap, the voltage can be increased and the electrodes raised slightly, lengthening the arcs and

increasing power to the melt. This enables a molten pool to form more rapidly, reducing tap- to-tap times. Oxygen is blown into the scrap, combusting or cutting the steel, and extra chemical heat is provided by wall-mounted oxygen-fuel burners. Both processes accelerate scrap meltdown. Supersonic nozzles enable oxygen jets to penetrate foaming slag and reach the liquid bath [24].

2.1.2 Post - melting process:

An important part of steelmaking is the **formation** of slag, which floats on the surface of the molten steel. Slag usually consists of metal oxides, and acts as a destination for oxidised impurities, as a thermal blanket (stopping excessive heat loss) and helping to reduce erosion of the refractory lining. For a furnace with basic refractories, which includes most carbon steel-producing furnaces, the usual slag **formers** are calcium oxide (CaO, in the form of burnt lime) and magnesium oxide (MgO, in the form of dolomite and magnesite). These slag formers are either charged with the scrap, or blown into the furnace during meltdown. Another major component of EAF slag is iron oxide from steel combusting with the injected oxygen. Later in the heat, carbon (in the form of coke or coal) is injected into this slag layer, reacting with the iron oxide to form metallic iron and carbon monoxide gas, which then causes the slag to foam, allowing greater thermal efficiency, and better arc stability and electrical efficiency. The slag blanket also covers the arcs, preventing damage to the furnace roof and sidewalls from radiant heat [25].

Once the initial scrap charge has been melted down, another bucket of scrap can be charged into the furnace, although EAF development is moving towards single- charge designs. The scrap-charging and meltdown process can be repeated as many times as necessary to reach the required **heat weight** - the number of charges is dependent on the density of scrap; lower-density scrap means more charges. After all scrap charges have completely melted, refining operations take place to check and correct the steel chemistry and superheat the melt above its freezing temperature in preparation for tapping. More slag formers are introduced and more oxygen is **blown** into the bath, burning out impurities such as silicon, sulfur, phosphorus, aluminium, manganese, and calcium, and removing their oxides to the slag. **Removal** of carbon takes place after these elements have burnt out first, as they have a greater affinity for oxygen. Metals that have a poorer affinity for oxygen than iron, such as nickel and copper, cannot be removed through oxidation and must be controlled through scrap chemistry alone, such as introducing the direct reduced iron and pig iron mentioned earlier. A foaming slag is maintained throughout, and often overflows the furnace to pour out of the slag door into the slag pit. Temperature sampling and chemical sampling take place via automatic lances. Oxygen and carbon can be **automatically** measured via special probes that dip into the steel, but for all other elements, a "chill" sample a small, solidified sample of the steel is analysed on an arc-emission spectrometer [26].

Once the temperature and chemistry are **correct**, the steel is tapped out into a preheated ladle through tilting the furnace. For plain-carbon steel furnaces, as soon as slag is detected during tapping the furnace is rapidly tilted back towards the deslagging side, minimising slag carryover into the ladle. For some special steel grades, including stainless steel, the slag is poured into the ladle as well, to be treated at the ladle furnace to recover valuable alloying elements. During tapping some alloy additions are introduced into the metal stream, and more fluxes such as lime are added on top of the ladle to begin building a new slag layer. Often, a few tonnes of liquid steel and slag is left in the furnace in order to form a **"hot heel"**, which helps preheat the next charge of scrap and accelerate its meltdown. During and after tapping, the furnace is "turned around": the slag door is cleaned of solidified slag, the visible refractories are inspected and water-cooled components checked for leaks, and electrodes are inspected for damage or lengthened through the addition of new segments; the taphole is filled with sand at the

completion of tapping. For a 90-tonne, medium-power furnace, the whole process will usually **take** about 60–70 minutes from the tapping of one heat to the tapping of the next (the tap-to-tap time). The furnace is completely emptied of steel and slag on a regular basis so that an inspection of the refractories can be made and larger repairs made if necessary. As the refractories are often made from calcined carbonates, they are extremely susceptible to hydration from water, so any suspected leaks from water-cooled components are treated extremely seriously, beyond the immediate concern of potential steam explosions. Excessive refractory wear can lead to breakouts, where the liquid metal and slag penetrate the refractory and furnace shell and escape into the surrounding areas [27].

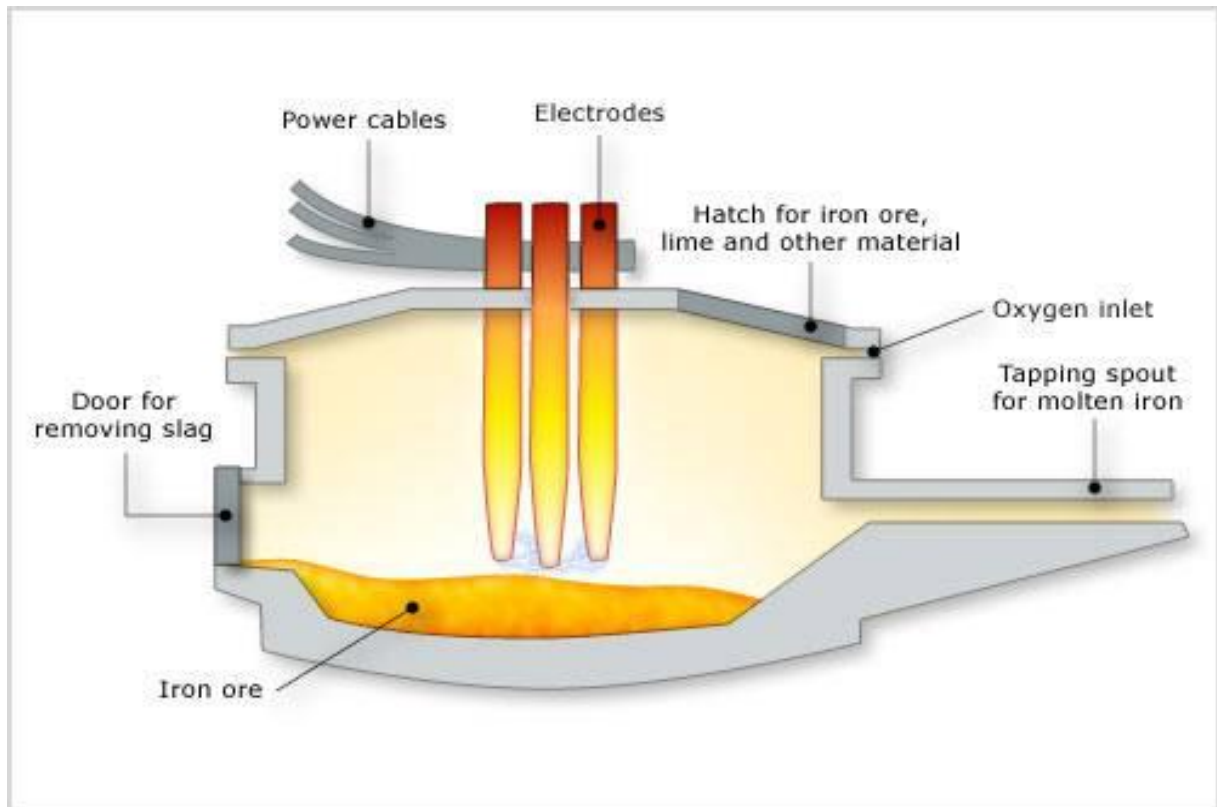


Figure 2.1 Electric arc furnace basic sketch [27].

2.2 Vacuum:

The process of the arc furnace occurs in a closed chamber with the help of an inert gas, nitrogen is used in this project. Vacuum arc remelting (VAR) is a **secondary** re-melting process for vacuum refining and manufacturing of ingots with improved chemical and mechanical **homogeneity**.

In critical military and commercial aerospace applications, material engineers commonly specify VIM-VAR steels. **VIM** means Vacuum Induction Melted and VAR means Vacuum Arc Remelted. VIM-VAR steels become bearings for jet engines, rotor shafts for military helicopters, flap actuators for fighter jets, gears in jet or helicopter transmissions, mounts or fasteners for jet engines, jet tail hooks and other demanding applications [28].

Most grades of steel are melted once and are then cast or teemed into a solid form prior to extensive forging or rolling to a metallurgically-sound form. In contrast, VIM-VAR steels go through two more highly purifying melts under vacuum. After melting in an electric arc furnace and alloying in an argon oxygen decarburization vessel, steels destined for vacuum remelting are cast into ingot molds. The solidified ingots then head for a vacuum induction melting furnace. This vacuum remelting process rids the steel of inclusions and unwanted gases while optimizing the chemical composition. The VIM operation returns these solid ingots to the molten state in the

contaminant-free void of a vacuum. This tightly controlled melt often requires up to 24 hours. Still enveloped by the vacuum, the hot metal flows from the VIM furnace crucible into giant electrode molds. A typical electrode is about 15 feet (5 m) tall and will be in various diameters. The electrodes solidify under vacuum. For VIM-VAR steels, the surface of the cooled electrodes must be ground to remove surface irregularities and impurities before the next vacuum remelt. Then the ground electrode is placed in a VAR furnace. In a VAR furnace, the steel gradually melts drop-by-drop in the vacuum-sealed chamber. Vacuum arc remelting further removes lingering inclusions to provide superior steel cleanliness and remove gases like oxygen, nitrogen and hydrogen. Controlling the rate at which these droplets form and solidify ensures a consistency of chemistry and microstructure throughout the entire VIM-VAR ingot, making the steel more resistant to fracture or fatigue. This refinement process is essential to meet the performance characteristics of parts like a helicopter rotor shaft, a flap actuator on a military jet, or a bearing in a jet engine. For some commercial or military applications, steel alloys may go through only one vacuum remelt, namely the VAR. For example, steels for solid rocket cases, landing gears, or torsion bars for fighting vehicles typically involve one vacuum remelt. VAR is widely used to improve the cleanliness and refine the structure of standard air-melted, vacuum induction melted or ESR remelted ingots. VAR steels and superalloys as well as titanium, zirconium and their alloys are used in a great number of high integrity applications where cleanliness, homogeneity, improved fatigue and fracture toughness of the final product are essential. Aerospace, power generation defense, medical and nuclear industries rely on the properties and performance of these advanced remelted materials. Vacuum arc remelting is also used in production of titanium and other metals which are reactive or in which high purity is required [29].

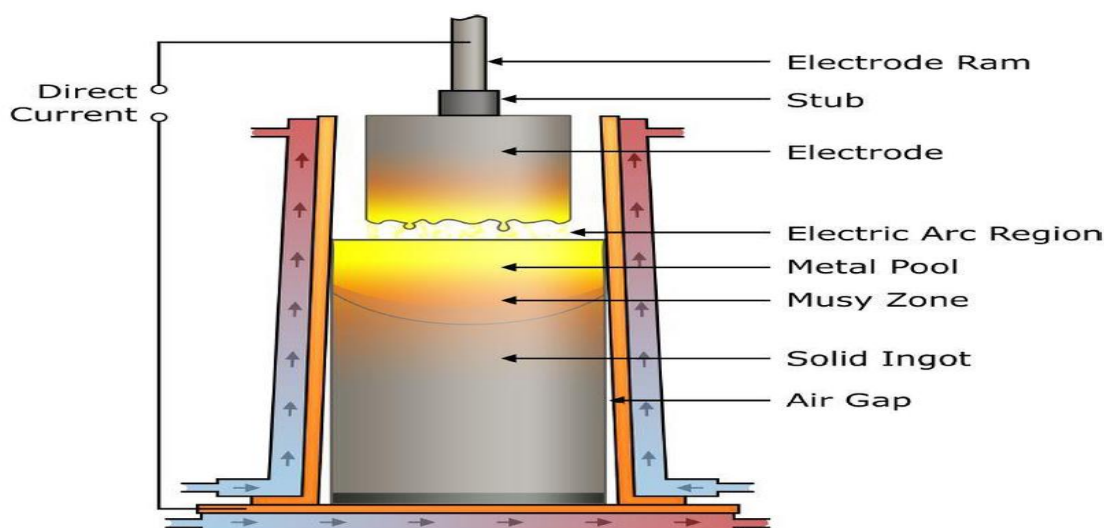


Figure 2.2 schematic procedure of vacuum arc re-melting [29].

VAR Advantages :

- Removal of dissolved gases, such as hydrogen, nitrogen and Carbon dioxide
- Reduction of undesired trace elements with high vapor pressure
- Improvement of oxide cleanliness
- Achievement of directional solidification of the ingot from bottom to top, thus avoiding macro-segregation and reducing micro-segregation
- Lowest energy input of all remelting processes
- Total ceramic free melting process [30].

VAR is the continuous remelting of a consumable electrode by means of an arc under vacuum. DC power is applied to strike an arc between the electrode and the baseplate of a copper mold contained in a water jacket. The intense heat that is generated by the electric arc, melts at the tip of the electrode and a new ingot is progressively formed in the water-cooled mold. A high vacuum is maintained throughout the remelting process.

The basic design of the VAR: furnace has been improved continuously over the years particularly in computer control and regulation with the objective of achieving a fully-automatic remelting process. This in turn has resulted in improved quality and reproducibility of the metallurgical properties of the products. Close control of all remelting parameters is required for reproducible production of homogeneous ingots, which are free of macro segregation and show a controlled solidification structure and superior cleanliness [31].

To fulfill today's most stringent material quality specifications, VAR furnaces make use of computer controlled process automation. Logic control functions, continuous weighing of the consumable electrode, closed loop control of process parameters (e. g. remelting rate, arc gap based on arc voltage or drip short pulse rate), data acquisition and management are handled by dedicated computer systems. An operator interface PC (OIP) acting hierarchically as master of the automatic melt control system (AMC) is utilized as the interface between operator and VAR process. The OIP provides process visualization, parameter indications, graphic displays, soft keys for operator commands, editing and handling of remelting recipes, data acquisition and storage as well as for generation of melt records. Optionally the OIP can be equipped with an Ethernet network interface which may be utilized for data transfer to other computers connected to the local area network (e. g. supervisory PC, customer's main frame, etc.).

ALD's automatic melt control system (AMC) is unsurpassed in the world for its versatile features and ease of operation to ensure accuracy and reproducibility of control [32].

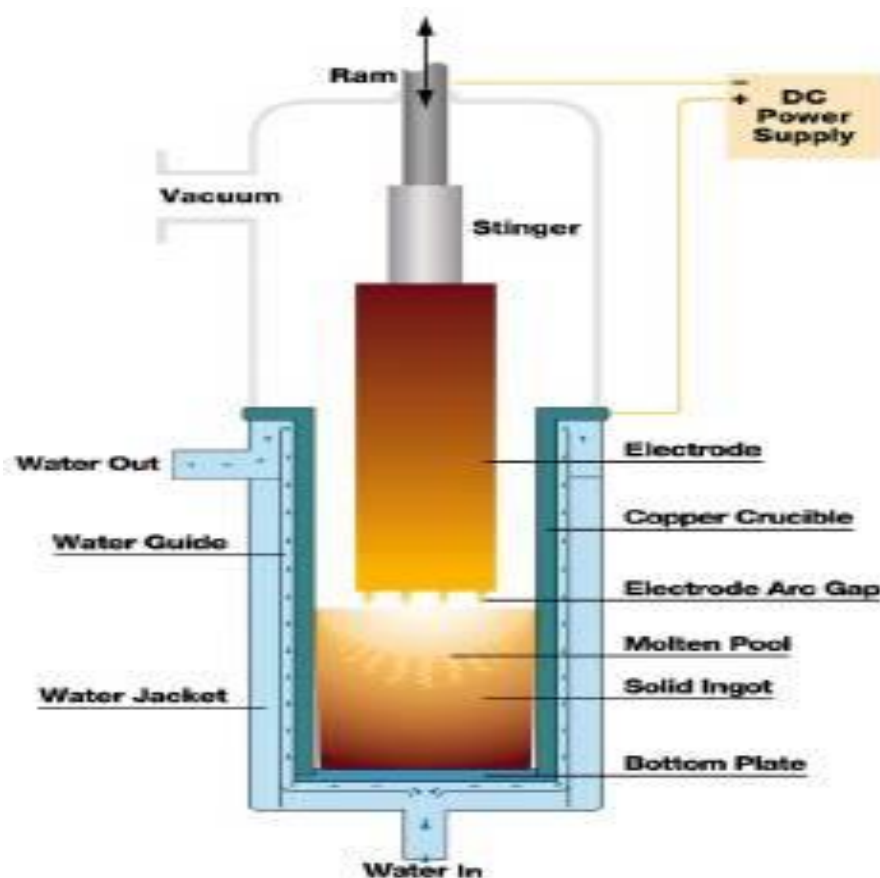


Figure 2.3 schematic diagram of VAR process [32].

Oxide removal is achieved by both chemical and physical processes. Less stable oxides or nitrides are thermally dissociated or reduced by the carbon present in the alloy and are removed via the gas phase. However, in special alloys and in high- alloyed steels, the non-metallic inclusions (e. g. alumina and titanium carbo nitrides) are very stable. Some removal of these inclusions takes place by flotation during remelting. The remaining inclusions are broken up and evenly distributed in the cross-section of the solidified ingot.

The laboratory Vacuum Arc Remelting furnace is primarily used to produce small ingots, button samples and precision cast parts. These products are used to examine the mechanical, physical and chemical properties of steel, reactive metals and their alloys [33].

Chapter Three

Experimental Procedure

3.1 - Melting Process:

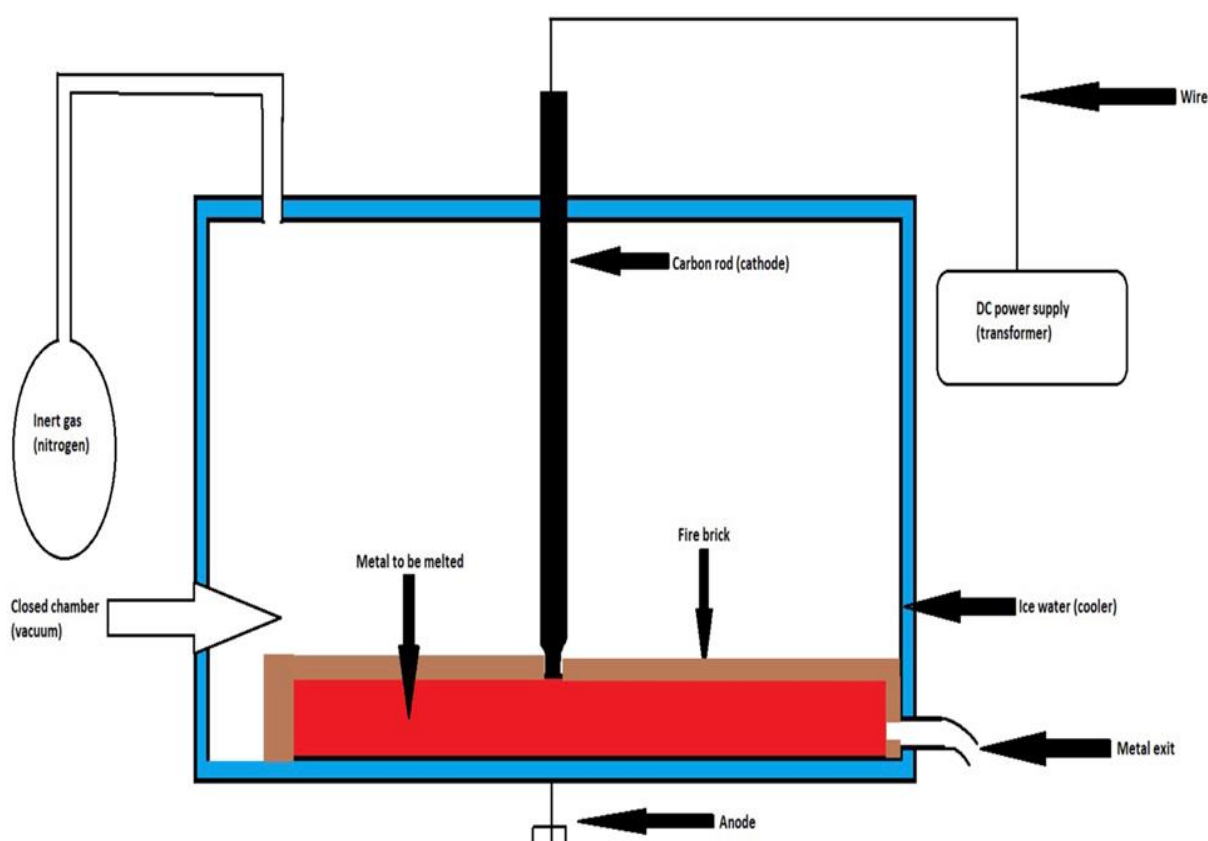


Figure 3.1 Electric arc furnace sketch.

Electric arc furnace is added to the material laboratory, it works with the principle of creating an electric arc between the tip of the carbon rod and the metal to be melted. The carbon rod is the main part in the melting process in any electric arc furnace, it is connected to an AC transformer (power supply) that has high amperage and low voltage which are necessary for the spark generation to melt the metal. This process takes place in a closed chamber (vacuum) with the help of an inert gas (nitrogen) to prevent oxidation and formation of slag mentioned the previous chapter. A metal outlet is located on the side of the chamber and used as pathway for the molten to move out of the fire brick. Fire brick surrounds the metal to be melted, it can handle extremely high temperatures. Between the inside and the outside shell, ice water is used and circulated through the wall to cool the fire brick and the whole chamber.



Figure (3-2a): Lab. arc furnace [33].



Figure (3-2b): Lab. arc furnace [33].

The electric arc furnace are temperature resistant, improvised modernized melting procedures to perform precise quality work. The double-layer forced air-cooling structure of the furnace shell is close to the room temperature at the time of operation. The appearance is sprayed with high-temperature and high-quality paint, and is not easy to fade. The door of the furnace is protected by stainless steel cover for a long time without blackening and easy to maintain.

It has an integrated compact design, step splicing structure, in accordance with the law of mechanics, heating force is uniform, heat is not easy to lose. It also has high quality and high alumina polycrystalline ceramic fiber, resistant to rapid cooling and heat preservation.

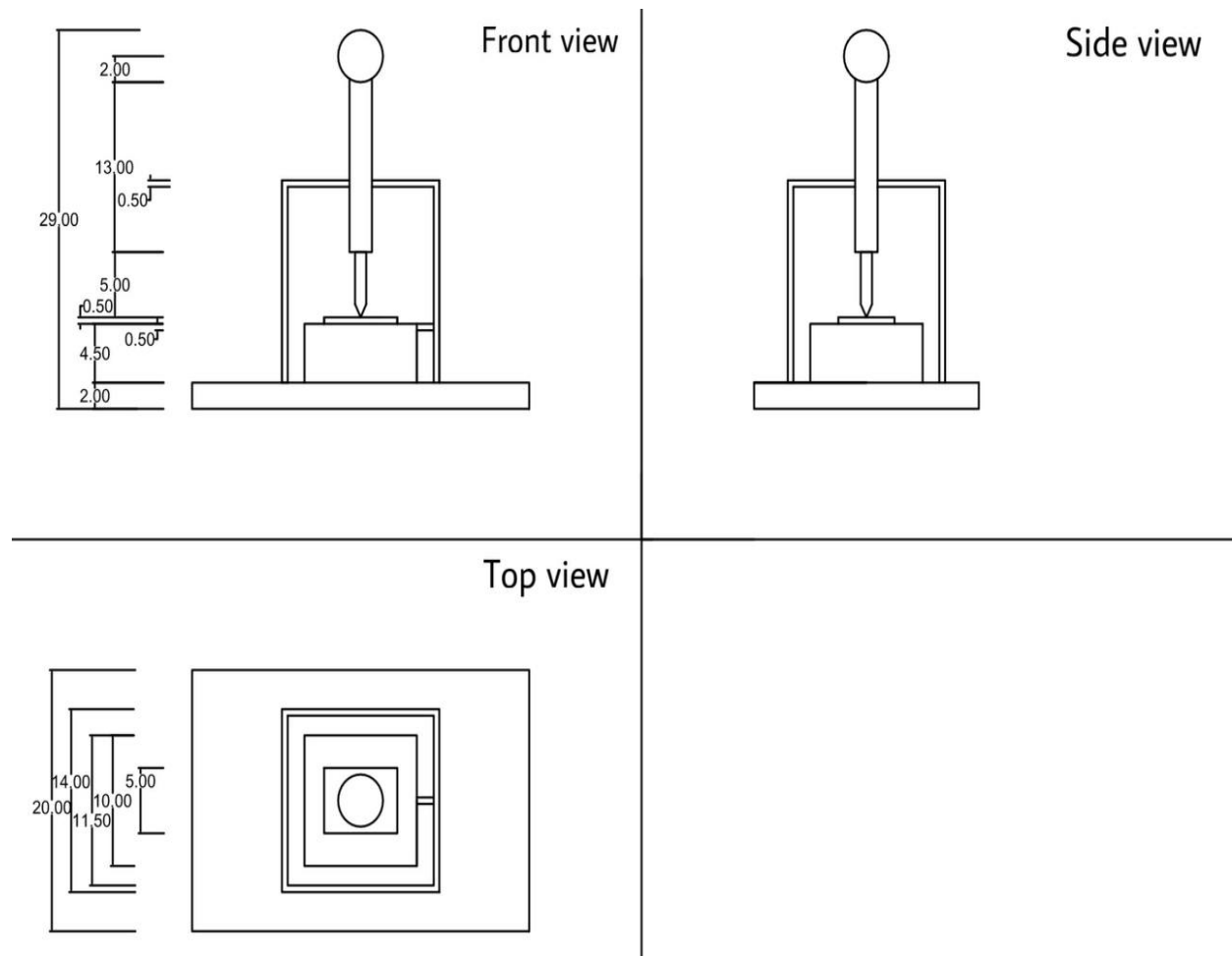


Figure 3.3 Engineering drawing for the electric arc furnace.

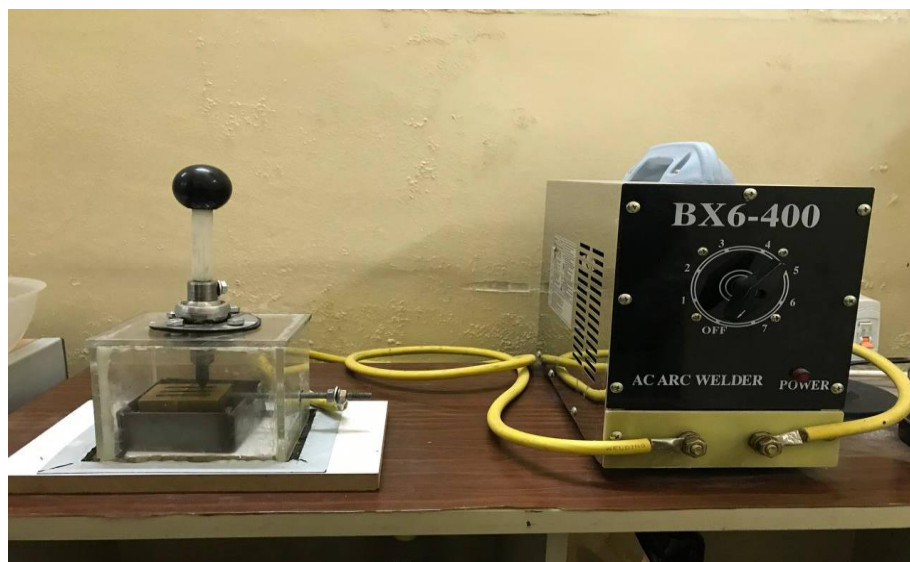


Figure 3.4.

Figure (3.4) shows the DC power supply, a BX6-400 arc welding transformer was used for this purpose with 2 connecting cable, the live cable goes directly to the electrode while the neutral cable is connected to the crucible.

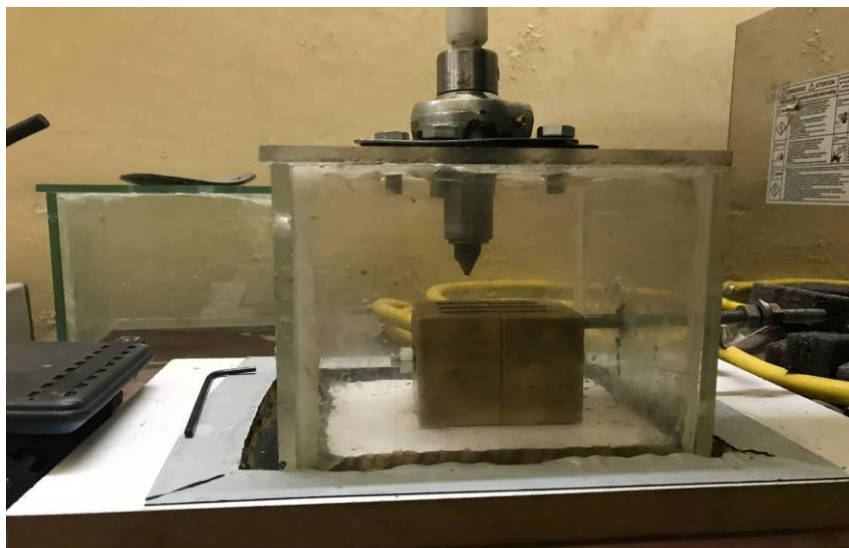


Figure 3.5.

Figure (3.5) shows the melting-vacuumed chamber, the carbon rod used to deliver the charge and the crucible.



Figure 3.6.

The pictures shown in figure (3.6) demonstrate the stages of the electric arc formation, from the electrode warming to the spark generation.



Figure 3.7.

Figure (3.10) shows a melted aluminum sample on the crucible after it has been exposed to the electric arc and instant cooling with the crushed ice.

Chapter Four

Discussion

4.1 Final Model:

As mentioned in the previous chapter, between the inside and the outside shell, ice water is used and circulated through the wall to cool the fire brick and the whole chamber, this has been replaced with crushed ice poured into the cooling path. Carbon rod mentioned earlier, has been replaced with tungsten rod because it requires less output power to achieve the electrical arc. The original electric arc furnace DC power supply has been replaced with an ordinary welding machine transformer converts the moderate voltage and moderate current electricity from the utility mains (typically 230 or 115 VAC) into a high current and low voltage supply, typically between 17 and 45 volts and 55 to 590 amperes. These changes were made to reduce the overall cost for this project, making it more affordable. Aluminum sample has been used as the first sample to be melted, full output power was used to achieve the electric arc, the sample was ejected out of the crucible. A picture under microscope was captured to give a clear picture for the microscopical structure and crystal size of the melted aluminum sample.

4.2 Sample Mounting:

In order to capture a picture for the melted specimen microscopic structure, the specimen was taken out of the crucible, polished, put under a polymeric material in a liquid state and left for 24 hours to solidify so the acrylic material can solidify and encapsulate the specimen. After that, the specimen should be ready to be put in the microscope object lens to capture a picture demonstrating both surface and microscopic (HF was used) structure with the aid of a digital video camera provided by the microscope manufacturer.



Figure 4.1 (Superficial structure for melted aluminum).



Figure 4.2 (Microscopic structure for melted aluminum, x5 zoom).

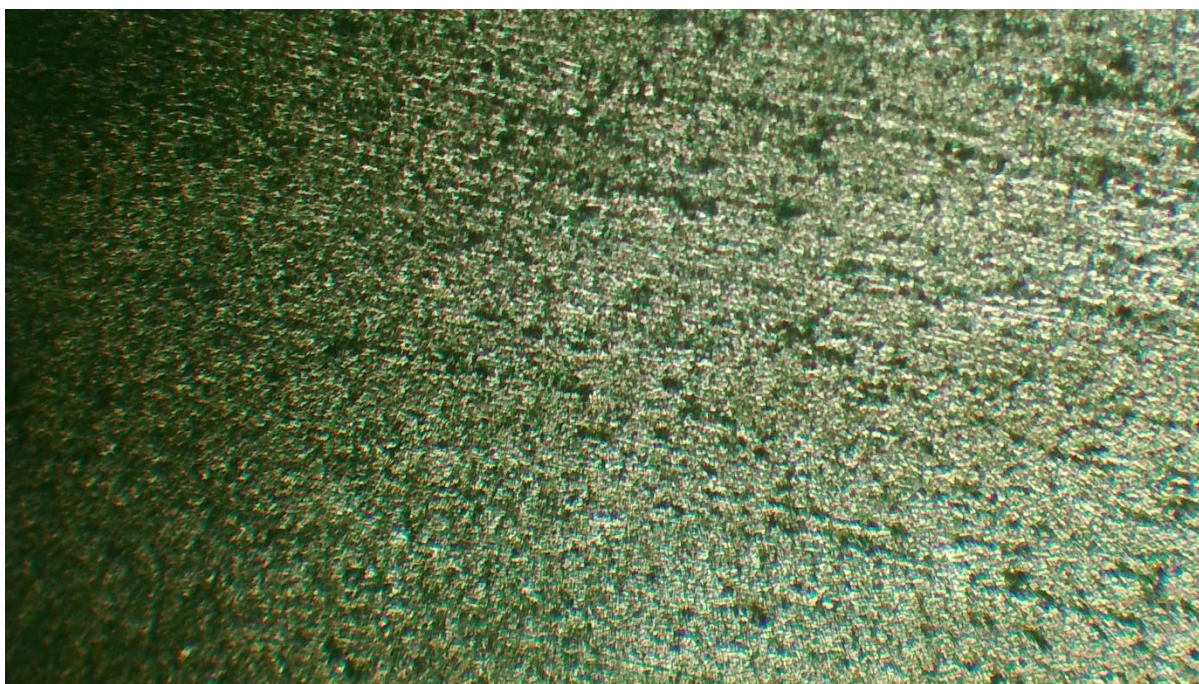


Figure 4.3 (Microscopic structure for melted aluminum, x10 zoom).

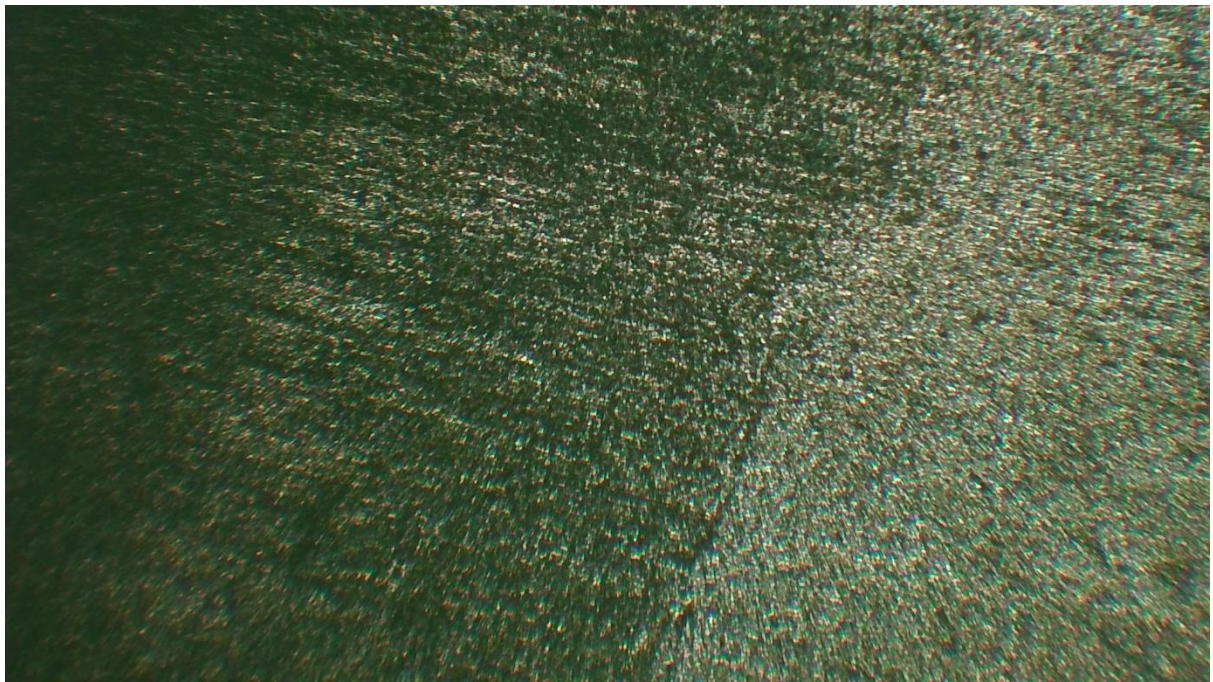


Figure 4.4 (Microscopic structure for melted aluminum, x20 zoom).

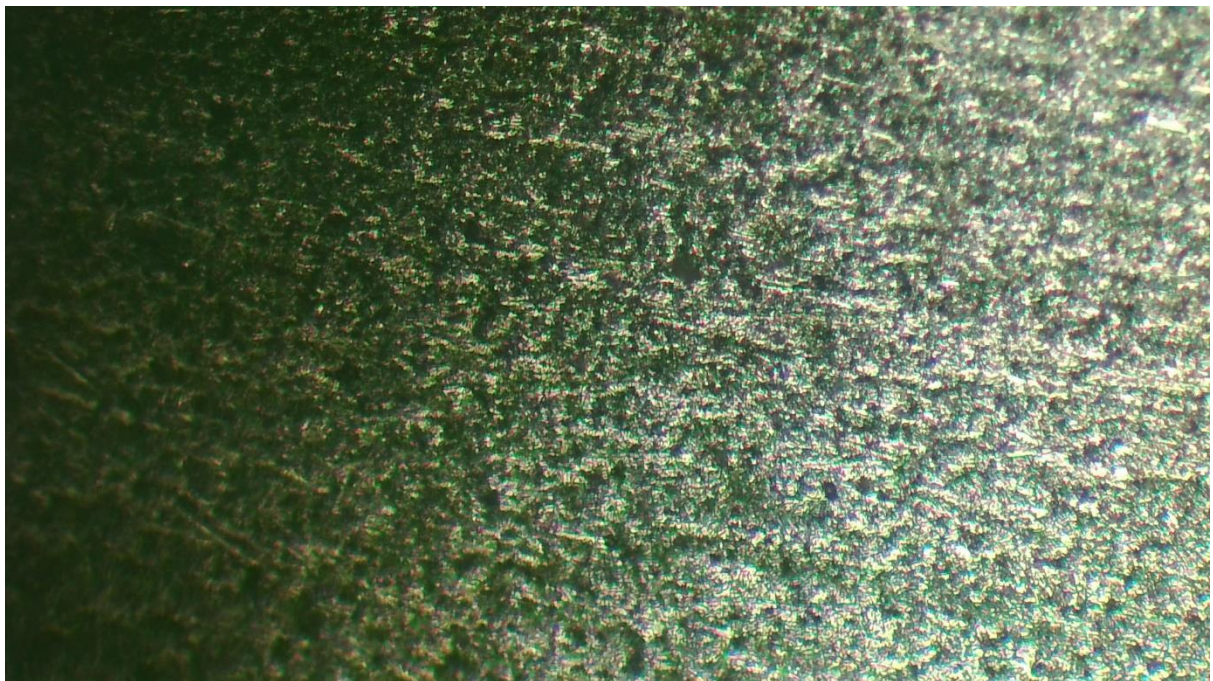


Figure 4.5 (Microscopic structure for melted aluminum, x40 zoom).

4.3 Conclusion:

At the beginning, classic electric arc furnaces (EAFs) have been studied intensively with their types and configurations to understand their advantages and disadvantages and how they will effect the decision making in picking the main part of minimized EAC that have been assembled inside the laboratory. Other procedures have been done on the classic EAF, like cooling, slag formation and vacuum, also have been studied and taken into considerations to help the process of creating the laboratory AC EAF, making it able to refine a material (like stainless steel), making it ready and useful to be used as a prosthetic inside the human body, for example, vascular implants, stents, artificial valves, joints and orthodontics.

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