

# DESIGN OF INTENSIVE FIRING ROASTING AND MELTING FURNACE FOR NON FERROUS METALS



## Author(s)

Muhammad Luqman	19-ME-124
Abdullah Javed	19-ME-156
Usman Hassan	19-ME-172
Muhammad Abdullah Saeed	19-ME-196

## Advisor

Dr. Azhar Hussain

Assistant professor

DEPARTMENT OF MECHANICAL ENGINEERING  
FACULTY OF MECHANICAL AND AERONAUTICAL ENGINEERING  
UNIVERSITY OF ENGINEERING AND TECHNOLOGY TAXILA

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Project Advisor:

Dr. Azhar Hussain

Assistant Professor

Neutral Examiner Signature: \_\_\_\_\_

Project Advisor Signature: \_\_\_\_\_

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## **Abstract**

Combustion is a very important process in the metal processing and refining industries. The furnaces available in the market are less efficient and generate a lot of waste heat. The thermal efficiency of furnaces used to melt nonferrous metals is about 30-35%. Also, a lot of flue gases are generated along with the emission of CO by using coke which increases the carbon footprint of such furnaces. The focus is to design an efficient burner incorporating the regeneration phenomenon in burners. In addition to this, the effect of combustion elements is also studied on efficient fuel burning. Increasing burner efficiency means increasing the flame temperature of the burner which is around about 800-1000°C to 1250-1300°C by using a combination of nozzles, a fuel pump, and a blower. The thickness of the refractory and shell were both adjusted within practical bounds, and the furnace was lined with fireclay refractory. Design, construction, and experimental techniques have received the majority of attention when assessing the cupola's thermal performance. This has been accomplished using mathematical models that have been created and improved over the time to validate outcomes. For the cupola, ensuring great operational efficiency is crucial. The furnace's available heating space is directly impacted by the thermal performance. So, a crucial component that requires careful attention is the quantity of heat that is readily available in the heating room. The operational, thermal, and overall efficiency of the cupola are greatly influenced by maximum combustion temperature.

### **Keywords:**

Elements of combustion, Coke less furnace, Reduce emissions, Efficient combustion, Recuperation

## Undertaking

I/WE certify that the final year project titled “DESIGN OF INTENSIVE FIRING ROASTING AND MELTING FURNACE FOR NON FERROUS METALS” is my/our own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged/referred.

Muhammad Luqman  
19-ME-124

Abdullah Javed  
19-ME-156

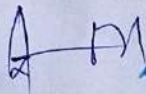
Usman Hassan  
19-ME-172

Muhamad Abdullah Saeed  
19-ME-196

## Acknowledgment Certificate

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Assistant Professor  
Mech. Engg. Deptt.  
University of Engg. & Tech  
Taxila

Dr. Azhar Hussain  
Assistant Professor  
MED, UET Taxila  
[azharhussain@uettaxila.edu.pk](mailto:azharhussain@uettaxila.edu.pk)  
0519047348

## United Nations Sustainable Development Goals

The Sustainable Development Goals are a call for action by all countries – poor, rich and middle-income – to promote prosperity while protecting the planet. They recognize that ending poverty must go together with strategies that build economic growth and address a range of social needs including education, health, social protection, and job opportunities, while tackling climate change and environmental protection. Check the appropriate SDGs related to the project.

SDGs		Tick the appropriate SDG
Quality Education		
Clean Water and Sanitation		
Affordable and Clean Energy		
Decent Work and Economic Growth		
Industry, Innovation, and Infrastructure		
Sustainable Cities and Communities		
Responsible Consumption and Production		
Climate Action		

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## Nomenclature

<b>AFR</b>	Air Fuel Ratio
<b>CO</b>	Carbon monoxide
<b>CFM</b>	Cubic Foot per Meter cube
<b>DeS</b>	Degree of Sulphur
<b>FIGR</b>	Flue Gas Recirculation
<b>FuGR</b>	Furnace Gas Recirculation
<b>LHV</b>	Light Heating Value
<b>NOX</b>	Nitrogen Oxides
<b>OEC</b>	Oxygen Enhanced Combustion
<b>PPMWW</b>	Parts Per Million Volume by Weight Percent

### Greek Symbol

$\alpha$ :	Alpha
$\varepsilon$ :	Epsilon
$\xi$ ;	Zeta

## CHAPTER 1

# INTRODUCTION TO FURNACES

A furnace generates a regulated quantity of heat through the combustion of a fuel source, following the specific design of the device. Subsequently, this thermal energy is employed to warm spaces such as rooms, buildings, or other structures. In commercial and industrial settings, specific types of furnaces can be employed to treat diverse materials like copper, cast iron, mild steel, glass, and more.

## 1.1 TYPES OF FURNACES

### 1.1.1 Induction Furnaces

Induction furnaces, as their name implies, utilize alternating electric currents to achieve the necessary temperature for melting metals. Foundries widely adopt induction furnaces due to their superior quality, user-friendly operation, and energy efficiency. This furnace's capacity to melt little amounts, even less than 1 kg, as well as massive volumes, up to 100 tons, is another benefit.



Figure 1.1 Induction Furnace [3]

The energy is transferred to the molten material through a cooled coil known as an inductor. These coils are specifically designed and fabricated to fit the shape of the furnace or the

individual workpieces. The electrically non-conductive crucible is located outside the water-cooled inductor.

### 1.1.2 Crucible Furnaces

Refractory materials, such as ceramics, are used in the construction of crucible furnaces to withstand and survive extremely high temperatures. To speed up the melting process, the metal and additive-containing crucible is placed above a heat source. Crucible sizes can vary greatly, and furnace designs and heating systems might also differ. Crucible furnaces come in a variety of styles, such as tiltable and fixed crucible furnaces as well as moveable and stationary crucible furnaces. It's critical to distinguish between fuel- and resistance-heated furnaces.



Figure 1.2 Crucible Furnace [3]

Crucible furnaces have a number of benefits, including as inexpensive upfront expenditures and simple operation and maintenance. They also allow for fast changes in crucible contents and the flexibility to melt tiny amounts of metal. However, when it comes to melting large quantities, crucible furnaces are no longer cost-effective due to significantly increased energy consumption and the time-consuming nature of manual operation.

### 1.1.3 Electric Arc Furnaces

An electric arc creates heat in an electric arc furnace, which uses that heat to melt metal. Carbon electrodes are utilized for this purpose. Electric arc furnaces are predominantly employed in practice for melting steel scrap, which is then used in the production of new items. The operation of an electric arc furnace is similar to that of Tesla coils, employing powerful electric arcs to achieve metal melting. While it is highly efficient in terms of melting capacity, it consumes excessive energy, rendering it a costly option in the metal melting industry.



Figure 1.3 Electric Arc Furnace [6]

### 1.1.4 Cupola Furnaces

The usage of cupola furnaces in foundries dates back a long time. These furnaces stand out for their towering, cylindrical chimneys that are coated with bricks, blocks, and clay to shield the inside from oxidation, abrasion, and high heat. Before adding the metal to the furnace to begin melting, layers of ferroalloys, coke, and limestone are added. As a result, impurities in the furnace start to rise to the surface of the molten metal due to a chemical reaction. However, in reality, only a small number of foundries still use cupola

furnaces since induction furnaces, which use less energy, are now the favored option over conventional cupola furnaces.



Figure 1.4 Cupola Furnace [3]

## 1.2 COMPONENTS OF CUPOLA FURNACE

Following are Components of cupola furnace.

- Legs
- A Slag Hole
- A Sand Bed
- Tuyeres
- The Preheating Zone
- The Melting Zone
- The Charging Door
- The Brick lining
- Spark Arrester

All components are shown in the following schematic diagram shown in figure.

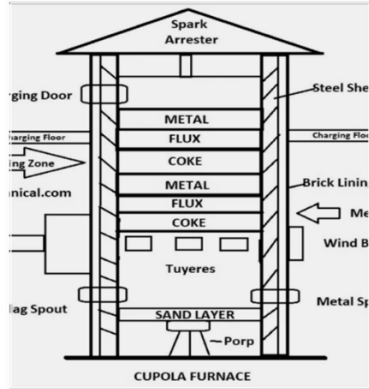


Figure 1.5 Cupola Furnace Components [4]

### 1.3 BENEFITS OF A CUPOLA FURNACE

Benefits of cupola furnace are given below:

- Easily constructed.
- A broad range of flexibility for melting materials.
- Compact floor area needed for operation.
- It is simple for people with minimal skill levels to operate.

### 1.4 DISADVANTAGES OF CUPOLA FURNACE

- It is difficult to keep temperature management under control.
- The carbon content of the iron product increases because of the heating of coke in conjunction with the metal.
- Elements made of metal undergo transformation into their oxides, which, due to their high melting temperatures, are unsuitable for casting.

### 1.5 DISCUSSIONS

Based on the previous discussion, we can draw the following conclusions:



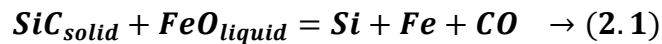
- Induction furnaces and electric arc furnaces are power-intensive, requiring a substantial amount of electricity.
- Crucible furnaces utilize expensive crucibles, which are available in small sizes, and they experience significant thermal losses.
- Cupola furnaces are suitable for large-scale operations due to the abundant presence of coke. However, if environmental concerns arise regarding coke usage, coke-less cupola furnaces can be employed.
- All furnaces mentioned require a continuous energy consumption, either in the form of heat generated via combustion or electrical energy to produce powerful sparks for metal melting.
- The figure highlights the presence of a slag hole below the metal, which is due to the difference in densities between sand and molten metal at respective temperatures. The slag settles below, allowing for the extraction of the metal. The slag hole is typically closed for most of the melting process.
- When developing a furnace, various materials are available in the market, such as different types of sheet metals, refractory bricks, and fuel. The selection of materials depends on factors like the furnace's temperature range, the type of metal being melted, economic considerations such as fuel costs and labor expenses, as well as environmental sustainability and carbon footprint concerns.

## CHAPTER 2

# BASIC REACTION IN INTENSIVELY FIRED FURNACE

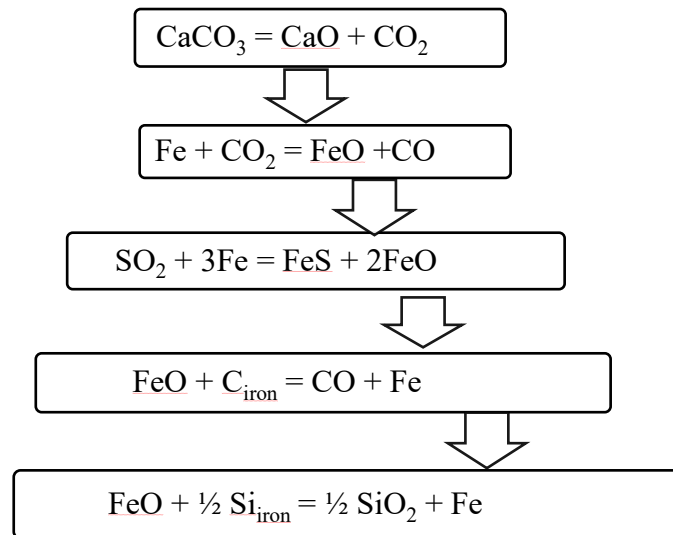
### 2.1 REACTION DYNAMICS

“The cupola furnace works on the principle where we generate heat from burning coke and when the temperature of the furnace is above the melting point of the metal then the metal is melted.”



This reaction occurs in the sand bed of cupola furnace and thus produces carbon monoxide Iron and Silicon which is then dumped as discussed in next portion. Also, all reactions in cupola furnace are endothermic reactions.

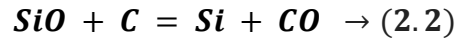
### 2.2 SUMMARY OF REACTIONS IN CUPOLA FURNACE



Schematic Chart 1 Reactions in a coke fired Cupola Furnace [2]

## 2.3 VARIATION IN SLAG COMPOSITION OF FURNACE

The figures below show that in the test blast furnaces, Si, Mn, and Ti concentrations in metal droplets tended to grow to exceptionally high values in the area of tuyere level before falling again in the hearth. A comparable tendency was not noticed in the working furnaces, with the possible exception of Si, which occasionally exhibited similar behaviour as seen in Figures 2.1 and 2.2. A fascinating finding about the behaviour of C and Si was made in a test furnace, as illustrated in Figure 2.1. Because of the reaction's decarburization, the C content may drop near the tuyere level, where the partial pressure of SiO is high.



may prevail over the reaction that causes carburization. Another noteworthy finding was for P, which was made in the Tsurumi 1 BF.

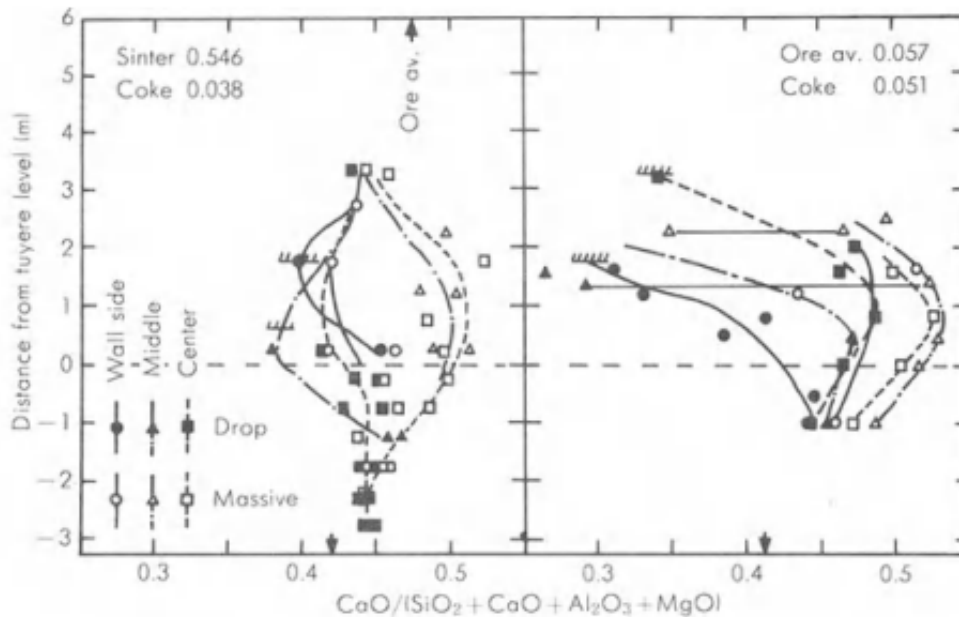


Figure 2.1 Change in slag droplet composition I [7]

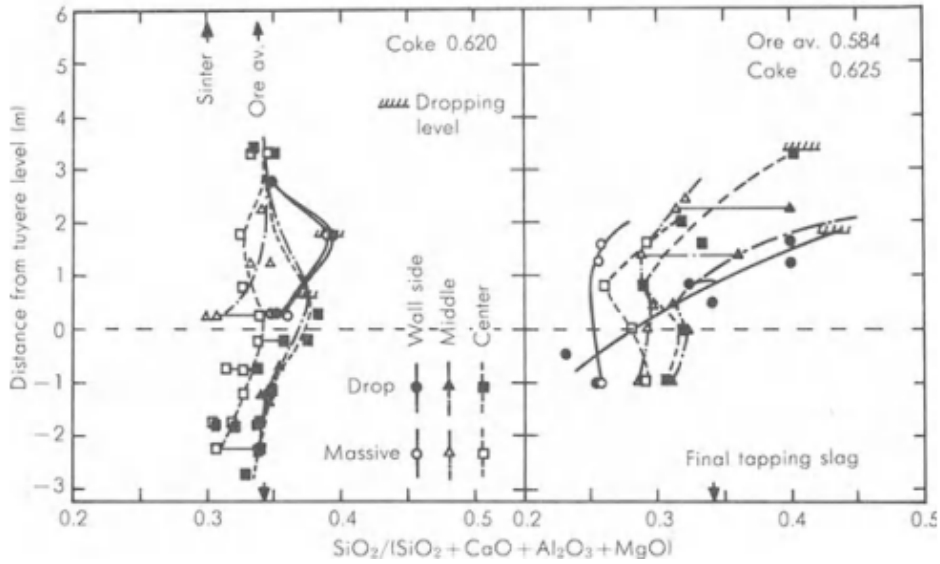


Figure 2.2 Change in Slag droplet composition II [7]

Figure shows that P had a larger radial distribution in the periphery than in the center, which was consistent with the distribution of the P-rich converter slag charge. These findings led to the following inferences about how those parameters affected the longitudinal and radial distributions of metal components in the furnace's bottom part:

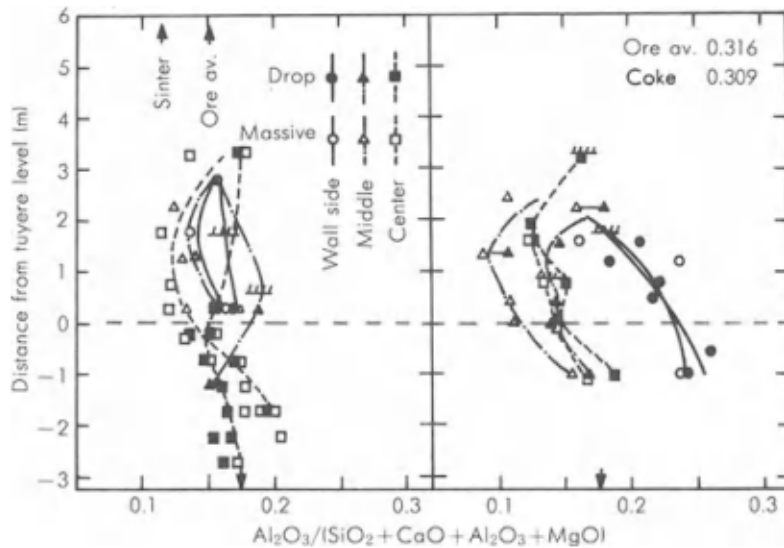


Figure 2.3 Change in slag droplet composition III [7]

1. Si is the component that is most heavily impacted by the gas that exits the combustion zone and flows into the melting zone.
2. The elements that the Si content affects are: (and C) Mn
3. The following element is affected by the cohesion zone's form and the way gas flows through it: S.
4. The element that is significantly represented in the component that is affected by the distribution of charged material: P.

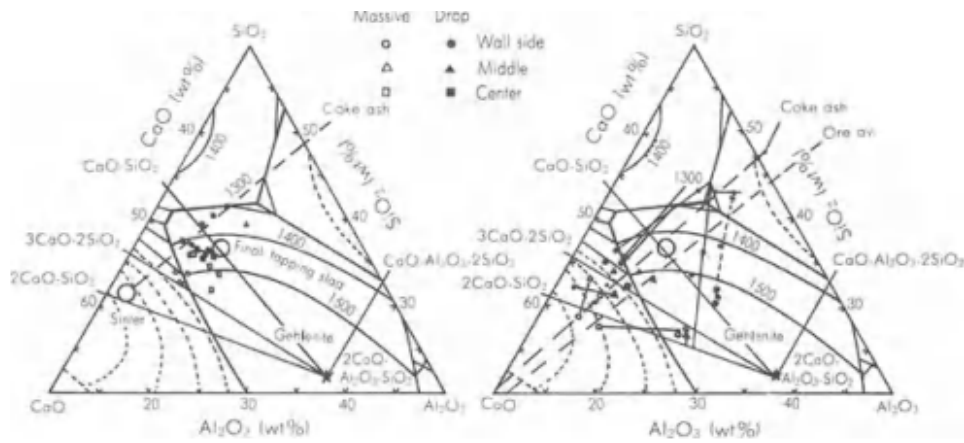


Figure 2.4 Relationships between the charge's gangue composition and changes [7]

## 2.4 DISCUSSIONS

The following is the reason why the aforementioned responses do not apply to coke-less cupolas. Hot metal is appropriate for producing SG iron since there is no sulfur pick-up by the metal during melting. As the amount of limestone in the charge mix grows, the De-S level also rises. Every test revealed that the product's phosphorus concentration was somewhat lower than the charge's initial phosphorus content, although it was also noted that lowering conditions were kept throughout the melting procedure. During melting, there

have been some carbon and silicon losses that have been documented. According to trial and published data, the greatest carbon and silicon losses were 3% and 8%, respectively. A carburizing agent was injected, and Ferro silicon was added to the charge mix, to produce the necessary carbon and silicon in the heated metal.

## CHAPTER 3

# ANALYZING DESIGN PARAMETERS

### 3.1 GENERAL PARAMETRE SELECTION

Some design parameters for cupola furnace

- Lining Diameter
- Height of cupola
- Charging door size
- Melting Capacity
- Total Tonnage of heat supplied.
- Fan Diameter
- Wind Pressure
- Speed of fan

### 3.2 DESIGN CALCULATIONS

Height of furnace = 8ft

Diameter of furnace including refractory bricks = 2 ft

Core diameter of furnace = 1 ft

#### 3.2.1 SHEET METAL CALCULATIONS

Diameter for bended sheet metal = 27 inch

Radius of bended sheet = 13.5 inch

Width of sheet metal  $W = 24$  inch

Parameter of bended sheet = length of sheet metal =  $2 \pi r$

$$= 2 \times \frac{22}{7} \times 13.5$$

$$= \mathbf{84.8 \text{ inch}}$$

length of sheet metal = 84.8 inch

Area of sheet metal = length of sheet metal  $\times$  Width of sheet metal

$$= 84.8 \text{ inch} \times 24 \text{ inch}$$

$$= \mathbf{2035.75 \text{ inch}^2}$$

### **3.2.2 RIVET HOLE DIAMETRE CALCULATIONS**

$$d = 6 \times \sqrt{2 \times t}$$

Where  $t$  is thickness of sheet metal = 5 mm

Diameter for rivets holes  $d=19$  mm

Diameter of rivets = 18mm (From table) and for length consult **table 9.4**



Table 3.0:2 Relationship between Rivet diameter and Rivet hole diameter [12]

Basic size of rivet mm	12	14	16	18	20	22	24	27	30	33	36	39	42	48
Rivet hole diameter (min) mm	13	15	17	19	21	23	25	28.5	31.5	34.5	37.5	41	44	50

Table 3.0:1 Design Guide for Rivets with Relationship between Diameter and Length [12]

<i>Length</i>	12	14	16	18	20	22	24	27	30	33	36	39	42	48
28	x	-	-	-	-	-	-	-	-	-	-	-	-	-
31.5	x	x	-	-	-	-	-	-	-	-	-	-	-	-
35.5	x	x	x	-	-	-	-	-	-	-	-	-	-	-
40	x	x	x	x	-	-	-	-	-	-	-	-	-	-
45	x	x	x	x	x	-	-	-	-	-	-	-	-	-
50	x	x	x	x	x	x	-	-	-	-	-	-	-	-
56	x	x	x	x	x	x	x	-	-	-	-	-	-	-
63	x	x	x	x	x	x	x	x	-	-	-	-	-	-
71	x	x	x	x	x	x	x	x	x	-	-	-	-	-
80	x	x	x	x	x	x	x	x	x	-	-	-	-	-
85	-	x	x	x	x	x	x	x	x	x	-	-	-	-
90	-	x	x	x	x	x	x	x	x	x	-	-	-	-
95	-	x	x	x	x	x	x	x	x	x	x	-	-	-
100	-	-	x	x	x	x	x	x	x	x	x	-	-	-
106	-	-	x	x	x	x	x	x	x	x	x	x	-	-
112	-	-	x	x	x	x	x	x	x	x	x	x	-	-
118	-	-	-	x	x	x	x	x	x	x	x	x	x	-
125	-	-	-	-	x	x	x	x	x	x	x	x	x	x
132	-	-	-	-	-	x	x	x	x	x	x	x	x	x
140	-	-	-	-	-	x	x	x	x	x	x	x	x	x
150	-	-	-	-	-	-	x	x	x	x	x	x	x	x
160	-	-	-	-	-	-	x	x	x	x	x	x	x	x
180	-	-	-	-	-	-	-	x	x	x	x	x	x	x
200	-	-	-	-	-	-	-	-	x	x	x	x	x	x
224	-	-	-	-	-	-	-	-	-	x	x	x	x	x
250	-	-	-	-	-	-	-	-	-	-	-	-	x	x

### 3.2.3 CALCULATION OF RIVETING PITCH

$$\eta_c = \frac{p_1 - d}{p_1} \dots\dots\dots(3.1)$$

$$\eta_c = 62 \%$$

Or 
$$X = \frac{W - n \times d}{n + 1} \dots\dots\dots(3.2)$$

$$P = X + d \dots\dots\dots(3.3)$$

From equation (3.1)

$$p_1 = 50 \text{ mm}$$

From equation (3.2)

$$X = 38 \text{ mm}$$

Rivet Pitch  $P = 38 + 19 = 57$  mm which is greater than  $2 \times d$

Total no of rivets in one sheet metal = 10

Total no of sheet metals  $N = 4$

Total no of rivets =  $10 \times 4 = 40$

### 3.2.4 BOLT AND FLANGE CALCULATIONS

Bolted Joints = 4

Total no of flanges for one sheet for nut and bolt  $F= 8$

If bottom sheet is welded with table, then.

Total no of flanges=  $F*(N-1)$

$$= 8*(4-1)=24$$

For M-24× 2 hexagonal bolt of fine series

Threaded Pitch  $p_t= 2\text{mm}$

Major or nominal diameter of nut and bolt  $D=d = 24\text{mm}$

$$d_c = 0.84 \times D$$

Pitch diameter of nut and bolt  $d_p = 22.701 \text{ mm}$

Minor diameter of bolt  $d_{c \text{ bolt}} 21.546 \text{ mm}$

Minor diameter of nut  $d_{c \text{ nut}} 21.83 \text{ mm}$

Depth of thread of bolt = 1.227 mm

$$\text{Shear Area} = \frac{\pi}{4} \left( \frac{d_p + d_c}{2} \right)^2$$

$$\text{Shear Area} = 384 \text{ mm}^2$$

Total no of nuts = 24

Total no of bolts = 24

Table 3.0:3 Design guide for nuts and bolts [12]

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
M 7	1	7.000	6.350	5.773	5.918	0.613	28.9
M 8	1.25	8.000	7.188	6.466	6.647	0.767	36.6
M 10	1.5	10.000	9.026	8.160	8.876	0.920	58.3
M 12	1.75	12.000	10.863	9.858	10.106	1.074	84.0
M 14	2	14.000	12.701	11.546	11.835	1.227	115
M 16	2	16.000	14.701	13.546	13.835	1.227	157
M 18	2.5	18.000	16.376	14.933	15.294	1.534	192
M 20	2.5	20.000	18.376	16.933	17.294	1.534	245
M 22	2.5	22.000	20.376	18.933	19.294	1.534	303
M 24	3	24.000	22.051	20.320	20.752	1.840	353
M 27	3	27.000	25.051	23.320	23.752	1.840	459
M 30	3.5	30.000	27.727	25.706	26.211	2.147	561
M 33	3.5	33.000	30.727	28.706	29.211	2.147	694
M 36	4	36.000	33.402	31.093	31.670	2.454	817
M 39	4	39.000	36.402	34.093	34.670	2.454	976
M 42	4.5	42.000	39.077	36.416	37.129	2.760	1104
M 45	4.5	45.000	42.077	39.416	40.129	2.760	1300
M 48	5	48.000	44.752	41.795	42.587	3.067	1465
M 52	5	52.000	48.752	45.795	46.587	3.067	1755
M 56	5.5	56.000	52.428	49.177	50.046	3.067	2022
M 60	5.5	60.000	56.428	53.177	54.046	3.374	2360
<b>Fine series</b>							
M 8 × 1	1	8.000	7.350	6.773	6.918	0.613	39.2
M 10 × 1.25	1.25	10.000	9.188	8.466	8.647	0.767	61.6
M 12 × 1.25	1.25	12.000	11.184	10.466	10.647	0.767	92.1
M 14 × 1.5	1.5	14.000	13.026	12.160	12.376	0.920	125
M 16 × 1.5	1.5	16.000	15.026	14.160	14.376	0.920	167
M 18 × 1.5	1.5	18.000	17.026	16.160	16.376	0.920	216
M 20 × 1.5	1.5	20.000	19.026	18.160	18.376	0.920	272
M 22 × 1.5	1.5	22.000	21.026	20.160	20.376	0.920	333
M 24 × 2	2	24.000	22.701	21.546	21.835	1.227	384
M 27 × 2	2	27.000	25.701	24.546	24.835	1.227	496
M 30 × 2	2	30.000	28.701	27.546	27.835	1.227	621
M 33 × 2	2	33.000	31.701	30.546	30.835	1.227	761
M 36 × 3	3	36.000	34.051	32.319	32.752	1.840	865
M 39 × 3	3	39.000	37.051	35.319	35.752	1.840	1028

### 3.3 ESTIMATED PARAMETRE FOR VARIOUS CUPOLA FURNACE

The data in the table below was compiled using information from the book Modern shop practise: a general reference work on machine shop practise and management, production manufacturing, metallurgy, welding, tool making, tool design, die making and metal stamping, foundry work, forging, pattern making, mechanical and machine drawing, etc. by Howard Monroe Raymond, American Technical Society.

In this table following parameters are given

1. Lining Diameter
2. Furnace Height
3. Charging Door Dimensions
4. Melting Capacity
5. Heat Supplied

for furnace parameters

Table 3.0:4 Furnace Parameters Tables [4]

<b>Diameter of Inside Lining(inches)</b>	<b>Furnace Height (feet)</b>	<b>Charging door Size(inches)</b>	<b>Melting Capacity Per Hour (tons)</b>	<b>Total Heat Supplied (tons)</b>
17.9	6-7	15x18	1/2-3/4	1-2
19.9	7-8	18x20	1/3-1	2-3
23.8	8-9	20x24	1-2	3-5
29.7	9-12	24x24	2-5	4-10
39.8	12-15	30x36	4-8	8-20
59.7	15-18	30x40	6-14	15-40

### 3.3.1 FAN SPECIFICATIONS

In the table of fan specification, we have taken into account various fan parameters i.e.,

1. Fan Diameter
2. Speed of Fan in rpm
3. Wind pressure generated in CFM.

Table 3.0:5 Table for various Fan Types [5]

Fan Diameter (inches)	Speed (revolutions per minute)	Wind Pressure (ounces per square inch)
18	4050	5.2
24	3730	6.1
36	2850	10.5
48	2540	13.8

This table is taken from the paper titled “Design of High Efficiency Blowers for Future Aerosol Applications” (December 2005) Raman Chadha, B-En., IIT-Kanpur

### 3.4 DISCUSSIONS

The radius of the circle produced with the mean running as its circumference is  $(304 - 2.5)$  mm or 302.5mm i.e. 11.88 inches and  $(304 + 2.5)$  mm i.e. 12.11 inch. This was obtained from the formula.

$$R_{M1} = R_E - \frac{1}{2} \times T \rightarrow (3.4)$$

&

$$R_{M2} = R_E + \frac{1}{2} \times T \rightarrow (3.5)$$

where  $R_M$  is the radius of the mean running,

$R_E$  is the external radius and

T is the thickness of sheet metal.

Now actually what we have done is as follows.

$$R_M = \frac{R_{M1} + R_{M2}}{2} \rightarrow (3.6)$$

This average is about as follow.

$$R_M = 11.95 \text{ inches}$$

Also we have assume a tolerance factor of 1.35 inches hence

$$R_M = 11.95 \text{ inches} + \text{of } 1.35 \text{ inches}$$

$$\mathbf{R_M = 13.5 inches}$$

## CHAPTER 4

# INTRODUCTION TO INDUSTRIAL COMBUSTION

The realm of industrial combustion encompasses a wide range of areas that directly or indirectly affect almost every aspect of our lives. Our electronic devices typically rely on power from power plants that typically operate on fuels like diesel, Heavy Furnace Oil, Light Furnace Oil, Coal, L.P.G. and Natural Gas while internal combustion engines propel the cars we drive, and jet-fuel-powered turbine engines propel the planes we fly in. Additionally, most of the materials we utilize are produced through various heating processes.

Industrial combustion is a complex field influenced by numerous factors. Firstly, the scientific understanding is of combustion evolving and yet has a ways to go before achieving a comprehensive result that can lead to improved application and control. Despite fire being a fundamental element since the dawn of humanity, there is much more to be discovered. The study of combustion incorporates disciplines such as heat exchange, thermodynamics, Reaction kinetics, and multi-phase flow Computational Fluid Dynamics, among other areas of Engineering. Hence, due to its multifaceted nature, the exploration of industrial combustion necessitates an interdisciplinary approach.

## 4.1 IMPORTANCE OF COMBUSTION IN MELTING INDUSTRY

According to US department of Energy Combustion is necessary in following fields of metallurgy.

### **Melting of Metal**

- Steel manufacturing



- Melting of steel and iron
- Ferrous and melting of Nonferrous.

### **Heating of Metal**

- Ladle preheating, steel soaking, and reheating.
- Forging
- Heating without iron

### **Heat Treat Metal**

- Annealing
- Tempering
- Solution heat treatment
- Aging

## **4.2 MAIN COMBUSTION ELEMENTS**

There are three main Combustion elements.

- Fuel
- Source of ignition
- Oxygen (Air)
- Available Space
- Diffusion in flame

This can be illustrated in the following combustion triangle shown on the next page.

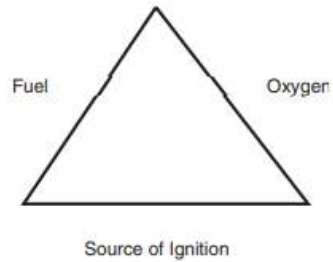


Figure 4.1 Combustion triangle [7]

In applications involving the melting of metals, higher intensity burners are commonly employed due to the higher temperatures required. Techniques such as combustion with oxygen enhancement and air heating are utilized to raise the temperature of the flame and enhance capabilities of melting of metal. However, it is important to mention that these higher intensity burners potentially result in elevated pollutant emissions. Therefore, careful burner design is crucial in order to minimize these emissions.

### **4.3 COMPONENTS OF A COMBUSTION FURNACE**

Following are components of Combustion Furnace

- Fuel Control System
- Combustion Air Blower
- Burner
- Exhaust Fan
- Heat Exchanger
- Pollution Control System

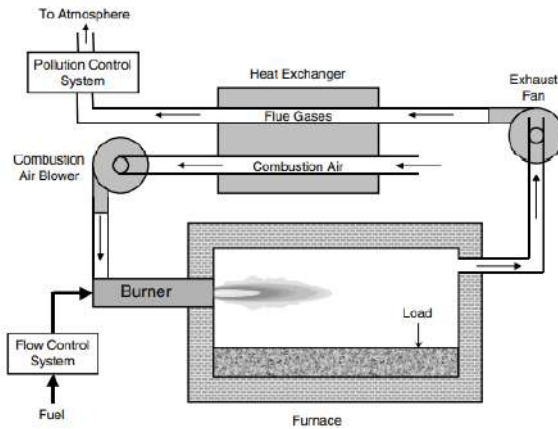


Figure 4.2 Schematic Diagram of typical regenerative furnace [7]

From this schematic diagram it is clear heat exchanger is a common component for recycled combustion air mixed with ambient air and the exhaust flue gases.

Some important factors while designing a burner with minimum carbon footprint are as follows.

- CO Concentration (Vol. %)
- Equivalence Ratio
- NO Concentration (ppmv)
- Gas Temperature
- Species Concentration (ppmv)

All these factors are given below in the following graphs.

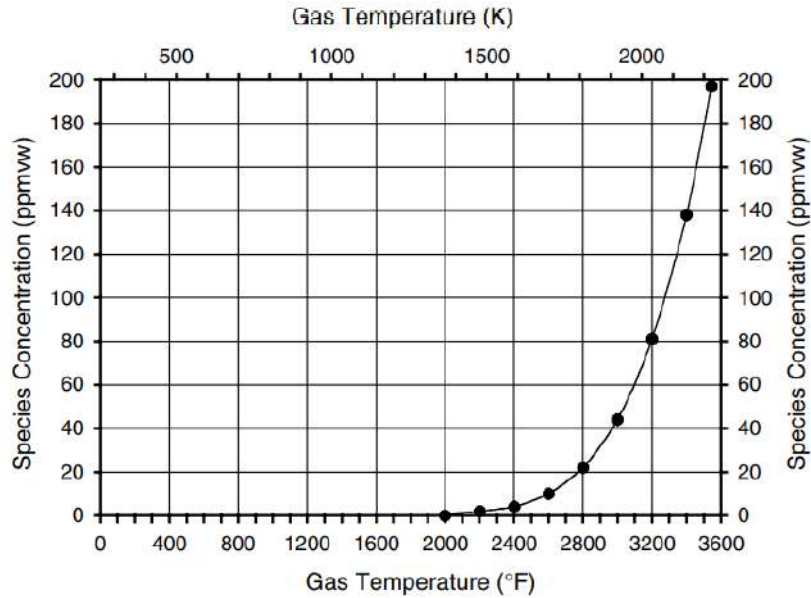


Figure 4.3 Relationship between gas temperature and species concentration [7]

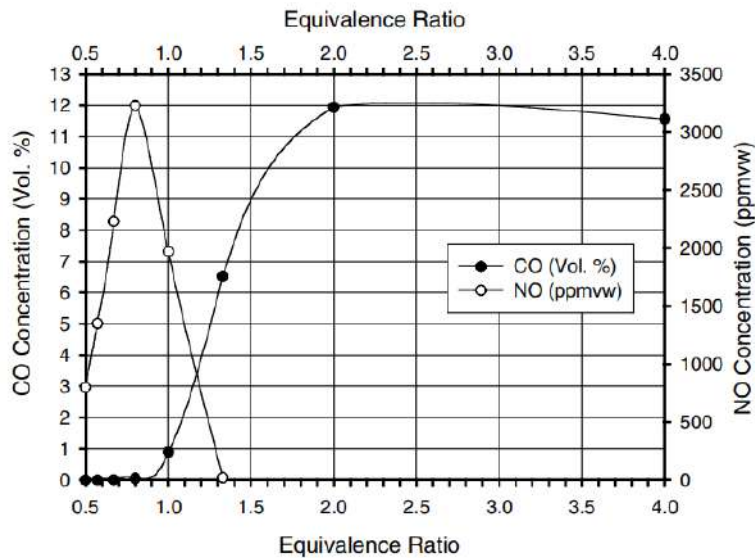


Figure 4.4 Relationship of Equivalence ratio with NO and CO concentration [7]

The design of a burner involves considering various factors that impact heat transfer and pollutant emissions. Recent focus on reducing emissions has led to significant changes in traditional burner designs. In the past, burner designers primarily focused on efficient fuel

combustion and energy transfer to the heat load. However, strict environmental regulations now require consideration of harmful emissions that the hob produces.

Sometimes the goals of reducing pollutant emissions and improving combustion efficiency clash. A staged descent strategy, for instance, can be used to cut NO<sub>x</sub> emissions when the primary flame zone is either fuel- or oxidizer-deficient. A secondary flame zone or another area of the combustion chamber can receive more fuel or oxidizer. Due to the fact that fuel-rich or fuel-lean zones are less prone to NO<sub>x</sub> generation than zones that are close to stoichiometry, staging lowers peak temperatures in the primary flame zone and changes reaction dynamics, hence minimizing NO<sub>x</sub> emissions. Because NO<sub>x</sub> emissions are strongly reliant on peak temperature, even slight changes can have a big impact by lowering peak flame temperatures. However, because radiant heat is governed by the fourth power of the absolute gas temperature, lower flame temperatures may result in less heat transmission from the flame.

Combustion that is staged produces more CO emissions, which causes incomplete combustion and eventually lower combustion efficiency. Additionally, staged combustion may raise the flame's soot concentration, which might enhance flame radiation. This particular hob design has a significant impact on how staging affects heat transmission from the flame.

For fuels with poor heating value, such as waste liquid fuels or process gases from chemical processing industries, the main issue for burner designers in the past was to maximize fuel-oxidizer mixing to achieve full combustion. However, in order to achieve high combustion efficiency and minimize all kinds of polluting emissions, current burner designers must now balance fuel-oxidizer mixing. Due of the inverse connection between NO<sub>x</sub> and CO

emissions, as seen in the above figure, this task is difficult. Conversely, large NO<sub>x</sub> emissions occur when CO emissions are minimal. While guaranteeing effective heat transfers to the required load, contemporary burners must adhere to environmental requirements.

#### **4.4 FUEL AND OXIDIZERS**

The choice of fuels is influenced by a number of variables, including availability and cost, which may differ geographically. Particularly natural gas is frequently utilised for industrial heating purposes in the United States. Natural gas is also widely used in Europe, where it is frequently combined with light fuel oil. Although the usage of gaseous fuels is expanding, heavy fuel oils are still often employed in Asia and South America. The particular use determines the fuel options as well. For instance, waste fuels are widely used alone or in conjunction with other fuels, such as natural gas, in incineration procedures where hazardous waste products are routinely burned at high temperatures. Fuel gases in the petrochemical sector frequently combine different fuels such hydrogen, methane, propane, butane, and propylene.

Heat transmission from a flame is impacted by the fuel choice. Both liquid and solid fuels, such as oil and coal, generally generate brilliant flames with soot particles that radiate heat like blackbodies. Natural gas and other gaseous fuels frequently produce nonluminous flames because they burn completely and cleanly without producing soot particles. Fuels like hydrogen generate absolutely nonluminous flames since there isn't any carbon present to produce soot. A bright flame is recommended when extremely brilliant flames are needed. To reduce the possibility of soot particle contamination on the heat load, a nonluminous flame may be desired in situations where convection heat transmission is

preferable. New methods are being developed to produce more dazzling flames in instances when natural gas is the primary fuel and is needed. These methods involve pyrolyzing the fuel in a partial oxidation process that uses plasma to form soot in the fuel, as well as managing the mixing of the fuel and the oxidizer to produce fuel-rich flame zones that produce soot particles. As a result, the kind of fuel utilized in combustion has a big influence on how heat is transferred from the flame to the load.

Most of the time, the client makes the fuel selection rather than the burner designer. Based on the chosen fuel, the burner design must be optimized.

#### **4.5 GAS RECIRCULATION**

In combustion systems, a typical technique known as boiler gas recirculation (FuGR) allows for the input of boiler gases to thin the flame. Despite being still warm, the boiler gases are much colder than the flame itself. By lowering the flame's peak temperatures, this dilution reduces NO<sub>x</sub> emissions, among other things. FuGR Furnace Gas Recirculation may be favored over Flue Gas Recirculation (FlGR) as shown in Figure 4.2 because it does not require external high-temperature ductwork or fans to carry product gases into the flame zone. Because of the increased gas volume and velocity, furnace gas recirculation also improves convective heating from the flame. Figure 4.5 provides a sample of flue gas recirculation into the burner.

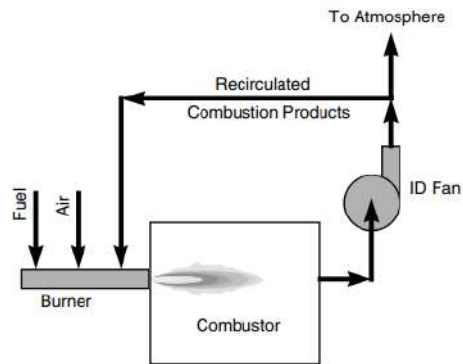


Figure 4.5 Schematic for gas circulation [7]

In this figure we can see following components

1. Combustor
2. Induced draft fan.
3. Burner
4. Recirculating mechanism for flue gases
5. Fuel carrying line.
6. Mechanism for feeding ambient air.

This kind of mechanism for furnace is the most advantageous and efficient. It is used in every heating industry and thus is the most common kind of heating system used in the furnace industry.



Table 4.0:1 Property Table for Hydrocarbons [17]

Hydrocarbon	Formula	Higher Heating Value, Vapor (Btu/lb <sub>m</sub> )	Theor. Air/Fuel Ratio, by mass	Max. Flame Speed (ft/s)	Adiabatic Flame Temp., in Air (°F)	Ignition Temp., in Air (°F)	Flash Point (°F)	Flammability Limits, in Air (% by volume)	
<b>Paraffins or Alkanes</b>									
Methane	CH <sub>4</sub>	23875	17.195	1.1	3484	1301	(gas)	5.0	15.0
Ethane	C <sub>2</sub> H <sub>6</sub>	22323	15.899	1.3	3540	968-1166	(gas)	3.0	12.5
Propane	C <sub>3</sub> H <sub>8</sub>	21669	15.246	1.3	3573	871	(gas)	2.1	10.1
<i>n</i> -Butane	C <sub>4</sub> H <sub>10</sub>	21321	14.984	1.2	3583	761	-76	1.86	8.41
<i>iso</i> -Butane	C <sub>4</sub> H <sub>10</sub>	21271	14.984	1.2	3583	864	-117	1.80	8.44
<i>n</i> -Pentane	C <sub>5</sub> H <sub>12</sub>	21095	15.323	1.3	4050	588	<-40	1.40	7.80
<i>iso</i> -Pentane	C <sub>5</sub> H <sub>12</sub>	21047	15.323	1.2	4055	788	<-60	1.32	9.16
Neopentane	C <sub>5</sub> H <sub>12</sub>	20978	15.323	1.1	4060	842	(gas)	1.38	7.22
<i>n</i> -Hexane	C <sub>6</sub> H <sub>14</sub>	20966	15.238	1.3	4030	478	-7	1.25	7.0
Neohexane	C <sub>6</sub> H <sub>14</sub>	20931	15.238	1.2	4055	797	-54	1.19	7.58
<i>n</i> -Heptane	C <sub>7</sub> H <sub>16</sub>	20854	15.141	1.3	3985	433	25	1.00	6.00
Triptane	C <sub>7</sub> H <sub>16</sub>	20824	15.141	1.2	4035	849	—	1.08	6.69
<i>n</i> -Octane	C <sub>8</sub> H <sub>18</sub>	20796	15.093	—	—	428	56	0.95	6.20
<i>iso</i> -Octane	C <sub>8</sub> H <sub>18</sub>	20770	15.093	1.1	—	837	10	0.79	5.94
<b>Olefins or Alkenes</b>									
Ethylene	C <sub>2</sub> H <sub>4</sub>	21636	14.807	2.2	4250	914	(gas)	2.75	28.6
Propylene	C <sub>3</sub> H <sub>6</sub>	21048	14.807	1.4	4090	856	(gas)	2.00	11.1
Butylene	C <sub>4</sub> H <sub>8</sub>	20854	14.807	1.4	4030	829	(gas)	1.98	9.65
<i>iso</i> -Butene	C <sub>4</sub> H <sub>8</sub>	20737	14.807	1.2	—	869	(gas)	1.8	9.0
<i>n</i> -Pentene	C <sub>5</sub> H <sub>10</sub>	20720	14.807	1.4	4165	569	—	1.65	7.70
<b>Aromatics</b>									
Benzene	C <sub>6</sub> H <sub>6</sub>	18184	13.297	1.3	4110	1044	12	1.35	6.65
Toluene	C <sub>7</sub> H <sub>8</sub>	18501	13.503	1.2	4050	997	40	1.27	6.75
<i>p</i> -Xylene	C <sub>8</sub> H <sub>10</sub>	18663	13.663	—	4010	867	63	1.00	6.00
<b>Other Hydrocarbons</b>									
Acetylene	C <sub>2</sub> H <sub>2</sub>	21502	13.297	4.6	4770	763-824	(gas)	2.50	81
Naphthalene	C <sub>10</sub> H <sub>8</sub>	17303	12.932	—	4100	959	174	0.90	5.9

## 4.6 RECUPERATORS

For low to medium-temperature applications (usually up to 1300°F or 700°C), a recuperator is a form of continuous heat exchanger. The combustion air is preheated using sensible heat energy from hot combustion products. Such heat exchangers are frequently built in a counterflow design, with the lowest temperatures at one end of the exchanger and the highest temperatures of the combustion air and products at the other. Metal is typically used for lower-temperature recuperators, while ceramics can be employed for higher-temperature recuperators. The utilization of recuperators is more common in lower-temperature applications due to thermal design limitations of metals used for constructing such heat exchangers.

## 4.7 REGENERATORS

An energy-efficient transient heat exchanger that is primarily used to improve the heating and melting of materials at high temperatures. These procedures are frequently used in sectors of the economy like glass manufacturing. The heat from the combustion products is temporarily retained in a unit made of refractory firebricks in a regenerator. During a certain stage of the firing cycle, this stored energy is then used to heat the incoming combustion air, boosting its temperature to above 2000°F (1000°C).

In most cases, regenerators are run in pairs. Hot combustion gases that are passing through one of the regenerators during one part of the cycle heat the refractory bricks. The second regenerator's combustion air circulates at the same time, cooling the refractory bricks. The bricks in the regenerators come into direct touch with the combustion air and exhaust gases, but they never do so at the same time since they are always in separate regenerators. The cycle is then reversed after a certain amount of time, often between 5 and 30 minutes. As a result, the hotter bricks in the first regenerator may transfer their heat to the entering combustion air, while the cooler bricks in the second regenerator can be warmed. Each regenerator has a reversing valve that changes the gas flow. The burners employed in these systems must be able to withstand both the high-temperature warmed air and the regenerator's continuous thermal cycling.

## CHAPTER 5

# CALCULATIONS FOR FUEL EMISSIVITY AND AFR

### 5.1 EMISSIVITY OF HYDROCARBONS

Depending on the fuel type utilized, soot generation has different meanings. Soot formation for natural gas is normally not a major problem. Higher carbon-to-hydrogen (C:H) weight ratio fuels, on the other hand, result in flames with more soot. Wagner's 1978 survey essay on soot generation in combustion noted that soot commonly occurs at temperatures between 1000 and 2500°C (1800 and 4500°F). Long chains of carbon molecules make up the majority of soot. When compared to the entire quantity of accessible carbon, the total amount of soot produced is often negligible. For determining the emissivity of bright flames, Tien and Lee examined a number of models in 1982, including the homogeneous non-gray model, the homogeneous grey model, and the nonhomogeneous non-gray model. Glassman talked on the complex chemistry of soot formation in relation to fuel mix in 1988. Figure's graph demonstrates how fuel type affects the flame's emissivity. The data are correlated using the following correlations for fuel gases with C:H weight ratios between 3.5 and 5.0.

$$\varepsilon = \sqrt{\frac{LHV}{900}} \rightarrow (5.1) \quad [7]$$

Where  $\varepsilon$  is emissivity of fuel for C/H ratio 3.5 to 5 and LHV is light heating value of fuel in BTU/ft<sup>3</sup>.

Another relationship is given as

$$\varepsilon = 0.0048\sqrt{MW_{FUEL}} \rightarrow (5.2) [7]$$

Where MW is molecular weight of fuel

For C/H ratio ranging from 5 and 15 we use following formula

$$\varepsilon = 1 - 68.2e^{-2.1\sqrt{\frac{C}{H}}} \rightarrow (5.3) [7]$$

For diesel we are using formula  $C_{12}H_{23}$  all parameters are calculated as

Table 5.0:1 Calculation of Molecular Mass of diesel [18]

WEIGHT OF ONE ATOM	TOTAL WIEGHT
12	144
1	23
Total Molecular weight	167

Table 5.0:2 C/H Ratio for diesel [18]

no of carbon atoms	12
no of hydrogen atoms	23
Ratio of C wrt mass	0.862275
ratio of H wrt mass	0.137725
C/H ratio	6.26087
Fuel emmissivity	0.643749

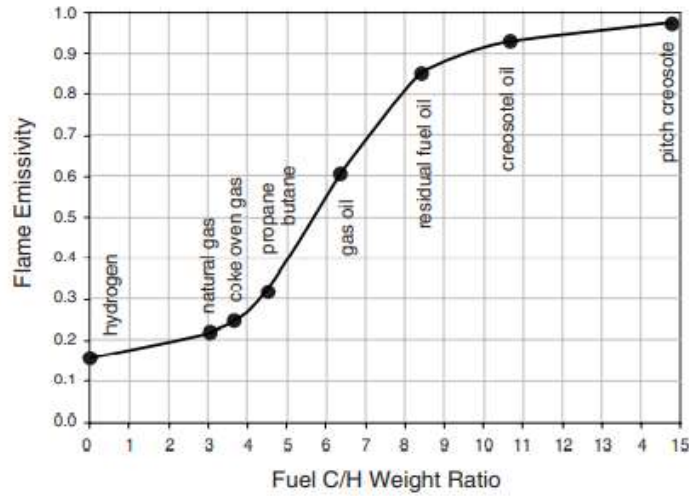


Figure 5.1 Graph for estimating emissivity of hydrocarbons [7]

## 5.2 CALCULATION OF EMISSIVITY AND ABSORBIVITY OF WATER AND CARBON

The individual emissivity of carbon dioxide or water is given by,

$$\varepsilon_i(p_a L, p, T_g) = \varepsilon_0(p_a L, T_g) \frac{\varepsilon}{\varepsilon_0}(p_a L, p, T_g) \rightarrow (5.4)$$

$\varepsilon_i$  = Emissivity of the specific gas

$p_a$  = gas partial pressure

$T_g$  = Absolute Temperature of gas

L = Path length through gas

$\varepsilon_0$  = Emissivity of individual gas state (environmental pressure and  $p_a \rightarrow 0$  but  $p_a L > 0$ )

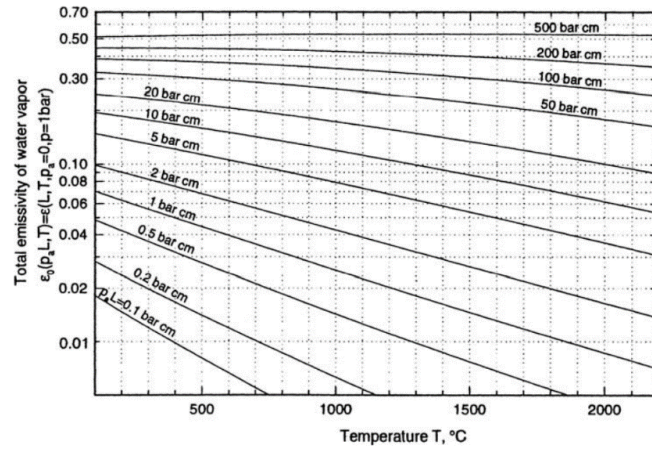


Figure 5.2 Graph for calculating temperatures from partial pressure [7]

This can be calculated by following equation,

$$\epsilon_0(p_a L, T_g) = \exp \left[ \sum_{i=0}^M \sum_{j=0}^N C_{ij} \left( \frac{T_g}{T_0} \right)^j \left( \log_{10} \frac{p_a L}{(p_a L)_0} \right) \right] \rightarrow (5.5)$$

Where  $T_0$  = absolute temperature of gas depending on the conditions and  $C_{ij}$  are constants.

$$\frac{\epsilon}{\epsilon_0}(p_a L, p, T_g) = \left( 1 - \frac{(a-1)(1-P_E)}{a+b-1+P_E} \exp \left[ -c \left( \log_{10} \frac{(p_a L)_m}{p_a L} \right)^2 \right] \right) \rightarrow (5.6)$$

All the above unknown quantities are calculated in table below,

Table 5.0:3 Relationship between Emissivity of water and carbon dioxide at temperature of 1000 K and pressure 1 bar cm [7]

Gas			Water Vapor				Carbon Dioxide		
$M, N$			2, 2				2, 3		
$c_{00}$	...	$c_{N1}$	-2.2118	-1.1987	0.035596	-3.9893	2.7669	-2.1081	0.39163
$\vdots$	$\ddots$	$\vdots$	0.85667	0.93048	-0.14391	1.2710	-1.1090	1.0195	-0.21897
$c_{0M}$	...	$c_{NM}$	-0.10838	-0.17156	0.045915	-0.23678	0.19731	-0.19544	0.044644
$P_E$			$(p + 2.5bp_d/\sqrt{t})/p_c$				$(p + 0.28p_a)/p_0$		
$(p_0L)_m/(p_aL)_0$			13.2t <sup>2</sup>				0.054/t <sup>2</sup> , $t < 0.7$		
							0.225t <sup>2</sup> , $t > 0.7$		
$a$			2.144,		$t < 0.75$		1 + 0.1/t <sup>1.45</sup>		
			1.88-2.053 log <sub>10</sub> t,		$t > 0.75$				
$b$			1.10/t <sup>1.4</sup>				0.23		
$c$			0.5				1.47		

Note:  $T_0 = 1000$  K,  $p_0 = 1$  bar,  $t = T/T_0$ ,  $(p_a, L)_0 = 1$  bar cm.

$$\varepsilon_{CO_2+H_2O} = \varepsilon_{CO_2} + \varepsilon_{H_2O} - \Delta\varepsilon \rightarrow (5.7)$$

$$\Delta\varepsilon = \left[ \frac{\xi}{10.7 + 101\xi} - 0.0089\xi \right] \left[ \log_{10} \frac{(p_{CO_2} + p_{H_2O})L}{(p_aL)_0} \right]^{2.76} \rightarrow (5.8)$$

$$\xi = \frac{p_{H_2O}}{p_{CO_2} + p_{H_2O}} \rightarrow (5.9)$$

Where p indicates partial pressure of the respective components.

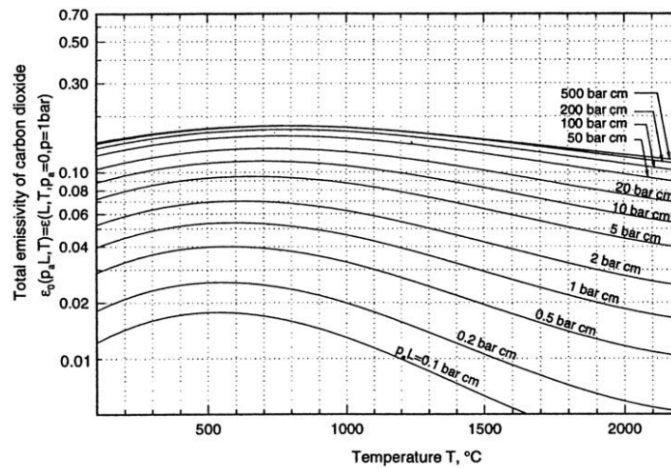


Figure 5.3 Graph for calculating carbon dioxide emissivity [7]

Similarly, the absorptivity of carbon dioxide and water is given as

$$\alpha(p_a L, p, T_g, T_s) = \left[ \frac{T_g}{T_s} \right]^{1/2} = \varepsilon \left( p_a L \frac{T_s}{T_g}, p, T_s \right) \rightarrow (5.10)$$

Where  $T_s$  is surface and  $T_g$  is temperature of gas.

Also

$$\alpha_{CO_2+H_2O} = \alpha_{CO_2} + \alpha_{H_2O} - \Delta\varepsilon \rightarrow (5.11)$$

Where  $\Delta\varepsilon$  is estimated emissivity on path length  $p_a L \frac{T_s}{T_g}$ .

Table 5.0:4 Calculation of emissivity of water and carbon dioxide [19]

Carbon dioxide percentage	9
Water percentage	18
Beam Length(ft)	10
Temperature (F) $T_s$	1500
Temperature(C)	815.5556
Temperature(K)	1088.706
Length in cm	304.7
Absolute pressure in bar(Carbon dioxide)	0.09
Absolute pressure in bar(Water)	0.18
P(water)* beam length(cm)	54.846
P(carbon dioxide)* beam length(cm)	27.423
E0 Carbon dioxide from graph	0.12
E0 Water from graph	0.29
Table temperature (K)	1000
Correction temperature factor t	1.088706
P(A for Carbon dioxide) bar cm	1
P(A for Water) bar cm	1
P(E for Carbon dioxide)	1.0252
P(E for Water)	3.453493
Carbon dioxide (Pa*L)m/P*L	0.266688
Water (Pa*L)m/P*L	15.64569
Carbon dioxide $\varepsilon/\varepsilon_0$	1.001022
E	0.666667
$\Delta\varepsilon$	0.050564



Table 5.0:5 Calculation of a b and c for Carbon dioxide [19]

a	1.088406
b	0.23
c	1.47

Table 5.0:6 Calculation of a b and c for Water [19]

a	1.804223
b	0.976603
c	0.5

Table 5.0:7 Calculations for absorptivity of Water and Carbon dioxide [19]

Temperature (F) Tg	1000
Temperature (C)	537.7778
Temperature(K)	810.9278
P(water)* beam length(cm)*Ts/Tg(bar cm)	40.85232
P(carbon dioxide)* beam length(cm)*Ts/Tg(bar cm)	20.42616
E0 Carbon dioxide from graph	0.12
E0 Water from graph	0.29
Correction temperature factor t	0.810928
Carbon dioxide (Pa*L)m/P*L	0.147961
Water (Pa*L)m/P*L	8.680371
Carbon dioxide $\epsilon/\epsilon_0$	1.001096
Water $\epsilon/\epsilon_0$	1.305799
P(E for Carbon dioxide)	1.031076
P(E for Water)	3.842817
E(Water)	0.378682
E(Carbon dioxide)	0.120131
Ts/Tg	1.5
Absorptivity Carbon dioxide	0.14713
Absorptivity water	0.463789
Total absorptivity	0.560355
Volume(ft <sup>3</sup> )	6.28
Area(ft <sup>2</sup> )	26.7
V/a	0.235206
Mean length Lm (ft)	0.846742

Table 5.0:8 Calculation of a b and c for Carbon dioxide [19]

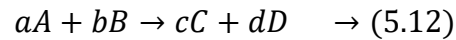
a	1.135511
b	0.23
c	1.47

Table 5.0:9 Calculation of a b and c for Water [19]

a	2.06686
b	1.475087
c	0.5

### 5.3 EXCESS AIR

The mass of the fuel, oxygen, and combustion products are not preserved during the combustion process. The response equations provide information on the transition that these qualities experience. As a result, if A and B burn to produce C and D in a combustion event, such that.



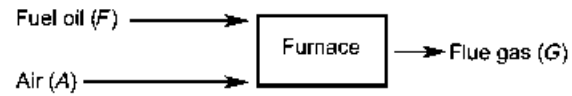
This is how a combustion process generally takes place. It should be observed that only the ratios of the coefficients a, b, c, and d are set, not their absolute values. The stoichiometric proportions for the reaction are known as these ratios.

Almost often, more air is required in systems to accomplish full combustion. This is the amount of air needed for full combustion that is over and beyond the stoichiometric air demand. The definition of the extra air percentage is

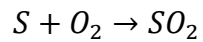
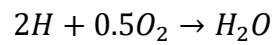
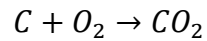
$$\text{excess air (\%)} = \frac{\text{Total air} - \text{Stoichiometric air}}{\text{Stoichiometric air}} \times 100 \quad \rightarrow (5.13)$$

As we know that

$$F + A = G$$



The complete combustion reaction is given by



Assume that,

c moles of  $CO_2$  are formed, w moles of  $H_2O$  are formed and s moles of  $SO_2$  are formed along with n moles of nitrogen and y moles of excess oxygen

Applying mass balance

Mass in = Mass out

Composition is given below.

Table 5.0:10 Composition of raw material by % w/w [22]

<b>Element</b>	<b>% w/w</b>
Carbon	84.6
Hydrogen	10.9
Sulphur	0.7
Oxygen	3.8
Total	100.0

Equating this to molecular mass of carbon hydron and Oxygen

$$12c=0.846 \text{ and } c=0.0705 \text{ kmol}$$

$$2w=0.109 \text{ and } w=0.0545 \text{ kmol}$$

$$32s =0.007 \text{ and } s =0.00022 \text{ kmol}$$

$$A * 0.767 = 28n \text{ for Nitrogen } N_2$$

$$A*0.233+0.038=32c +16w+32s+32y \dots\dots\dots \rightarrow (5.14)$$

Putting values of c, s and w we get

$$A*0.233=3.097+32y$$

Thus, stoichiometric oxygen requirement is 3.097 kg

Supply of Oxygen Overall =(3.097+32y) kg

$$y=0.0145$$

Now by using above relation amount of air A is given by.

$$A=15.29 \text{ kg}$$

$$\text{Flue Gases } G= 15.29+1=16.29\text{kg}$$

Flue gas composition is given in following table.

Table 5.0:11 Composition of flue gases by % v/v [22]

Flue gas component	kmol	% mol (= % v/v)
CO <sub>2</sub>	0.0705	12.62
H <sub>2</sub> O	0.0545	9.76
SO <sub>2</sub>	0.0002	0.03
N <sub>2</sub>	0.4188	74.99
O <sub>2</sub>	0.0145	2.60
Total	0.5585	100.00

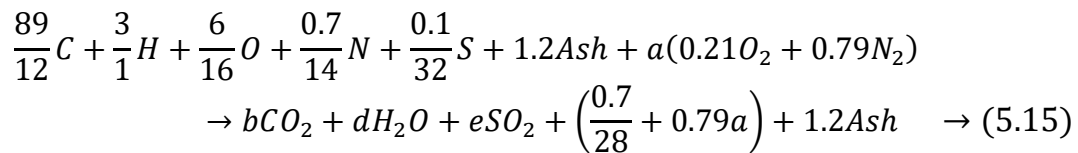
Flue gases produced at 573 K and 1 atm pressure with a gas constant of  $0.03697 \frac{m^3 atm}{K.kmol}$

Hence using general gas equation

$$PV = nRT$$

$$V = 12m^3$$

## 5.4 COMBUSTION ANALYSIS OF CUPOLA FURNACE



For carbon balance  $b=89/12=7.42$

For water  $2d=3$  and  $d=1.5$

Table 5.0:12 Property and Composition table for fuel used in blast furnaces [25]

S/N	Properties	Value	Wood	Peat	Lignite	Bituminous Coal	Charcoal
1	Moisture content as found	%	25-50	90	50	2	-
2	Moisture content at firing	%	10-15	15-20	15	2	2
3	Volatile matters	%	80	65	50	30	10
4	Fixed carbon	%	20	30	45	65	89
5	Ash	%	Trace	5	5	5	1
Chemical Analysis							
6	Carbon, C	%	50.0	57.5	70.0	86.0	93.0
7	Hydrogen, H	%	6.0	5.5	5.0	5.5	2.5
8	Oxygen, O	%	43.0	35.0	23.00	6.0	3.0
9	Nitrogen (N) + Sulphur (S)	%	1.0	2.0	2.0	2.5	1.5
Calorific Value							
10	Dry fuel (Cal/g)	Gross	4450	5000	6400	8600	8300
		Net	4130	4710	6140	8310	8170
11	Normal fuel (Cal/g)	Gross	3780	3800	5170	8000	8050
		Net	3420	3460	4870	7720	7910

For Sulphur balance  $e=0.1/32=0.00312$

Oxygen balance  $=6/16=3/8$

$$0.375+0.42a=2b+d+2e$$

After putting values of b d and e we get

$$a = 38.03$$

The quantity of air needed to burn 1 kilogramme of fuel is now calculated using.

$$\frac{a(0.2 \times 32 + 0.79 \times 28)}{100} = 0.2884a$$

Now

$$\text{AFR(Stoichiometric)}=0.288 \times 38.03=10.98$$

Mass flow rate of air = Volume flow rate in  $m^3/s$  \* density ( $kg/m^3$ ) @ 1 atm and 298K

Now AFR(Actual) is calculated as

$$\text{AFR(Actual)} = \frac{\text{Mass Flow rate of air}}{\text{Mass flow rate of fuel}} \rightarrow (5.16)$$

## 5.5 INTRODUCTION TO JET THEORY

A jet entrainment device is typically included into burner systems to aid in the mixing of fuel and air. The example of a free jet being released into the environment, as shown in Figure 5.4, may be used to demonstrate the concept of jet entrainment. Usually, the jet's starting velocity is high enough to create turbulent flow. It is clear that friction at the boundary between the jet and its surroundings results in the local acceleration of the surrounding fluid to the jet's velocity. The jet expands as a result of drawing in the accelerated air. Entrainment is the name given to this phenomena.

The momentum flux of the jet regulates the amount of air entrained, and this process continues until the jet's velocity is equal to that of its surroundings. More surrounding fluid will be entrained into the jet as its momentum flux increases. A free jet can spread unhindered and can use a large portion of its surrounding medium to meet its entrainment capacity. According to experimental experiments carried out in 1961 by Ricou and Spalding, the entrainment rate of a free jet depends on the mass flow rate and velocity and is connected using the formula below.

$$\frac{m_x}{m_o} = \frac{\rho_1}{\rho_0} \times \frac{x}{d} \rightarrow (5.17)$$

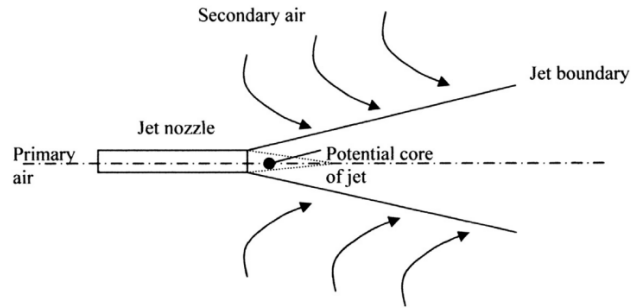


Figure 5.4 Representation of a basic premixed air fuel jet [25]

$m_x$  mass flowrate of the jet fluid owing to entrainment at a distance  $x$  from the nozzle

$m_o$  - mass flowrate using jet fuel at the nozzle

$\rho_1$  the fluid's entrained density

$\rho_0$  density of nozzle jet fluid

$x$  distance from potential core of jet

$d$  nozzle diameter

## 5.6 CONCLUSION

Aiming at a design that enables the production of larger cupola furnaces. Additionally, a model-type cupola has been developed, which can serve as a demonstration model for foundry technology in tertiary institutions. The design and modification of this cupola took inspiration from an outdated cupola furnace in the MOUAU Mechanical Engineering Workshop. Moreover, the produced cupola can be of assistance to manufacturers who aim to construct larger furnaces for commercial applications, with reduced cost implications. During test runs, the fabricated cupola, as modified, demonstrated improved economics,



optimal technical and operational characteristics, including productivity, efficiency, reliability, simplicity, ease of operation, and maintainability.

1. The LPG/NG fired cupola exhibits the best energy efficiency and CO<sub>2</sub> generation. We have commenced with both indigenous [16] and imported technology [13]. However, we need to observe for a year or two to assess the impact of technical challenges such as carbon loss, availability and cost of refractory balls, and the cost of gas (whether piped or from installations) on its commercial viability.
2. Considering these points and the evolving circumstances, induction furnaces should be primarily used for SG iron, alloy cast irons, steel castings, and production of alloy steel/special steel.
3. There is a significant scope for modifying the design and operational practices of conventional cupolas, such as adopting DBC (Downward Burn Cupola) or other approaches, to achieve cost savings and reduce greenhouse gas emissions.
4. The table provided clearly demonstrates the considerable advantages of cupola melting compared to induction and arc melting from various perspectives. Cupolas are widely utilized globally, and continuous developments have been made in their design and fuel efficiency.
5. However, given the substantially changed circumstances, it is crucial for us to align with global trends. We currently lack expertise in modern cupola technology, especially for larger cupolas, concerning cupola design engineering and the design of pollution control equipment to meet pollution standards.

## **5.7 FUTURE RECOMMENDATIONS:**

Based on current trends and advancements in technology, here are some future recommendations for cupola furnaces:

- Use of alternative fuels: In order to reduce carbon emissions and promote sustainability, cupola furnaces can consider using alternative fuels such as biomass, hydrogen, or even electricity.
- Automation and control: With the help of advanced sensors and control systems, cupola furnaces can be automated to optimize their performance and reduce energy consumption.
- Improved refractory materials: Using high-quality refractory materials can improve the durability and efficiency of cupola furnaces, leading to reduced downtime and maintenance costs.
- Heat recovery systems: By capturing waste heat from the furnace, cupola furnaces can generate additional energy for use in other processes, further reducing their environmental impact.
- Integration with other processes: Cupola furnaces can be integrated with other processes such as casting and forging to create a more streamlined and efficient manufacturing process.

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