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PROJECT REPORT

Design Development, Fabrication and Testing of Mini Laboratory Cupola Furnace

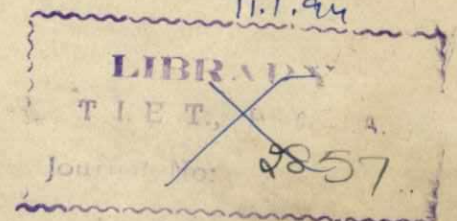


May, 1986

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CERTIFICATE

Certified that this Project Report entitled
|Design Development, Fabrication and Testing of
Laboratory Minim Cupola|, is a record of the following
students own work carried out during their B.E. Final
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This work carried out under my supervision, is
being submitted in partial fulfilment for the Award
of B.E. Degree in Mechanical Engineering of T.E.E.T.,
to them.

The matter embodied in this dissertation has
not been submitted for the award of any other Degree.

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I. INTRODUCTION

I.1. STATEMENT OF PROBLEM

Design Development, Fabrication and Testing of a Laboratory Mini Cupola.

Cupola is the most commonly used furnace for producing cast iron in the foundry. It is a continuous shaft furnace and its contribution in the field of cast iron foundry has been remarkable. Cupola's of various sizes from 1 to 100 tons capacity are available in the market. Largest Cupola in the world has a capacity of 100 tons/hr and it runs continuously for 5 to 6 days a week.

Although conventional Cupola's are most commonly used, yet it is difficult to run a big Cupola for the occasional or demonstrational work on account of large running costs. Hence it was envisaged to develop a small laboratory Cupola in the department for demonstration of the process in foundry shop as well as for laboratory work. Another intention under current of this project has been to make available a portable, low cost Cupola to small shop foundrymen to save them from heavy investment and enable them to produce quality jobs.

I.2. METHODOLOGY

The methodology adopted for the development of this laboratory mini cupola has been as under:

I- Design Stage: The dimensions for the cupola furnace were derived from that of conventional ones with the help of

empirical formulae. The specific diameter was chosen to get a desired output of 250 Kg/hr. Discussions with small cupola operators, teachers and technicians formed the basis of design criteria. Literature of American Foundry Society was also consulted.

2- Development/Fabrication Stage: The fabrication of the cupola was done in our College Workshop according to the dimensions deduced in the design stage from the empirical relations. Relevant standards were consulted and discussions with practicing foundrymen were carried out.

3- Testing Stage: The cupola was tried on actual run with cast iron/pig iron scrap and commercial hard coke twice for ascertaining its workability. The draw backs were noted and improvements for further refinement have been suggested.

2- LITERATURE REVIEW

2.1. CUPOLA IN METAL CASTING INDUSTRY

Despite inroads made by electric furnaces, the cupola still dies the vast bulk of the melting in the iron industry today. And it will continue to play the leading role for years to come. Cupola installed in the next few years will again be the conventional in design, still enlarged, water cooled, and enriched with hot blast and controlled for more easily than those in use today. Further in the future, developments of externally fired cupola or the down draft cupola may drastically alter the size, shape and mode of operation of the cupola.

For long it has been the only practical melter for the typical iron foundry, but because of the interest the iron foundry industry has showered on induction melting, the casual observer might conclude that the cupola is on its way out.

Interest in making the switch to electrics has been given a certain impetus by the spread of tough air pollution codes. Purchase of electric furnaces which produce less effluent than cupolas, was regarded by many foundries as the alternative to purchasing expensive air pollution control equipment for cupolas.

In other instances, interest in the use of electric was spurred by power companies that offered special power rates to tip the fuel cost balance in the favour of electrics which resulted in decline of cupola usage.

Yet, the consensus of people who deal daily with cupola users is a foreseeable future, the conventional cupola will continue to play a very significant role in iron melting. Whereas today, 95% or all iron melted is tapped from cupola, there is reason to believe that the percentage of iron melted in cupola will decline with the widely predicted growth in iron castings production, however, that lower percentages still might represent little decrease or even a net increase in total capacity.

The conventional cupola will continue to be the main stay, but development work now under way holds the potential for drastically changing the size, shape, and mode of operation of cupolas.

Lowest Cost Melter :

A study conducted among 79 foundries showed that the cost per ton of melted iron in cupolas (in 1961) of the foundries averaged from 10-30% below that of the cost of melting iron in electric furnaces in the other 18 plants.

The advantage of the cupola held true even when operating costs for pollution control equipment were added in with the cupola operating figures and early complications show that the cost spread has narrowed somewhat partly due to operational improvements made in the arc furnace segment of the study. Nevertheless, the cost edge still goes to cupola.

2.2. Upside - Down Cupola:

A new approach that may improve the air pollution control situation confides in the "Upside - down" or "down draft" Cupola. In which air is blown in near the top of the stack and drawn out with the molten metal at the bottom.

Its attraction with regard to air pollution hinges on the fact that it is cleaner burning than commercial cupola. The effluent from the down draft cupola is such that it meets existing air pollution codes in many parts of the country without further processing.

The key is in the combustion process. Instead of the charge being heated gradually as it **decends** down the cupola shaft, until it melts near the bottom, as in the cinventional cupola, it is melted at the tryers near the top of the shaft. Melting occurs in an oxidising atmosphere, and molten is reduced as it passes down the shaft. The charging arrangement involves a pressure tight cylindrical chamber, much like the typical blast furnace. The charge is deposited into the chamber, the lid is closed, and the bottom is opened to drop the charge into the shaft. That approach reduces the amount of air that is needed in the cupola, thereby helping the pollution problem.

Another advantage of the down draft approach is that almost any type of scrap can be charged into it. Except large chunky pieces. Borings and turnings could be used, because

they would be melted immediately, rather than blown out the stack.

Molten metal and combustion gases flow out through the cupola tophole into a closed forehearth that might be linked to an air furnace. The combustible in the gases are burned in the special forehearth, and those gases then are used to preheat the incoming blast air in a recuperative preheater. Hot blast is essential in operation of the down draft cupola because the coke must be ignited immediately at the top of the cupola. There is little opportunity to preheat the coke as in the conventional cupola.

2.2.2 CUPOLA WITH MULTITUYERS ROWS:

As Repositions for the tuyers offer the chance to produce a wide range of carbon contents in cupola, Moore have tried two rows of tuyers (36" apart for 73" dia cupola). They suggested that by carefully dividing the blast between these rows, preferably equally, it may yield metal with higher temperature, about 70 - 90^{oF} higher, for a given coke consumption, and the melting rate can be increased by 11-23%. Besides coke consumption could be reduced by 20-32%.

On varying the distance between two rows the carbon contents and manganese contents of the metal was increased to maximum values and 5 content lowered to minimum value with 36" apart rows, silicon content of metal decreases continuously as distance between two rows of tuyeres is increased.

The increase of distance between the rows affects the following:-

1. Increase in metal temperature until it reaches the maximum.
2. Decrease in melting rate.
3. Increases combustion efficiency and also stack gas temperature.

The effects of increase in the proportion of air supplied to the upper tuyeres are:-

- (i) Increased carbon content of the metal, a maximum value is obtained when the blast is equally divided between the rows of tuyeres.
- (ii) There is tendency to reduce Si content of the metal slightly.

By operating with two rows of tuyeres with optimum spacing, carbon content was approximately 0.06 per cent higher than Si content 0.17 per cent lower than obtained when operating with a single row of tuyeres initial temperature being identical in both cases. The carbon equivalent value $(C + \frac{Si + P}{3})$ was not therefore effected by tuyere spacing at constant metal temperature.

2.2.3 CUPOLA SHELL

The cupola is housed in steel body fabricated to shape out of steel. Refractories are provided to enable the shell withstand the melting temperature. Inefficiency of this may lead to buckling and cracking of shell. In order to avoid these:

- (1) The internal skin temperature should be low.
- (ii) The heat transfer through the shell should be as rapid as possible.

(iii) Heat should be radiated/conducted from the outside skin of the shell as rapidly as possible.

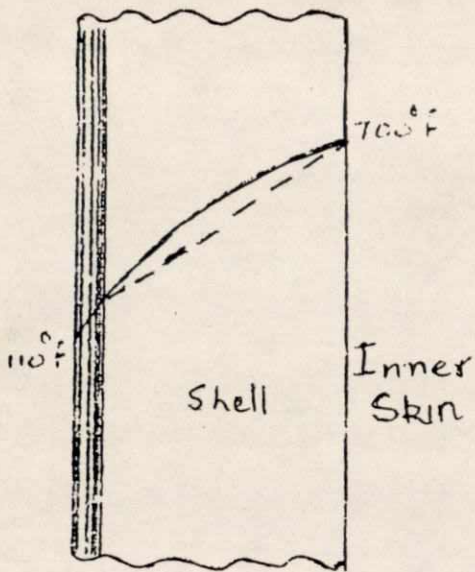
In order to facilitate the lower skin temperature the charge should have smooth descent. A taper of approximately 1° may be provided to allow this. The amount of tuyere protrusion, tuyere diameter in relation to cupola diameter and amount of downward inclination of tuyere determine the location of combustion zone and metal superheat zones. Improper location can lead to excessive temperature on the inner surface with resultant abnormal temperature gradient through the shell, and hence give rise to hot spots.

Shell should have structural strength to support load, resistance to internal and external corrosion, resistance to thermal fatigue and excellent thermal conductivity and hence it should not be excessively alloyed. Cupola shell is subjected to 75000 Lb/in^2 hoop stress at 600°F . For shell plain carbon steel with high deformation capability or a low carbon steel with 0.2 per cent C, Max^m 0.06 per cent P, 0.05 per cent S, is suggested.

Insulating layers on outside skin should be avoided suitable for lining this part. Above the charging door, the function of the lining is to protect the shell from the heat of stack gases.

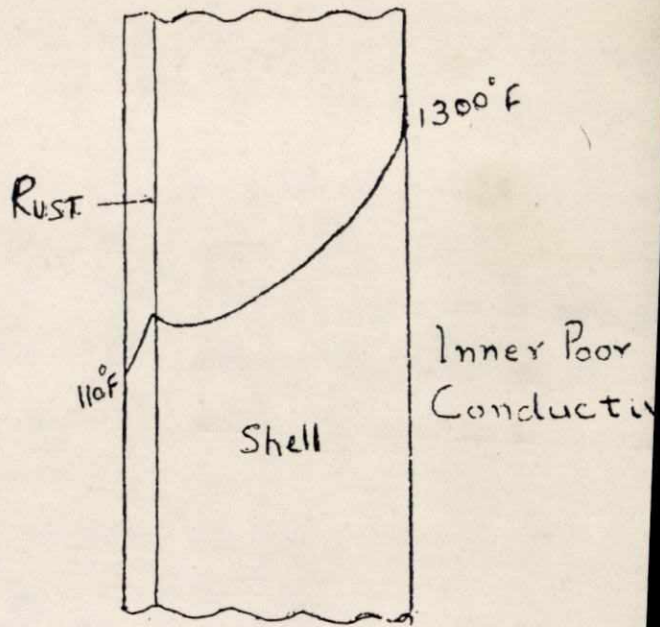
ACID CUPOLA

The material most commonly used for lining acid cupola is fire bricks. The fire clay refractories, which are essentially composed of Al_2O_3 and SiO_2 are severally corroded



DESIRABLE THERMAL GRADIENT

(a)



THERMAL GRADIENT UNDESIRABLE

(b)

FIG 1

by the acid slags encountered in cupola. Cupola slag can be considered essentially as composed of CaO , Al_2O_3 and SiO_2 and other minor oxides. Thus CaO remains the main fluxing constituent.

Silica bricks are not used to any great extent in Cupola lining since they tend to spall and disintegrate with repeated heating and cooling under the usual conditions of operations.

BASIC CUPOLA

Basic Cupoles operate on a basic (high CaO + MgO/SiO_2) Slag. It then becomes necessary to line these cupolas with basic refractories. Basic cupola has an advantage over the acid process in that the desulphurization of the metal can also be effected. As there is greater carbon pickup by the metal in the basic process, steel scrap can also be used as a charge material.

The chemistry of slag attack on refractories in basic cupola is complicated. Cupola slags are known to consist of the following minerals: monticellite, merwinite, akermanite, diopside, dicalcium silicate and tricalcium silicate. It has been shown that in cupola the coar of basic lining is mainly due to the reaction with silica in the slag. Basic refractories have good resistance to calcium silicate slags.

Several basic linings have been used in cupolas ranging from magnesite to chrome magnesite and dead burned delomite with or without tar bond.

Magnesite is the most suitable material for lining basic cupola, but it has certain disadvantages namely, high thermal conductivity slow spalling resistance and high cost. These disadvantages can be overcome by water cooling or by as it reduces the rate of heat extraction. Rust, water bubbles etc. should also be avoided between the shell and lining as it also reduces the rate of heat extraction. The preferable thermal gradient of steel shell should be as shown in Fig. I(a). The thermal gradient in case of steel shell rusted on the inner/outer surfaces or processing water or oil, bubble layers are deteriorated as shown in Fig. I(b) which result in failure of shell due to buckling or cracking.

2.2.4 INNER LINING:

The new advances in cupola operation have imposed some of the most severe conditions to which the refractories can be subjected. Even under the best melting condition it is necessary to repair the lining after the melting operations are completed. The successful selection of refractories demands a knowledge of characteristics of the refractories on the one hand the service condition on the other hand.

In the melting zone, which extends from the top of the tuyeres upwards for a distance depending upon the height of the coke bed and the velocity of blast air. The refractories encounter high temperature, slight slag corrosion and chemical attack and the fluxing action of lime, coke, ash and sand. Spalling is not likely to occur during the melting operation, but when the bottom is dropped, the cold air rushing pass

the hot refractories creates conditions of severe thermal shock.

In the hearth of cupola, the lining is in contact only with the molten metal, slag and relatively static coke, so that the effects of temperature and abrasion are not serious. The choice of refractories in these two zones depends largely on the slag practice acidic or basic.

The lining in the charging zone is not subjected to high temperature or slack attack, but severe abrasion occurs due to the charge moving downwards. Some foundries use cast iron blocks in the upper part near the charging door. Hard burned fire clay refractories of low porosity are quite giving a fire clay back up lining and by the use of monolithic linings.

Dolomite linings are liable to perish by absorption of atmospheric moisture. However, stabilized dolomite linings are known to give service. Carbon linings have occasionally been used in cupolas operating on high basic slags. The chief drawbacks of carbon refractories are oxidation above red heat and high thermal conductivity. Carbon refractories for cupolas should have the following properties apparent density 1.5 gm/c.c., porosity 10 per cent.

Although the initial cost of basic linings would be much higher than that of acidic linings, considerable saving can be achieved in the subsequent processing of the metal, and the overall performance cost of basic lining may be much less. It has been reported that basic linings give more life and less refractory cost per ton of iron.

2.2.5 CHARGING AND KINDLING

The use of wood kindling is one of four common techniques for lighting a cupola. Other techniques employ gas or oil burners, an electric igniter, or externally fired coke. In smaller cupolas oil or gas burners are inserted through the breast opening. Channels often are formed during building of the bed. After the coke is ignited, the burner is withdrawn and the breast is made.

In the kindling operation an even layer of dry wooden chips is spread on the bottom and on top of its chopped fire wood is layed in a crib. The pieces of fire wood must not be longer than 2-3 inches and thicker than half inch. Now firewood is ignited and air is admitted when the wood is burning freely, the bed coke is charged. Usually, the bed is divided into 3 portions, a small quantity of the first portion of the coke is carefully forked in on top of the freely burning wood. Large size coke up to one inch lumps is used for the bed charge, when the coke is burning well, a sign of which is a smokeless yellow ~~flame~~ flame, the remainder of first portion of coke is charged, the balance being added in two doses. Each consecutive coke charge is made only after the preceding batch is well alight.

The height of coke bed is the height of the column of coke above the row of tuyeres. The height depends on the quality of coke and on the volume and pressure of the blast.

2.2.6 CONTROL OF CHARGE

The cupola is charged after the bed charge has been blown. Small quantity of flux is first charged into the bed charge

followed by alternating layers of metal, coke and flux. The metal charge is effected in the following sequence - steel scrap, pig iron, cast iron scrap, home scrap. For the first two or three layers, small size melting stock is used, normally small gatings or sprues. As a rule, the whole of the cupola shaft should be filled to the level of the charging door throughout an entire heat.

The weight of metal charge should be from 10-15 per cent of the hourly output of the cupola. A certain amount of lime stone, the flux used to form the cupola slag, is added above the first metal charge. Upon being heated in the cupola the lime stone is decomposed into CaO and CO_2 . The lime neutralises the silica introduced into the cupola with the coke ash and sand formed in the oxidation of silicon, the CO_2 is carried out by the flue gases. The reaction between the silica and lime reduces the melting point of slag and increases its fluidity.

After the first layer of metal charge and flux, the first working charge of coke is made, it weighs from 8-12 per cent of the metal charge. As the coke in the bed charge burns, that of the working charges gradually drop down together with the molten materials under it to maintain a constant rate of coke combustion in the bed charge. Alternate charges of coke and metal are made up to the charging level.

2.2.7 CONTROL OF COKE

The effects of size and quality of coke are reviewed as under:

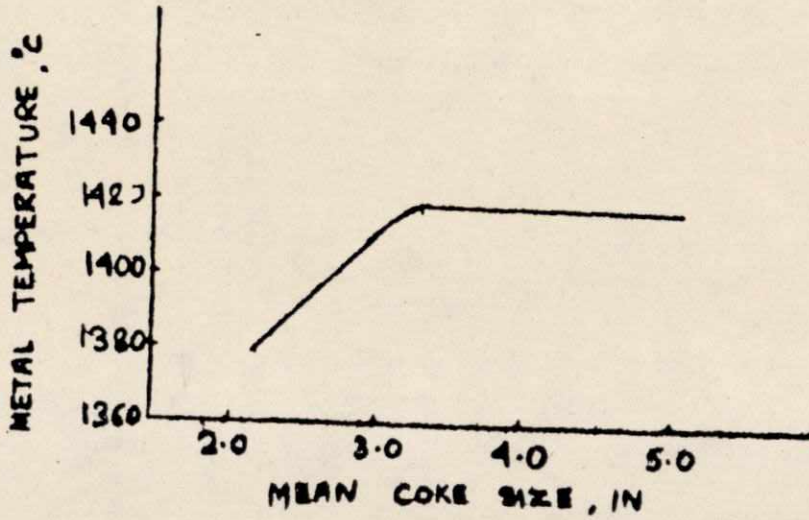


Fig 2(a)

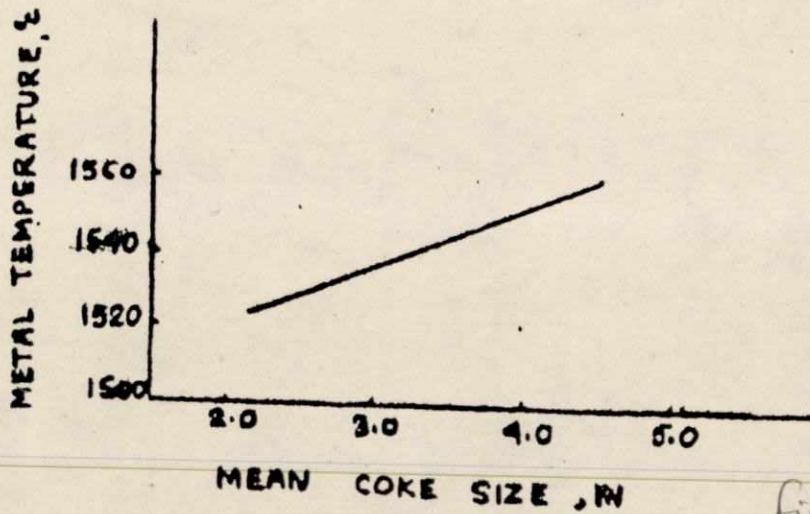


Fig 2(b)

EFFECT OF COKE SIZE ON METAL TEMPERATURE

(a) EFFECT OF COKE SIZE

(i) Effect on metal temperature - The increase in coke size increases the metal temperature as shown in Fig.(2). Investigation conducted on a hot blast cupola shows that the effect of coke size on tapping temperature is small. The effect is shown in Fig. 2 (a and b)

(ii) Effect on Combustion Ratio - The increase in coke size is accompanied by an increase in the combustion ratio.

(iii) Effect of Stack gas Temperature - The Stack gas temperature increases with increasing mean coke size.

(iv) Effect on Heat Utilization - Increasing coke size increases the sensible heat content of the stack gas reduces the latent heat content of the stack gas and improves the thermal efficiency slightly as shown in Fig. 3 (a and b).

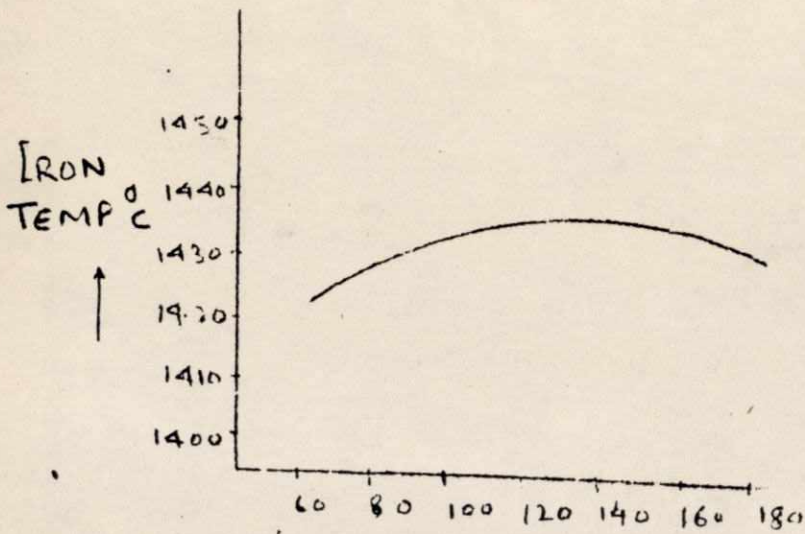
(v) Effect on Melting Rate - Increasing coke size ~~reducing~~ reduces the melting rate slightly.

(vi) Effect on Metal Composition - In such investigations where the molten metal produced is of hyper-eutectic composition, ~~increasing~~ the coke size increases the carbon content of metal and decreases the loss of iron. Increasing coke size has no significant effect on silicon, manganese, sulphur or phosphorous contents of metal.

(b) EFFECT OF COKE QUALITY

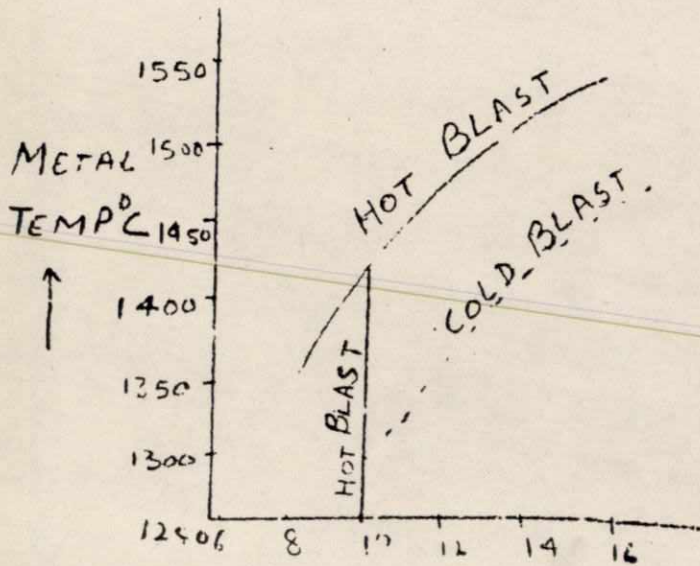
(i) The influence of coke quality on the metal temperature is generally small and can not be correlated with the physical properties of cokes.

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OIL RATE $\frac{L}{H}$ →
RELATIONSHIP BETWEEN IRON TEMP & OIL
RATE AT CONSTANT COKE BLAST RATE

FIG 3(a)



COKE CONSUMPTION →
RELATIONSHIP OF METAL TEMP. & COKE CONSUMPTION
FOR HOT & COLD BLAST CUPOLAS FOR SAME M

(ii) The changes in metal composition with change in coke quality are associated with the chemical composition of the cokes used. An increase in the carbon content of the coke appears to result in an increased carbon pickup by the metal and a lower sulphur content of the coke is associated with the decrease in the sulphur content of metal.

(iii) There is no significant change in general cupola performance e.g. in such items as Blast pressures, lining wear or slagging up of tuyeres, due to change in coke quality.

2.2.8 CHARCOAL ADDITION:

In India Charcoal Addition is done due to the shortage of coal, and the existing coke ovens can not cope up with the demand. Also the ash content of coke produced is nearly 25 per cent which is necessary for the use of additional lime stone.

Charcoal can be used to melt iron in cupola if it is handled suitably. Dust and fines should be screened out and a hard charcoal should be used. Charging should be done by hand to avoid crushing of charcoal. The hardness of coal depends upon the kind of the wood used and methods of burning and converting into charcoal.

A greater weight portion of iron melted will be necessary than the good coke since charcoal is very reactive and solution loss or carbon monoxide content of top gas will be higher. That could be recovered by use of iron probably would not be much higher than the coke with 25 per cent ash.

2.2.9 EFFECT OF MOISTURE IN COKE

Moisture in the coke used in cupola operation often is blamed for porosity or blow holes in castings. The coke contains little moisture after it has descended a short distance into the cupola and farther the descent the less likelihood of moisture being present.

Usually the bed in cupola is thoroughly ignited, which means that no moisture is present. Additionally some coke is placed on the bed to bring it to the desired height is penetrated rapidly by ascending extremely hot gases and any moisture is driven off.

The same thing occurs with succeeding coke charges moisture is driven off higher and higher in the cupola as it is filled with coke and iron charges. That temperature is sufficient to drive off moisture in the upper portion of cupola. This is indicated by the fact that flue gases are at a temperature of around 900^oF of course heat is required to drive off moisture and theoretically more coke will be required to attain the same temperature than when moisture free coal is used.

A similar situation prevails if the air blown into the cupola contains high moisture. In summer, when air is humid, many foundries increase the amount of coke in splits to attain the desired temperature.

2.2.10 CONTROL OF LIME STONE

The general practice is to use lime stone equal to 3 per cent by weight of the iron charge and about twice that

amount on the bed. Lime stone is placed away from lining, preferably in the centre. Slag hole should be opened just before the slag reaches the tuyeres.

Indications are that liquid slag is about one third the weight of iron. To hold this amount of slag as well as the usual amount of iron in the well, the tuyers would have to be located quite high above the bottom plate. Also that the amount of slag would make quite a mess when the bottom is dropped.

The slag hole should be opened as soon as the slag rises a few inches above the hole, and ofcourse before the slag reaches the tuyers. That can be determined by keeping a close watch at the tuyeres after melting begins.

2.2.II CONTROL OF SCRAP- PIG IRON RATIO

The use of scrap in the charge reduces the cost of the charge and improves the mechanical properties of castings. Addition of steel scrap reduces the carbon content of cast iron. The scrap should not contain non-ferrous metals or other alloys, for production of alloy cast iron chromium steel scrap is mostly used.

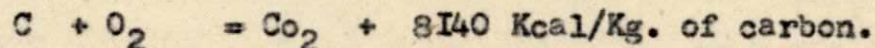
Scrap for cupola and furnace charges includes gates and sprues rejects from the foundry and metal working shops, turning and other waste, products of the enterprise.

Turnings which constitute 10-25 per cent of the weight of castings are packeted on presses of various designs before use, as loose turnings will burn in the cupola.

2.3 CHEMISTRY OF CUPOLA REACTIONS

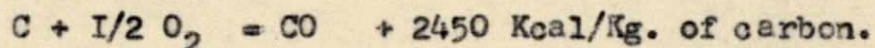
The melting of cast iron depends in the first place on the features of the fuel combustion process, solid fuel usually coke normally used.

Combustion of Solid Fuels - The combustion is a chemical reaction in which atmospheric oxygen combines with the carbon. Two chemical compounds, both of them gases CO_2 and CO are produced in the reaction.

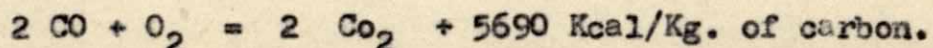


Carbon di-oxide is a product of the complete combustion of carbon and is not capable of further oxidation.

Carbon Monoxide is obtained in the reaction



Carbon Monoxide is a product of incomplete combustion, carried by insufficient oxygen. In air, carbon monoxide burns with a blue flames, when CO combines with atmospheric oxygen it is completely burned to form carbon - dioxide according to the reaction



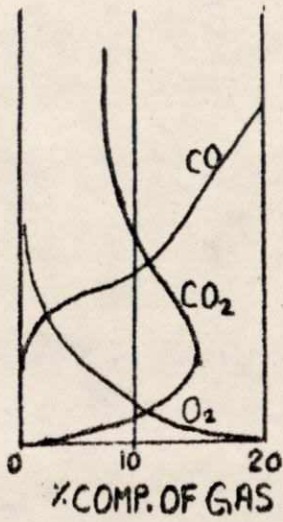
The reaction in which CO_2 is formed produces considerably more heat than incomplete combustion in which CO is formed.

The reaction is $\text{CO}_2 + \text{C} = 2\text{CO} - 3240 \text{ Kcal/Kg. of fuel.}$

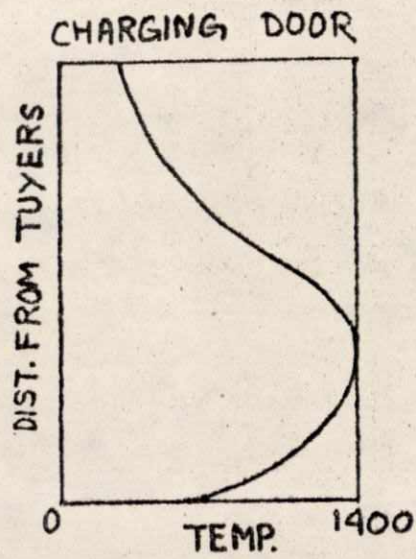
In this reaction heat is absorbed so it should be prevented.

The quantity of heat liberated in the combustion of 1 Kg. of fuel is known as heating or calorific value of fuel.

The heating value of the fuel depends upon the amount of combustible materials which it contains (mainly carbon) and on the amount of inert material (ash, moisture). Moist fuels with a high ash content have a lower heating value,



[A]



[B]

FIG-4

than pure and dry fuel.

The cupola is designed not only for the melting of cast iron but also for heating it to a temperature adequate to ensure the production of high quality shaped castings. The heating of molten cast iron to a very high temperature is facilitated when complete combustion of the carbon of the fuel takes place with the formation of Co_2 .

It must be noted that Co_2 is capable of releasing part of its oxygen to oxides. Apart from causing losses of elements contained in the cast iron, the formation of oxides might well lead to deterioration in iron quality. The normal ratio of Co_2 to CO in cupola gases is approx. 2:1, two third of carbon being burnt to form Co_2 and one third forming CO.

The contents of the product of combustion of carbon and oxygen of gases at various levels of cupola shaft from tuyeres to the charging door is shown in Fig. 4-A. The maximum amount of Co_2 and O_2 is observed above the plane of row of tuyeres, as the amount of O_2 decreases, the Co_2 content rapidly drops to 15.5 per cent and there is practically no change upto the level of charging door.

In the begining the CO content increases up the cupola shaft, then it holds steady at about 9 per cent.

Fig. 4-B illustrates the change in temperature of gases as they rise up the cupola shaft. The curves in Figures 4-A and 4-B show the maximum Co_2 content corrossponding

to the highest gas temperature. As the Co_2 decreases the the CO content increases, the temperature of cupola gases fall.

A further drop in shaft gas temperature with constant Co_2 and CO content is caused by heat removal from gases for heating up the metallic charge and coke moving downwards.

Thus two processes occur during cupola melting, combustion of fuel, which is the source of heat and heat exchange between the heated gaseous products and colder charge.

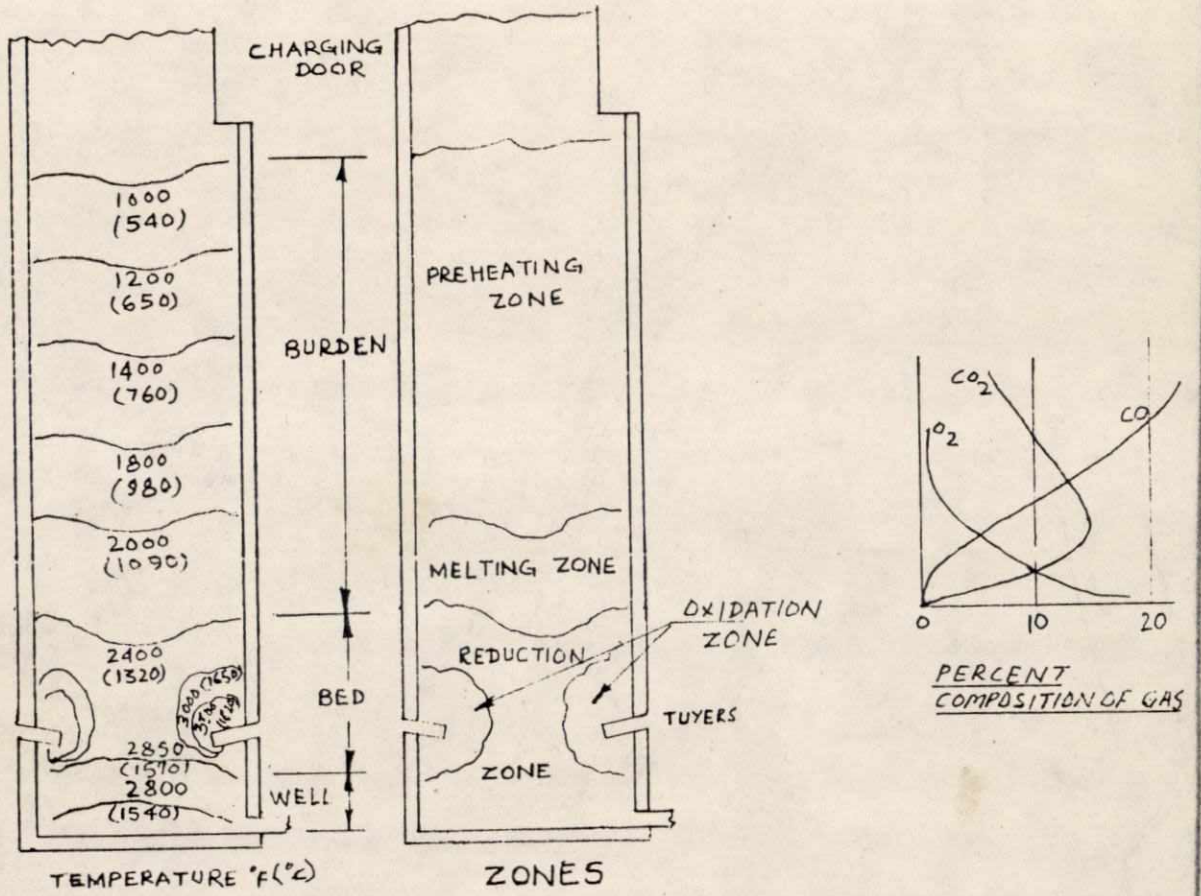
2.4 OPERATION AND COMPOSITION CONTROL

2.4.1 CONTROL OF CARBON STEEL : Bringing the carbon content of first iron under control requires a correct and reproduceable balance between bed height and steel content of first few charges. In a cupola of 42 inches a height of 48 inches bed coke should be chosen, the bed made carefully to that height after a standardized burn in procedure carbon content in melt depends upon steel scrap to pig iron ratio as discussed before.

If first iron is hot enough the bed height can be made standard and carbon analysis will tell whether or not steel scrap is required and how much to get the desired carbon content. It is important to standardise the bed preparation.

Carbon content also increases with temperature, higher temperature can be obtained by hot blast by oxygen enrichment or by CaC_2 addition. Carbon injected with nitrogen to the

20-b



SCHEMATIC OF COMBUSTION CONDITIONS IN A CUPOLA

FIG 5

fore-hearth helps in increasing carbon content upto 0.2 per cent.

2.4.2 REMOVAL OF SULPHUR

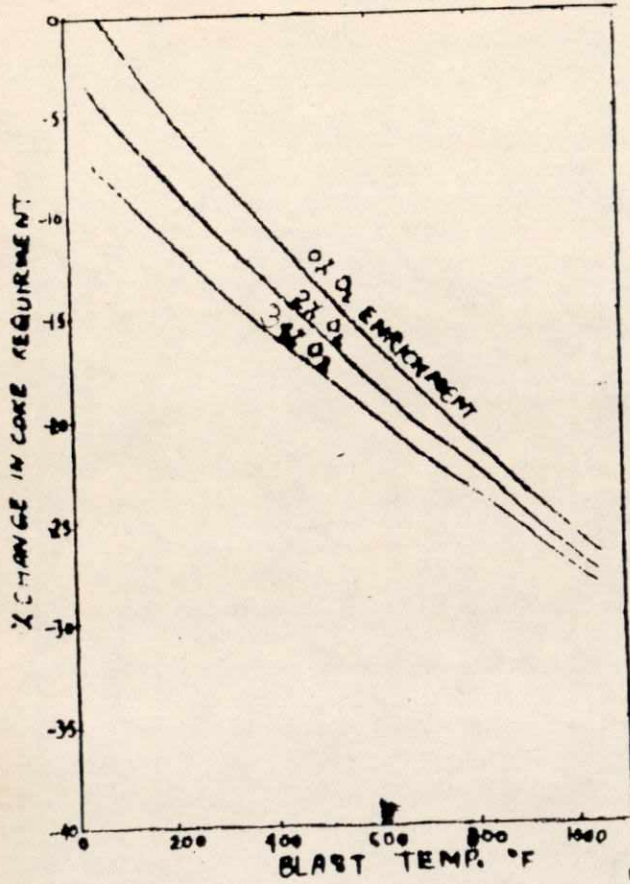
Control of sulphur in cupola is not possible. Generally there is sulphur pick-up due to sulphur present in the coke. The sulphur in cast iron is controlled by ladle desulphurisation.

Other methods of reducing free sulphur (normally from .05 per cent to .12 per cent) in a melt of CI to less than .02 per cent are affected by use of non-active gas as an agitator to mix or desulphurisation agent such as Ca C_2 , with molten iron. It may be otherwise combined with iron in a giant milk shake.

Desulphurising process developed in Japan also uses a desulphurising agent. The melt discharges continuously from cupola through troughs into a rotary fore-hearth, where it is stored temporarily. A blanket of desulphurising agent covers the melt and is brought into physical contact with sulphur. The agent can be added at intervals or continuously. Acting as a blanket to cover the melt, the agent assists in reducing heat loss. Slag is removed by inclining the hearth and raking it off.

2.5 MELTING RATE

It is affected in cupola by oxygen enrichment and blast temperature. Plant and laboratory test of cupola operation with oxygen enrichment unanimously. The effect of change of



CALCULATED EFFECT OF OXYGEN ENRICHMENT ON COKE REQUIREMENT

FIG 6

CALCULATED EFFECT OF OXYGEN ENRICHMENT ON MELTING RATE

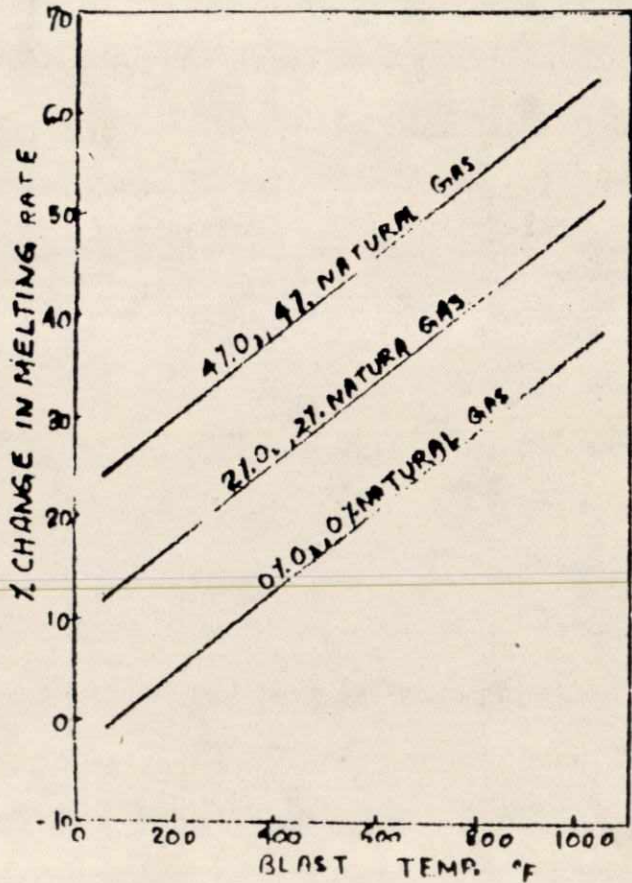


FIG 7

blast temperature and oxygen enrichment on melting rate are shown in Figs. 6 and 7 respectively. The effect of oxygen enrichment, hot blast and natural gas enrichment are discussed in the next sections.

2.5.1 OXYGEN ENRICHMENT:

The use of oxygen to speed up melting in cupola is based on the fact that it increases the iron temperature and so for a given iron temperature, less coke is required per ton of iron melted when oxygen is used. In this respect, it functions in the same way as using hot blast. In fact, the two might be considered interchangeable.

The effect of enrichment of blast with oxygen differs from that of injecting the same amount of O_2 into the well of cupola. The use of 2 per cent oxygen in a blast will reduce coke consumption by 0.6 per cent. If same is injected into the well we can replace 4 per cent of coke.

If coke split is 8 to 1 per cent (or 12 per cent of charge weight) 2 per cent of oxygen amounts to about 570 Cft. per ton of fire. Replacement 4 per cent coke and 0.6 per cent coke would increase melting rate by about one third and one twentieth respectively.

In 48 inches cupola with an 8 to 1 coke ratio, the melting rate could be about 8 tons per hour. Under best conditions the use of 4560 Cft. of oxygen per hour would increase the melting rate by about 2 to 5 tons per hour.

2.5.2 HOT BLAST CUPOLA

A hot blast cupola is one which is designed to produce

iron of the required temperature together with blast pre-heating systems guaranteeing that hot blast temperature is maintained at a constant level even over a prolonged melting period, thus assisting in successful execution of each individual melting operation.


The blast is pre-heated to 300-500°C it results in reduced coke consumption and increased productivity. High temperature tends to reduce sulphur absorption in the furnace.

Modern trend is to use the combination of a shaking ladle with a hot blast cupola. This method has several advantages. It has been shown that shaking ladle is capable of affecting any desired degree of desulphurisation and that the shaking ladle makes it possible to carbonize to any extent in a simple way and with a great certainty. Thus hot blast cupola can be operated in conjunction with a shaking ladle.

The acid hot blast cupola together with the shaking ladle makes possible the conclusion of an all scrap charge into high grade CI, with an iron temperature after treatment in shaking ladle of 1420 - 1435°C, which amply satisfies the requirements of standard grey iron foundry. The effect of hot blast on coke and melting rate is shown in table

TABLE II

<u>Change in Coke Rate per cent.</u>	<u>Change in Melting Rate per cent.</u>	<u>Hot Blast Temp. °C</u>
0	13.5	520
33	0	520
-30	0	450 -500
0	30 -50	450 -500



I.	2.	3.
-8	-	600
-35-50	-	-
-	4	500
-22-30	-	500
-55	50	600
-	15-20	-
-33	33	-
-27	X	500-550
-28	X	430
-	20	400
-14.4	17	470
-19	22	470
-27	25	550
-28.7	33	450
-33	20	450
-6	-	500
-25.5	50	390
-14.2	17	390
-28.7	49	500
-39.7	21	500-600
33	-12.5	400-500
-32	32	500
-23	-	500
-12	-	520
-29	-	525
-28	25	320

Where

X is increased corresponding to decreased coke rate.

2.5.3 NATURAL GAS ENRICHMENT

The predicted coke and melting rates of 0, 2 and 4 per cent natural gas injection were evaluated for various blast temperatures. The results of these are shown in Figs. 8 and 9.

In Fig. 8 the coke rate is shown to decrease with increasing natural gas injection, as indicated by the respective positions of curves. In Fig. 9 the curves have same relative positions that they held in Fig. 8.

This indicates that production rate will slightly decrease, as shown by the proximity of the curves, with increasing level of natural gas injection.

The reported plant trials are given below:

TABLE

Influence of natural gas injection on coke and melting rates.

<u>Change in Coke Rate per cent.</u>	<u>Change in Melting Rate per cent.</u>	<u>Natural Gas per cent.</u>
-50	-	-
-50	-	-
-27.5	5 x	4.7
-46.5	60 xx	4.52
-46.5	18.2 x	4.34
-40-50 xx	15-20 xx	4.5 xx

x Corrected to reference blast rate.

xx Average Value.

From table we see that use of natural gas would be marked by the decrease in coke rate. On a more completely reported series of tests the coke rate was observed to decrease on the order of 40-50 per cent whereas the melting rate increased by 15-20 per cent at 4.5 per cent Natural Gas level.

There is, however, some indication that improved combustion efficiency and top gas temperature may be achieved with changes in blast conditions. The conclusion that can be reached by the above results is that a coke saving can be realised with natural gas injection but that the improvement in melting rate is less than the corresponding improvement in coke rate.

The injection of cold natural gas at tuyeres decreases the temperature in the melting zone because of the decomposition of natural gas (approx. 90 per cent methane) to carbon and hydrogen. Since the ensuing combustion in the presence of hot coke does not proceed beyond CO and hydrogen, the overall result is that less energy is developed within the melting zone with injection. Consequently, natural gas injection should be accompanied by oxygen enrichment on an increased blast temperature to maintain a given melting zone temperature.

2.6 FLEXIBILITY EXPERIMENTAL CUPOLA

The experimental cupola of segmental construction with interchangeable melting zone and well sections. Two melting zones sections have been provided, although the cupola can be adapted to operate with other, different melting zones, if necessary.

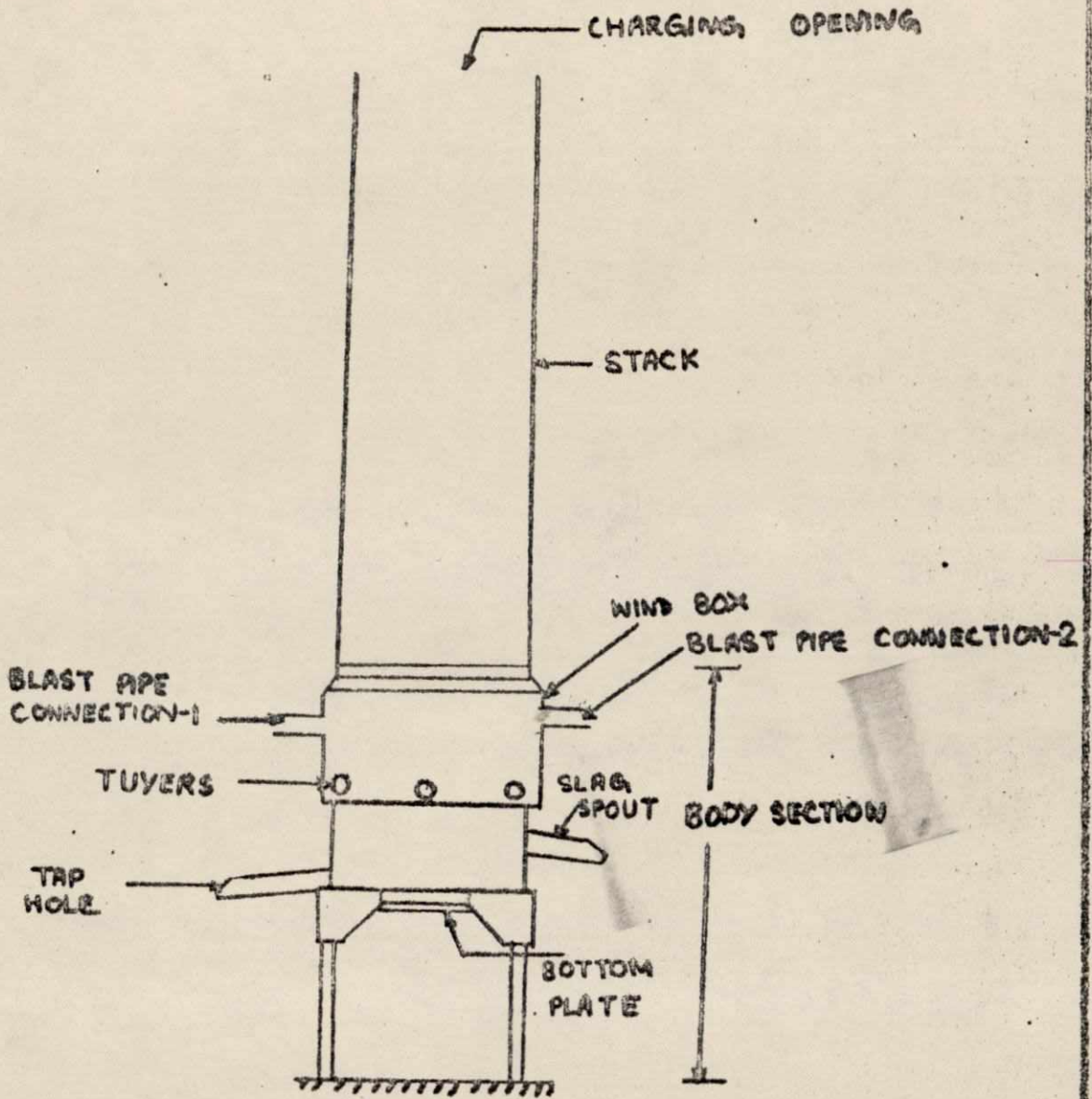
One of the melting zone sections is of conventional design with a parallel bore to be used with a normal refractory lining. The other melting zone section is conical, widening towards the lower end, and is provided with four protruding copper tuyeres, which will be water cooled. The conical melting zone will not be lined, but will be extensively water cooled on the external surface. By the use of this section and the selection of a suitable refractory in the well, the cupola may be operated over a wide range of slag compositions from acid to highly basic.

The cupola can be operated with hot or cold blast. The blast heated in directly fired by oil and is designed to operate at air outlet temperature upto 800°C.

2.7 PROBLEMS IN CUPOLA MELTING:

Hanging is a common melting troubles. Usually hanging is called by inefficient repair of lining. In which acceleration and projecting parts of the lining were not removed and sometimes due to oversized pieces in the charge. Accelerations and projecting parts of the lining and also branching to lumps of scrap which get caught prevent the uniform descent of the charge. Consequently the basic measures to prevent hanging include proper lining repairs and breaking up of outside scrap.

To eliminate hanging the blast is reduced and a heavy crowbar is inserted through the charging hole into the shaft to loosen and break through the hang up. During this operation, blast should be shut off completely to facilitate operations and avoid burning up of bed coke. Frequently the shutting of the blast alone allows the hanging portion of the charge to descend.



DROP BOTTOM CUPOLA

FIG-11

Second way of eliminating hanging is to add one or two extra charges of coke.

Other problems such as run out of the molten iron through the bottom occurs when the hearth has not been properly rammed or when too dry foundry sand has been used. A minor run out of iron can be dealt with by cooling the point of leakage with a water jet.

Heating up of the shell occurs when an insufficiently refractory mortar is used for lining, the joints are eroded by the molten iron and there is a partial failure of lining. If a jet of water is played on the heated part of the shell, this region and the molten iron around it are cooled and melting may continue.

3. LABORATORY MINI CUPOLA

3.1 DESIGN REQUIREMENTS AND PARAMETERS

Capacity - 250 -300 Kg/hr.

Corresponding to the required capacity the dimensions and other design parameters were obtained from the general charging directions for cupolas (FROM American Foundrymen's Society).

The dimensions for 0 size cupola were taken from the above said table and accordingly reduced to suit our requirements. The results of which are listed as under:

Shell dia	I4 inches
Thickness of Lining	2.25 inches
Dia Inade	I4 - (2.25 x2)
Lining	9 inches.
Height	67 inches
Melting Rate	300 Kg/hr.
Coke/Iron Charge Ratio	6:I Coke 9 Kg. } Iron 54 Kg. }

3.2 ESTIMATING AND COSTING FOR LABORATORY CUPOLA

	<u>Material</u>	<u>Quantity</u>	<u>Rate</u>	<u>Cost.</u>
i)	M.S. Sheet I6 SWG	28 ft ²	27.70 Sft.	777.77
	I8 SWG	9.0 ft ²	33.33 Sft.	300.00
	I4 SWG	5.0 Ft ²	22.22 Sft.	III.II
ii)	G.I. Pipe I inch dia.	4 ft	II.00 Ft.	44.00
				<hr/> <u>1232.II</u> <hr/>

			I232.11
iii) Angle Iron 2 inch x 8 ft.	I5/ ft.		I20.00
2-1/2 inch x I7 ft.	I7/-ft.		289.00
iv) Fire Bricks 80 No.	4.50 each		360.00
v) Fire Clay 2 Bags	30/- each		60.00
vi) Elbow I x I-1/2 Inches 3 No.	I5/- each		45.00
I-1/2xI-1/2 Inches I No.	I5/- each		I5.00
vii) Bend 90° x I-1/2 inches I No.	I8/- each		I8.00
viii) Electrodes I5 No.	2.50 each		37.50
ix) Nuts and Bolts I2.5mm I5 No.	} lumpsum		25.00
8 mm I0 No.			
x) Overhead/Miscellaneous	Lumpsum		I00 .00
	Total -		<u>2301 .61</u>

4. TESTING (Experimental)

4.1 HOUSING THE CUPOLA

The cupola was fabricated out of mild steel sheets (16 SWG). Dimensions for the cupola were derived from standard dimensions.

4.2 LINING

Lining of the cupola was done by ramming around a wooden block having internal contour of the cupola with a backing of insulating bricks.

4.3 EXPERIMENTAL SET UP

Bottom of the cupola was prepared by ramming moulding sand, blowers were connected to the blow pipes. Manometer was connected to the wind hose through manometer tube. The plugging sand was made for closing top hole and slag hole.

4.3.1 KINDLING

After the moulding sand was rammed, the level of bed was raised to top hole which had a slope towards the top hole. The cupola was completely dried and filled with dry wood up to the tuyer level. Woods were ignited and simultaneously air was blown in. Then coke was charged upto about half of the bed charge and other half was charged as soon as the first half was ignited. The top of the bed charge was made level. When the bed charge was well ignited, the first charge of iron was put in.

The cupola was charged after the bed charged had been blown. A small quantity of lime stone weighing about 2 - 3 per cent of metal charge by weight was first charged into the bed followed by alternative layers of metal coke and lime stone. The metal charged i.e. cast iron scrap weighs about 10-15 per

cent of the hourly output of the cupola. Coke charged weighs from 8-12 per cent of the metal charged. After this full blast to tuyeres from the blower from the blast in bed pipes.

4.3.2 MELTING

As the coke in the bed charge burns that of the working charge gradually drops together with the molten materials under it to replace the burnt coke of the bed charge and a constant rate of coke combustion in the bed charge is maintained.

The top hole is kept open until the iron begins to melt. After it begins to melt the top hole is closed with a plug. The first slag starts coming from the slag hole when level of iron reaches the slag hole then top hole is opened and metal is tapped.

4.3.3 ACCESSORIES

1) Blower

Volts	250
Ampere	F/L I.56
Watts	
H.P.	I
RRM	2825.

4.4 OPERATION

Two trials were made to standardise the melting of scrap used.

The results of the trials have been depicted in the following table.

5- RESULTS

<u>Firing Date</u>	<u>CHARGE</u>	<u>RESULT</u>	<u>FAULT ENVISAGED</u>
9 May, 85	Coke Bed height 15" =CI and CI Scrap 35 Kg. (in 2 changings) Lime Stone - 1.5 Kg. Coke Ratio 6:1, Coke - 38 Kg. (of which 33 Kg. were used for pre-heating)	(i) Charge did not descend continuously at the bottom. ii) Slag did not come out of the slag hole. iii) Furnace was blocked after firing.	i) Insufficient taper of bed made to remove the metal. ii) Refractory burn out and cracked lining. iii) Coke used was of inferior quality.
14 May, 1985.	Coke Bed height 21" Pig Iron and C.I. Scrap 60 Kg. (in 3 changings) Lime Stone - 2 Kg (2 Change) Coke Ratio 4:1 Coke (in 3 changing)	i) Continuous flow of molten metal was observed. ii) Slag did not come out iii) Cupola was blocked.	i) Slag hole not at a proper height. ii) Insufficient taper of lining.

6- ANALYSIS OF EXPERIMENTATION

The major drawbacks in the trials made by us can be listed as follows:-

- i) The diameter of the furnace is not sufficient.
- ii) The taper of the refractory lining is not adequate.
- iii) Excessive heat loss due to insufficient thickness of lining.
- iv) Height of slag hole not proper.
- v) The refractory lining cracked due to vibrations caused by the blower.

7- SUGGESTIONS FOR FURTHER WORK

The following suggestions are made to modify the existing Cupola:-

- i) Outer shell dia to be increased.
- ii) Fire brick lining can be made in a better way so that the heat loss is reduced.
- iii) Provide sufficient taper to lining.
- iv) Height of slag hole be adequate.
- v) Make separate platform for fixing the blower in order to minimize vibrations.
- vi) Use of better coke for furnace.

8- CONCLUSION

Smaller Cupolas have been tried for experimentation purpose and it is worthwhile for want of operational ease. The dimensional variables seem to be derivatives of the conventional cupolas.

Experimental cupola of 225mm I.D. can be very helpful in providing sufficient working experience in cupola operation. Quality grey iron and sphenoidal graphite iron can be economically produced from the experimental cupola molten iron.

DIMENSIONS OF WORLD'S LARGEST CUPOLA

Capacity	= 100 Tons/hr.	
Diameter	= 150 Inch Internal Diameter	
Height	= 116 Ft.	
Pre-heated Air	= 1200°F.	
Homogeneous	= 3.4 per cent C, 1.8 per cent Si	
Out put.	0.35 per cent Mn, 0.05 per cent S,	
	.04 per cent P.	
Coke Ratio	= 7-3/4 to 1	
Charge	= 48 Inch Steel	7500 lb.
	Steel Bundles	3000 lb.
	Car Wheels	2000 lb.
	24 Inch Steel	2500 lb.
	Foundry rejects	2000 lb.
	Ductile Revert	2000 lb.

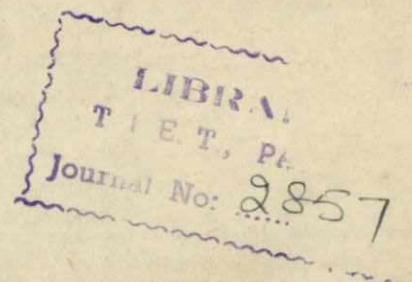
When fully charged = 18 Charges

10 ton each, 180 tons of charge + 33 tons one charge
is made after 6 minutes.

Coke	= 2600 lb.
Lime	= 1300 lb.
Dolomite	= 500 lb.
Felspar	= 100 lb.
50 per cent Fe Si	= 1050 lb.
Slag	= 37 per cent Si O ₂ 1.5 per cent Mn O 7 per cent MgO, 8 per cent CaO, 0.7 per cent FeO, 5.6 per cent Al ₂ O ₃ 0.2 per cent Ti O ₂ .

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STRUCTURAL

1. Height from floor to top of Cupola = 90 Ft. 6 Inch.
2. Height from floor to bed plate = 17 Ft. 6 Inch.
3. Height from bed plate to Centre line of tuyeres = 7 Ft. 6 Inch.
4. Shell dia at tuyeres = 150 Inches
5. Shell dia at expansion joint = 140 Inches
6. Shell dia above gas take off = 120 Inches

Melt zone construction $3/4$ inches thick five box quality grade 6.

Upper shell One inch thick Corton on inside and $1/2$ inch mild steel on out shell.

Tuyeres 12-10 inches Cast Copper - projecting 15 inches apart the shell with 15 degree declination.

REFRACTORIES

Basic 4- $1/2$ inches 70 per cent Al_2O_3 against shell with 18 inches Carbon, brick inside Total 22- $1/2$ inches thick. Bottom sand thickness = 20 inches.

Tap hole, breast, slag supporters and iron runners rammed with 80 per cent Al_2O_3 85 ton forehearth: 60-70 per cent Al_2O_3 brick ladles 60 per cent Al_2O_3 bricks.

AIR SUPPLY

3 blowers rated 25000 Scfm 96 Oz. driven by 900 HP Motors (One Spare) 2 - 1200°F hot. blast unit.

EMISSION CONTROL

High energy venture type scrubber 2 exhausters 43,500 Cfm. 80 inches Wc. driven by 700 HP Motors guaranteed for 0.05 gm/Cft. of effluent.

MIX 75 per cent Steel, 20 per cent Revert, 5 per cent FeSi, 13 per cent Coke, 6- $1/2$ per cent Lime Stone 2.5 per cent 2.5 per cent Dolomite 0.5 per cent Fluorspar

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