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# Design and Fabrication of an Experimental Set-Up to Measure Carbon Content of an Alloy

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## Abstract

*Steel and steel alloys are essential ingredient to build nation and quality of steels depend on chemical composition especially on carbon. Nowadays, we perceive how important the quality of steels for construction. In steel, carbon exists in combined and uncombined conditions and in Ferro-alloys, it only in combined state. To measure carbon content is an important criterion to select the quality of steel. Therefore, different methods are used worldwide to do that. This project deals with the measurement of carbon content by combustion process. The objective of this procedure is to determine the total amount of carbon content in all types of iron, steel, cast iron and Ferro-alloys. When regulated oxygen is passed over the heated metal, the oxygen is oxidized with carbon and produced carbon dioxide as well as a small amount of Sulphur dioxide and ferrous oxide. At the end of combustion, carbon dioxide is adsorbed by activated carbon powder inside an airtight jar. The amount of carbon increases with the increasing the weight of airtight gas jar.*

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***Key words**: Steel, Carbon, Chemical composition, Combustion, Adsorption, Measurement etc.*

## 1. Introduction

Generally, carbon is the most important commercial steel alloy. Increasing carbon content increases hardness and strength and improves harden ability. But carbon also increases brittleness and reduces weld ability because of its tendency to form Martensite. This means carbon content can be both a blessing and a curse when it comes to commercial steel.

Where there are steels that have up to 2 percent carbon content, they are the exception. Most steel contains less than 0.35 percent carbon. To put this in perspective, keep in mind that's 35/100 of 1 percent.

Carbon, the sixth most abundant element in the universe, has been known since ancient times. Carbon is most commonly obtained from coal deposits, although it usually must be processed into a form suitable for commercial use. Three naturally occurring allotropes of carbon are known to exist: amorphous, graphite and diamond.

Amorphous carbon is formed when a material containing carbon is burned without enough oxygen for it to burn completely. This black soot, also known as lampblack, gas black, channel black or carbon black, is used to make inks, paints and rubber products. It can also be pressed into shapes and is used to form the cores of most dry cell batteries, among other things.

Graphite, one of the softest materials known, is a form of carbon that is primarily used as a lubricant. Although it does occur naturally, most commercial graphite is produced by treating petroleum coke, a black tar residue remaining after the refinement of crude oil, in an oxygen-free oven. Naturally occurring graphite occurs in two forms, alpha and beta. These two forms have identical physical properties but different crystal structures. All artificially produced graphite is of the alpha type. In addition to its use as a lubricant, graphite, in a form known as coke, is used in large amounts in the production of steel. Coke is made by heating soft coal in an oven without allowing oxygen to mix with it. Although commonly called lead, the black material used in pencils is actually graphite. Diamond, the third naturally occurring form of carbon, is one of the hardest substances

known. Although naturally occurring diamond is typically used for jewelry, most commercial quality diamonds are artificially produce.
Carbon is often added to steel to increase its hardness. Adding as little as 0.5% carbon can make a huge difference in the hardness of the steel. However, the increased hardness comes with a disadvantage -it is much less ductile. Careful control of the heat treatment allows one to control the tradeoff between hardness and ductility - but if you make a mistake you can end up with a blade that won't hold an edge or one that shatters if you drop it. Very high quality Japanese steel tools often laminate a piece of high ductility, low carbon steel to a thin layer of low ductility, high carbon steel to give a blade with a hard cutting edge and a reasonably ductile body. Cast irons listed as having 2 to 5% carbon are generally too brittle to make good cutting tools. However, they do make wonderful machine tools since they are extremely dimensionally stable.
In case of stainless steel that does not contain much carbon to make sure that it remains stainless. What is the result? Well carbon is responsible for making steels hard so they hold a really nice cutting edge. Therefore, SS is not very hard and makes lousy cutting tools. Well not really. Metallurgists figured that a metal that was both stainless and held a decent cutting edge would be great so they developed some SS that held a fairly good cutting edge. In the US these are the 400 series SS. The key is that through careful control of the composition and heat treatment you can create a metal that is a good compromise between corrosion resistance and hardness. However, it you make a mistake in either one you end up with a material that is too hard (brittle) or too soft (won't hold and edge). Generally cheap SS tools such as knives err on the side of too soft while high quality tools generally are right on or err on the side of too hard. If you look up the composition of most SS you will find that the carbon content is limited to less than 0.1%. Therefore, SS is technically not steel. Why is the carbon content of SS limited? Well, if you mess up the heat treatment the carbon likes to combine with the Cr to form chromium carbide which has the formula $Cr_{23}C_6$. This compound forms along the grain boundaries (not defined here) and robs the regions along the grain boundaries of Cr. However, Cr was added to the material to make it corrosion resistant so if you remove it the SS is no longer stainless. That is why the carbon concentration of SS is limited. Now, any steel in the 0.35 to 1.86 percent carbon content range can be hardened using a heat-quench-temper cycle. Most commercial steels are classified into one of three groups.

i. Plain carbon steels
ii. Low-alloy steels
iii. High-alloy steel

## 2. Objectives of the project

The main objectives of this project are as follows.
i. Design and fabrication of an experimental set-up
ii. To determine the total amount of carbon in a metal.

## 3. Importance of carbon in metal

Some basics concerning the iron-carbon-steel relationship and it has influences on welding and metal alloys. Next time we'll look at influences of some key alloying elements and the effects of welding on metallurgy. Iron is the fourth most abundant element and makes up more than five percent of the earth’s crust. Iron exists naturally in iron core (sometimes called ironstone). Since iron has a strong affinity for oxygen, iron ore is an oxide of iron; it also contains varying quantities of other elements such as silicon, sulfur, manganese, and phosphorus. Smelting is the process by which iron is extracted from iron ore. When iron ore is heated in a charcoal fire, the iron ore begins to release some of its oxygen, which combines with carbon monoxide to form carbon dioxide. In this way, a spongy, porous mass of relatively pure iron is formed, intermixed with bits of charcoal and extraneous matter liberated from the ore, known as slag. (The separation of slag from the iron is facilitated by the addition of flux, that is, crushed seashells or limestone.) The formation of this bloom of iron was as far as the primitive blacksmith got: he would remove this pasty mass from the furnace and hammer it on an anvil to drive out the cinders and slag and to compact the metallic particles. This was wrought iron (“wrought” means “worked,” that is, hammered) and contained generally from .02 to .08 percent of carbon (absorbed from the charcoal), just enough to make the metal both tough and malleable. Wrought iron was the most commonly produced metal through most of the Iron Age.

## 4. Methodology

In order to getting and determining the amount of carbon, the experiment is properly set up by assembling required instruments. The procedure and method of determining total amount of carbon in a metal is fully based on combustion method. The combustion process is done by burning coal with high flame temperature without losing a little portion of heat energy inside the furnace. Ferrous sample is burnt inside the furnace with the presence of oxygen. When a regulated of oxygen is passed over the heated ferrous sample, the carbon is oxidized to yield carbon dioxide and Sulphur dioxide that are passed through the metal tube and store in a gas jar or funnel where activated carbon is kept to adsorb hot carbon dioxide gas from combustion chamber. Activated carbon [Fig.1] that is used as a solid adsorbent (powder form) and it is kept inside the jar. Another name of activated carbon is charcoal. Traditionally, active carbons are made in particulate form as powders or fine granules less than 1.0 mm in size with an average diameter between .15 and .25 mm.Thus they present a large surface to volume ratio with a small diffusion distance.

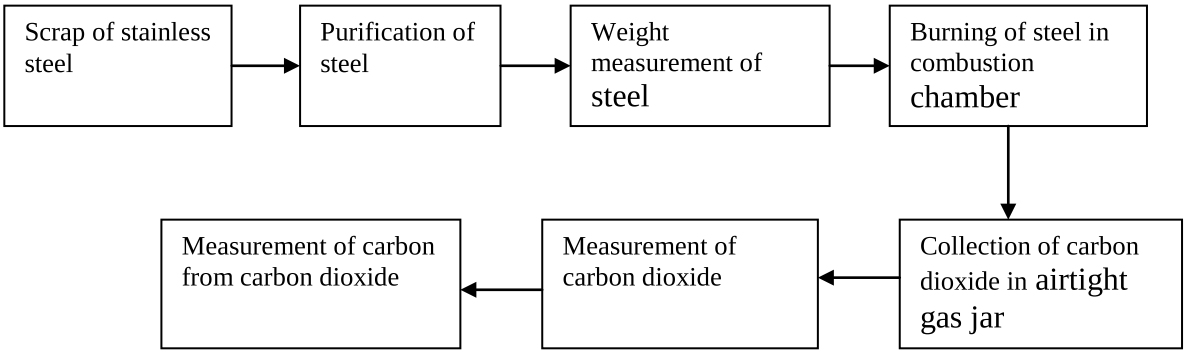
**Fig.1:** Activated powder carbon

The main function of activated powder carbon is high adsorption capacity of $CO_2$ as well as with strong adhered. The gas jar is fully airtight since $CO_2$ is very volatile. In jar a little amount of impurities are presence such as Sulphurous gases, nitrogen, and iron oxide. The increase in weight of the absorbent gives the amount of carbon.

Chemical reaction that is happened during combustion is following:

Ferrous sample + Oxygen = Carbon dioxide +Iron oxide + (Sulphur dioxide) (less amount).

## 5. Flowchart




## 6. Experimental set up

Different types of equipment's are needed for fabricating of an experimental set-up. Lists of equipments use for fabrication of an experimental Set-Up which are given below.

### 6.1 Oxygen Cylinder

The set-up required for the determination of carbon by the combustion method with combine equipments. Oxygen cylinders one of the major component. The oxygen cylinder contains oxygen at least 99.5 percent purity and should be free from contaminated and carbonaceous matter. But here we used oxygen from natural ambient air since my project furnace has sufficient ventilation of flowing air for complete combustion.

### 6.2 Safety valve

Safety valve containing mercury is introduced in the line to limit the working value. The valve is connected with two metal tubes where the hot gas is passed and that is totally controlled by it. The main function of safety valve is remaining and storing $CO_2$ gas in the chamber. As a result $CO_2$ can't come out in the environment through the metal tube since the gas is high volatile when switch off of valve. After completing combustion I take $CO_2$ gas in a jar and continuously adsorbing by activated carbon with the help of switch on of the safety valve.

## 6.3 Furnace

A furnace is an equipment used to melt metals for casting or to heat materials to change their shape (e.g. rolling, forging) or properties (heat treatment). Since flue gases from the fuel come in direct contact with the materials, the type of fuel chosen is important. For example, some materials will not tolerate Sulphur in the fuel. Solid fuels generate particulate matter, which will interfere in the materials placed inside the furnace. For this reason:

i. Most furnaces use liquid fuel, gaseous fuel or electricity as energy input
ii. Induction and arc furnaces use electricity to melt steel and cast iron
iii. Melting furnaces for nonferrous materials use fuel oil
iv. Oil-fired furnaces mostly use furnace oil, especially for reheating and heat treatment of materials
v. Light diesel oil (LDO) is used in furnaces where Sulphur is undesirable

Fig.2: Experimental furnace.

The experimental furnace in [Fig.2] that is made by refractory material as an insulator with high effectively and reliability protecting heat energy. The temperature of the furnace may be developed up to $1550^0$ c that is quite enough for melting steel.

Furnace ideally should heat as much of material as possible to a uniform temperature with the least possible fuel and labor. The key efficient furnace operation lies in complete combustion of fuel with minimum excess air. Furnaces operate with relatively low efficiencies (as low as 7 percent) compared to other combustion equipment such as the boiler (with efficiencies higher than 90 percent. This is caused by the high operating temperatures in the furnace. For example, a furnace heating materials to 1200 $^0$C will emit exhaust gases at 1200 $^0$C or more, which results in significant heat losses through the chimney.

## 6.4 Metal melting combustion chamber

The metal melting combustion chamber in [Fig.3] with metal tube is a part of furnace where the scraps or chips of steel are kept. It can take high temperature without deformation. Here we used scrap of steel that is easily melted inside melting chamber under the influence of heat energy.

Fig.3: Metal melting combustion chamber with metal tube.

## 6.5 Refractory material

Any material can be described as a 'refractory' if it can withstand the action of abrasive or corrosive solids, liquids or gases at high temperatures. The various combinations of operating conditions, in which refractories are used, make it necessary to manufacture a range of refractory materials with different properties. Refractory materials are made in varying combinations and shapes depending on their applications. General requirements of a refractory material are:

i. Withstand high temperatures
ii. Withstand sudden changes of temperatures
iii. Withstand action of molten metal slag, glass, hot gases, etc
iv. Withstand load at service conditions

For my experiment we used refractory material as an insulator to protect heat energy inside the furnace. As a result my furnace produces high heat energy with losing a small portion of heat.

## 6.6 Burning coal

Burning coal in [Fig.4] is used for completing combustion process of furnace because of melting metal and determining the amount of carbon.

Fig.4: Burning coal [7]

## 6.7 Electronic weighing balance

The electronic weighing balances in [Fig.5] that measure up to milligram since my amount of output $CO_2$ will be measured in milligram. This type of balance imparts the actual value, incorporating a small portion of fraction what will be measured.

Fig.5: Electronic weighing balance

## 6.8 The airtight gas jar

The airtight gas jar in [Fig.6] is the most important equipment of this project where the activated carbon is kept inside it. The activated carbon adsorbs the leaving hot $CO_2$ from the metal melting combustion chamber after opening the safety valve. The main function of airtight is to keep hot gas inside the jar. So that hot gas cannot come out in the environment from the jar.

Fig.6: The airtight gas jar

## 7. Data collection

The combustion process takes a specific time for completing combustion and reaction when safety valve is fully switched off. When the valve is opened and hot gas from the melting chamber comes out through the metal tube and is accumulated inside the airtight gas jar where it is being absorbed by activated carbon. [***Table 1***] imparts various data of this project.

**Table 1: Data collection**

<table>
<tr><th>Initial reading of jar with cork and activated carbon, $m_1$ (gm)</th><th>Final reading of jar with cork, activated carbon and $CO_2$ gas, (gm</th><th>Average reading of jar with cork, activated carbon and $CO_2$ gas, $m_2$ (gm)</th><th>Amount of $CO_2$ gas ($m_2$-$m_1$) (gm)</th><th>Amount of steel (scrap) that is melted, M (gm)</th><th>Amount of available carbon(c) in $CO_2$ gas, m (gm)</th><th>% of carbon(C) in steel= {(m÷M)×100}</th></tr>
<tr><td rowspan="3">183.00</td><td>183.50</td><td rowspan="3">183.667</td><td rowspan="3">0.667</td><td rowspan="3">550.00</td><td rowspan="3">0.1819</td><td rowspan="3">0.033</td></tr>
<tr><td>184.00</td></tr>
<tr><td>183.50</td></tr>
</table>

## 8. Calculation

Amount of steel (scrap) =550 gm.

Initial reading of jar with cork and activated carbon, $m_1$ = 183.00 gm.

Final reading of jar with cork, activated carbon and hot CO2 gas, $w_1$ =183.50gm
$w_2$ =184.00gm
$w_3$= 183.50gm.

Average final reading of jar with cork, activated carbon and hot CO2 gas, $m_2 = (w_1+w_2+w_3)/3$
= (183.5+184+183.5)/3
= 183.667 gm.

Therefore, amount of $CO_2$ gas, m = ($m_2$ − $m_1$)
= (183.667-183.00) gm
= 0.667 gm.

Now, 44.00 gm $CO_2$ contains = 12.00 gm carbon (c)
0.667 gm $CO_2$ contains = (12.00×0.667) ÷ 44.00
= 0.1819 gm

Therefore, 550.00 gm steel contains 0.667 gm$CO_2$means = 0.1819 gm carbon (c)
100.00 gm steel contains 0.667 gm$CO_2$means= (0.18190 × 100) ÷ 550.00
= 0.033 gm carbon

Therefore, amount of carbon in steel = 0.033%.

## 9. Result and discussion

The concerning matter of my project is to find out how much amount of carbon is available in stainless steel. I have successfully determined the amount of carbon in steel and its amount is 0.033%. The experimental value of carbon varies with actual value since stainless steel contains less than 0.10% that is discussed in limitations.

## 10. Discussion

In case of steel and cast iron especially carbon has merits and demerits due to the amount of it, I have learnt from this project. During combustion available oxygen is passing inside the furnace. As a result over heated ferrous sample oxidizes with the oxygen due to the reaction of oxidization. Then carbon dioxide is absorbed in an activated carbon. The increase in weight of the absorbent gives the amount of carbon. We know that carbon is most important for both organic and inorganic substance due to its physical and chemical properties. In commercial sphere carbon is very essential. As a result a small amount of carbon can vary physical and chemical properties of metal. The experimental value of carbon is 0.033% of stainless steel but actually stainless steel contains less than 0.10% carbon [Reference 10, (duplex stainless steel)].But duplex stainless steel contains maximum 0.03% carbon. Therefore error is 0.003 %, (0.033-0.03) %, due to a small amount of impurities such as $SO_2$, FeO are included with $CO_2$ during measurement.

## 11. Scope and limitations

With the help of this experimental project we can measure the total amount of carbon from the steel and cast iron by combustion process. The combustion takes place inside a furnace where we use refractory material as an insulator protecting heat energy. The operating and maintenance cost are so effective.

It is quit impossible to find out the exact amount of carbon content of a metal by this experiment since it is analogue system. During the combustion some of the carbon will remain in combustion chamber due to ambient pressure, incomplete reaction and combustion and what not. A little amount of $CO_2$ will be loss during taking it in gas jar since $CO_2$ is volatile. Therefore final value of carbon will vary from actual value. But in modern technology the carbon measuring instruments are digital such as spectrophotometer that imparts the proper reading and widely used.

## 12. Conclusion and recommendation

I have to find out the total amount of carbon finally from the stainless steel by the properly designing and fabricating of an experimental setup. I have become successful to design and fabricate my project. To apply this method in to practical field, it is needed to be modified. Since the carbon measuring instruments are digital in modern technology so it should be digital by proper designing in future with relatively effective cost.

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