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NOTES ON IRON FOUNDRY PRACTICE

1. **Foundry Pig Irons. Grading.**—Foundry pig irons are often graded by the nature of the fracture; those showing a distinctly graphitic structure being classed as No. 1 Foundry Pig Irons. If the structure is mainly granular with perhaps small graphite flakes at the centre, the iron will probably be classed as No. 4.

This system of grading is somewhat unsatisfactory, and is now falling into disuse, as the grade numbers assigned by different makers vary to a considerable extent, and can therefore only be used as a rough indication of the probable nature and composition of the iron. In addition, pig irons of similar composition, but produced from different blast furnaces may have distinctly different fractures.

In certain cases pig irons are now ordered to definite analyses, within specified limits, for various classes of work. The percentages of carbon, silicon, manganese, phosphorus and sulphur must be considered together, but the general tendency is to take the silicon content as a basis both when ordering pig iron for general foundry purposes and when computing charges for the cupola furnace.

Absolute regularity of composition in pig irons ordered to specification by analysis is unobtainable, but sufficient accuracy is possible for all practical purposes. The best results are obtained when pig iron is used with due regard to both fracture and analysis. In foundries producing high-duty iron castings metallurgical control of the metal mixtures charged into the cupola is a necessity.

The following table gives an example of grading by composition.

Brand.	Graphitic Carbon.	Combined Carbon.	Silicon.	Manganese.	Sulphur.	Phosphorus.
No. 1	3·45	0·25	3·25	1·20	0·02	0·6
No. 3. Soft	3·40	0·30	2·80	1·15	0·03	0·5
No. 3. Medium	3·30	0·35	2·40	1·10	0·04	0·6
No. 3. Hard	3·20	0·45	2·10	1·00	0·05	0·6
No. 4. Soft	3·10	0·50	1·75	0·95	0·06	0·6
No. 4. Hard	2·80	0·65	1·40	0·90	0·08	0·6
Cylinder Iron	2·65	0·67	1·50	0·90	0·09	0·5

Hot Blast Pig Irons.—These are so named from the fact that preheated blast air is supplied to the furnaces in which the iron is smelted. The use of a hot blast gives increased economy of working and the pig iron is the cheapest type produced for foundry purposes. It is of a coarse, soft and weak structure with a high graphitic carbon content as compared with cold blast irons. Hot blast irons are used for general foundry work, but for important castings they are mixed with cold blast, hematite, or special pig irons.

Cold Blast Pig Irons.—Cold blast irons have a close grained, whitish fracture and are usually lower in silicon and higher in combined carbon than the hot blast irons. They are used for castings in which strength and density are of first importance. They must be poured at a high temperature and are generally more difficult to cast than the hot blast irons.

2. **Effects of Various Elements on the Properties of Cast Iron.**
Carbon.—The total carbon content of pig irons used for ordinary purposes varies from 3·0 per cent. to 3·6 per cent. Of this total carbon content free graphitic carbon forms about 2·5 per cent. to 3·3 per cent., and the remainder is in combination with the iron.

Irons are soft or hard, according to whether the carbon is free or combined, and a low total carbon content is necessary for the greatest strength.

The state in which carbon exists in the iron is considerably influenced by the amount of silicon, manganese, phosphorus and sulphur which are also present. Pig irons low in silicon are usually high in combined carbon and have a close-grained fracture.

The rate of cooling in the mould has a marked effect on the state of the carbon in the casting, and the structure and hardness of an iron may therefore vary considerably in the different parts of one casting, especially when abrupt changes in cross-section occur. Quick cooling tends to retain carbon in the combined state, and therefore gives a closer grain and a harder iron. In some cases special precautions are necessary in order to ensure machinability in the thinnest sections, especially when the percentage of silicon in the castings is low.

When strength and good wearing properties are of first importance, it becomes necessary to obtain a casting in which combined carbon is high, and in which the graphitic carbon is small in size and evenly distributed.

The general formation of the graphitic carbon in the pig-iron may be to some extent transmitted to the casting. A casting made from pig iron containing large graphite flakes may also contain large flakes, even though the total amount of graphite is small. There is, therefore, a general tendency to use chill-cast irons for important work, as these have the graphite in a finely-divided state.

As against the above "hereditary" theory, it must be remembered that in molten iron the carbon is wholly "dissolved," and that the final proportions and state of the graphite depends on the rate of cooling, the pouring temperature, and the amounts of other elements contained in the iron.

Considerable difference of opinion exists on this subject, but experience shows that a fine-grained pig iron will usually produce a fine-grained casting.

Silicon.—Silicon has a much greater effect on the properties of cast iron than any other constituent, and for this reason it is good practice to consider the silicon content as the principal basis on which to calculate pig iron mixtures for the cupola. Up to 1 per cent. silicon produces a slight hardening effect on cast iron, but when present in greater quantities, as in ordinary castings, it tends to throw the carbon into the graphitic state and therefore has a softening and weakening effect.

As stated before, a thin casting will be of closer grain than a thick one if both are allowed to cool under the same conditions. In order to obtain a close grain in a thick casting it is therefore necessary to use a pig iron low in silicon.

When deciding the silicon percentage to be aimed at in the casting, due consideration must be given to the purpose for which it is required, its thickness, shape, and probable rate of cooling, and the degree of machinability required.

These considerations generally necessitate some sort of compromise, but full advantage should be taken of other methods of controlling the properties of the iron, such as the addition of nickel, the use of chills on thick sections, heating of the moulds, etc. Reduction of silicon below 1·2 per cent. produces a strong hard iron which may be difficult to machine. This may be overcome to some extent by keeping the manganese and sulphur low, but the metal may then be sluggish and difficult to cast, and will give excessive shrinkage in the mould.

The following figures are given as a rough guide only, and must be considered jointly with the influence of the other elements present in the casting.

			Silicon, per cent.
For	maximum	tensile strength ..	1·7
,,	,,	crushing strength ..	0·9
,,	,,	density and stiffness ..	1·0
,,	,,	hardness	0·8
,,	,,	general strength ..	1·4

Manganese.—Manganese assists in the formation of combined carbon, hardens the iron, and generally increases its strength. From 0·6 per cent. to 0·9 per cent. is desirable in iron castings for ordinary engineering purposes.

By reducing the absorption of sulphur, manganese tends to prevent blow-holes and assists in eliminating occluded gases.

It should be noted that pig irons and castings high in manganese may be open grained and appear soft, even when they are quite hard.

Manganese may be added in the cupola or in the ladle as Ferro-Manganese (80 per cent. Mn.), and in this form it tends to deoxidise the molten metal and helps to produce sound castings. But it is generally better to use pig irons high in manganese (1·0 per cent to 1·5 per cent.) rather than add ferro-manganese to the molten metal in the ladle, since the former method results in a more homogeneous casting and reduces the possibility of "hard spots" in the thinner sections of the castings.

In the cupola there is a heavy loss of manganese (from 20 per cent. to 30 per cent.), especially when sulphur is also present in large quantities. Remelting of cast iron tends to destroy the hardening effect of manganese.

Phosphorus.—The principal effect of phosphorus is to increase the fluidity of the molten metal, and for this reason it assists in the production of sound castings of thin section or intricate shape by making the metal sufficiently fluid to run easily into the mould. It has, however, a weakening effect on the casting and should never exceed 1·0 per cent., even for ornamental work. At least 0·3 per cent. is generally desirable, and with low silicon as much as 0·7 per cent. is often necessary to prevent the metal being too sluggish.

Phosphorus is particularly unsuitable in castings, such as cylinders, valves, etc., which are required to withstand considerable changes in temperature. It reduces shrinkage, and if present in large quantities may even produce a slight expansion of the iron on solidification. This is an advantage for ornamental castings where a well-defined impression of an intricate pattern is often required, and where strength is not of first importance.

Phosphorus in pig irons is not easily eliminated in the cupola. High-phosphorus pig irons are therefore unsuitable for ordinary foundry work, but may be mixed with pig irons low in phosphorus, such as the hematites.

Sulphur.—Sulphur has a generally bad effect on cast iron and should be kept below 0·09 per cent.

It increases the fluidity of molten iron, but reduces the time the metal will remain fluid in the ladle and tends to form blowholes in the casting due to quick setting of the metal.

Cast iron containing an excess of sulphur has a white close-grained fracture and may be hard and unworkable.

Sulphur tends to neutralise the effect of silicon, and so to increase the percentage of combined carbon. For this reason, up to 0·07 per cent. is sometimes considered desirable.

The molten iron in the cupola takes up sulphur from the coke. A good quality coke of low sulphur content is therefore necessary. Manganese tends to prevent the absorption of sulphur.

Nickel.—The addition of nickel to cast iron of suitable analysis gives increased strength and uniformity of structure throughout castings of varying section, and increases the resistance to wear. It tends to prevent the formation of a hard white iron in thin sections and closes the grain of the thicker, slow cooling, sections. The use of nickel therefore allows silicon to be reduced without rick of producing an unmachinable casting, and with a resultant increase in strength, but its chief value is as an aid to the production of sound castings where the design includes considerable variation in section which might lead to porosity in the thickest parts. It should be particularly noted that the addition of nickel is useless unless the casting is of suitable analysis. The total carbon content should be kept low, and the silicon must be reduced in proportion to the amount of nickel to be added. A safe rule is that two to three parts of nickel replace one part of silicon. Other constituents may be as for ordinary cast iron.

The amount of nickel usually added is from 1·0 per cent. to 2·0 per cent.

The melting loss is so small as to be negligible.

A 9-ton (tensile) cast iron can be improved to 13-14 tons by the addition of 1 per cent. Ni, if remelted after the addition. An iron normally requiring 1·8 per cent. of silicon should have this content reduced to about 1·4 per cent. if 1 per cent. of nickel is added.

Nickel is usually added in the form of shot, known as F. nickel-shot, to the stream of molten iron as it issues from the tapping-hole into the cupola spout. This F-shot is a nickel-silicon alloy, containing about 90 per cent. nickel, with a melting point below the normal pouring temperature of molten iron.

If the nickel shot is added by means of a funnel placed immediately above the tapping hole, the calculated weight required for each ladle of molten metal can be added with accuracy.

By experience, it is found that a stronger cast iron (by approx. 2-3 tons tensile) is produced if the iron is poured into pigs after adding the nickel shot and is then remelted. Also the material is more homogeneous and there are no signs of hard spots. The loss of Ni is negligible.

The increased uniformity of structure and closeness of grain obtained in nickel-cast irons renders them especially suitable for such purposes as internal-combustion engine cylinders, liners, etc. The molten iron should be clean and free from slag, and should be poured as hot as possible.

Aluminium.—A small amount of aluminium or ferro-aluminium alloy placed in the ladle before tapping, has a beneficial effect by deoxidation. It causes scum and dirt to rise to the surface, tends to close the grain of the metal, and to increase its fluidity.

With low silicon irons, aluminium increases the percentage of graphitic carbon. It should not be used when silicon is below 1·4 per cent. If pure aluminium is used, about 2 lb. per ton of molten cast iron is a suitable quantity.

3. **Changes in Composition in the Cupola.**—In passing through the cupola the molten iron changes in composition to a considerable extent and allowance must be made for this when making-up the charge. The object is to aim at a definite composition in the casting according to the purpose for which it is to be used. The total loss varies somewhat with individual cupolas, and the extent of change in composition depends upon the conditions of melting, the temperature in the melting zone, the amount of blast air used, the quality of the coke, the original composition of the metal charge, and the amount of flux used to liquefy the slag. As a rough guide, until experience has been gained with the furnace in use, the total loss may be assumed to vary from about 3 per cent. to 6 per cent., and is greatest when a large amount of scrap is used.

Iron.—The iron loss is generally about 2 per cent. to 3 per cent. This is chiefly due to oxidation of the metal, and is increased by excessive blast air, insufficient limestone flux, and by insufficient fuel.

Silicon.—Silicon loss varies from 17 per cent. to 22 per cent. A high temperature in the cupola reduces the loss of silicon. A low temperature drives silicon into the slag, reduces its power to absorb sulphur, and so increases the amount of sulphur in the castings.

Silicon per cent. in original charge ..	1·40	1·60	1·80	2·00	2·20	2·40	2·60	3·00
Loss in Cupola ..	0·23	0·27	0·32	0·38	0·44	0·50	0·57	0·70
Silicon per cent. in castings ..	1·17	1·33	1·48	1·62	1·76	1·90	2·03	2·30

Manganese.—Loss of manganese varies from 25 per cent. to 30 per cent. A high percentage of sulphur increases the loss of manganese.

Manganese per cent in original charge ..	0·40	0·60	0·70	0·80	0·90	1·00	1·10	1·30
Loss in Cupola ..	0·10	0·15	0·17	0·21	0·23	0·27	0·32	0·39
Manganese per cent in castings	0·30	0·45	0·53	0·59	0·67	0·73	0·78	0·91

Sulphur.—Sulphur generally increases from 0·03 per cent. to 0·06 per cent., but this depends on the melting conditions, the amount of flux used and the nature of the slag, the amount of sulphur in the coke, and the amount of manganese in the original charge.

The flux and the manganese both tend to eliminate sulphur from the castings.

The absorption of sulphur from the coke depends upon the thickness of the coke bed, the quality of the coke, and the length of time the molten metal remains in contact with the coke.

The use of a Receiver, into which the molten iron runs continuously from the cupola, reduces the amount of sulphur absorbed.

Phosphorus.—Change in the cupola is negligible. Remelting of cast-iron produces a slight increase in the percentage content, due to loss of other constituents.

Carbon.—No definite statement can be made as to the probable change in the total carbon content of the charge in its passage through the cupola.

As a general rule, a gain in total carbon will occur, but the extent of the gain is subject to wide variations according to the method of working the furnace, and the nature and composition of the original charge.

For important work, and for all pressure castings, pig-irons containing large amounts of graphitic carbon should be avoided. The state of the carbon is of much more importance than its total quantity.

A gain in carbon will certainly occur if the original charge is low in both silicon and carbon.

Heavy fuel charges and a high working temperature will also increase the absorption of carbon, and since low carbon and silicon and a high pouring temperature is normal foundry practice for important work, a gain in total carbon is generally to be expected.

4. **Compositions of Iron Castings for Various Purposes.**—The following Table is given as a rough guide, and to illustrate the relationship between the service for which a casting is required and its appropriate composition. All figures are given as percentages.

Castings for ordinary Fleet purposes range between the following limits :—

Silicon.	Manganese.	Phosphorus.	Sulphur.	Total Carbon
1·2 to 2·0.	0·6 to 0·9.	0·9 max.	0·09 max.	3·2 to 3·5

Description of Casting.	Si.	Mn.	P.	S.
I.C.E. Cylinders (small)	1·4 to 1·7	0·7 to 0·9	0·5 to 0·8	0·09 max.
Motor Boat Piston Rings	1·3 to 1·5	0·7 to 0·9	0·3 to 0·8	,,
Diesel Engine Cylinder Heads	0·9 to 1·2 (Ni 1·2%)	,,	0·4 to 0·8	,,
Hydraulic Cylinders ..	1·1 to 1·4	0·6 to 0·8	0·4 to 0·7	,,
Gear Wheels (Heavy) ..	1·0 to 1·4	0·8 to 1·0	0·4 to 0·7	,,
,, (Small) ..	1·6 to 1·9	0·6 to 0·8	0·6 to 0·8	,,
Ornamental Castings ..	2·0 to 2·3	0·5 to 0·7	0·8 to 1·2	,,
Chilled Castings ..	0·9 to 1·1	0·8 to 1·0	0·2 to 0·4	0·08 to 0·10
Heat-resisting Irons ..	1·0 to 1·5	0·7 to 0·9	0·2 max.	0·06 max.

Note.—Carbon should be kept as low as possible consistent with obtaining the requisite machining properties. It is not generally possible to obtain less than 3·0 per cent. total carbon from the metal mixtures normally used in the Cupola, and iron containing less than 3·2 per cent. total carbon is somewhat difficult to cast.

5. **Calculation of Metal Charges.**—The analysis required in the casting having been decided upon, a survey of the nature and analyses of the materials available will generally indicate which of them are most suitable and suggest a possible mixture as a first trial calculation. Allowance must be made for the probable melting losses already discussed.

Pig irons of widely differing analyses should not be charged together. In such a case it is better to run the mixture into pigs of suitable composition for remelting, in order to obtain homogeneous castings.

A record should be kept showing the nature and estimated analysis of the charge, and the resultant castings.

Example :—

Materials available.	Si.	Mn.	P.	S.	Carbon.	
	%	%	%	%	Combined. %	Graphitic. %
Hot Blast Pig	2·40	1·1	0·6	0·05	0·5	3·1
Cold Blast Pig ..	1·42	1·2	0·5	0·03	0·9	2·4
Pig Iron No. 4 ..	1·75	0·9	0·8	0·08	0·8	2·5
Cast Iron Scrap No. 2..	2·00	0·7	0·9	0·09	0·7	2·6

CUPOLA MIXING SHEET.

No...........

Job Nos............ Date Cast ....

Metal Charge.	%	Si.	Mn.	P.	S.	Weight. Lbs.
Hot Blast Pig	35	84·0	38·5	21·0	1·75	910
Cold Blast Pig	20	28·4	24·0	10·0	0·60	520
Pig Iron No. 4	15	26·2	13·5	12·0	1·20	390
Cast Iron Scrap No. 2 ..	30	60·0	21·0	27·0	2·70	780
	100	198·6	97·0	70·0	6·25	2,600
Estimated analysis of charge..	—	1·97	0·97	0·70	0·06	
Estimated analysis of castings	—	1·61	0·71	0·70	0·09	

Remarks :

Analysis of castings :

Test results :

Note.—If two metals of differing analyses are required from the cupola in the same " blow," an overlap should be arranged between them, the better quality metal being in excess, in order to avoid the possibility of casting important work with inferior metal.

The Charge Sheet.—The proportions of the charge having been calculated, a Cupola Charge Sheet is prepared, copies of which are forwarded to the foundry and to the foundry storekeeper; the storekeeper being responsible that metal charges are accurately weighed and issued to the charging platform in the proper order.

Limestone is stowed on the charging platform, and is weighed out ready for charging before the beginning of the blow.

Coke is obtained from bins adjacent to the charging door and is measured into a circular tray 7 in. in depth and of the same internal diameter as the cupola. This tray holds about 44 lb. of coke.

The specimen Charge Sheet given below applies to a cupola with a melting rate of about 18 cwt. per hour.

Metal charges for this cupola are about 400 lb. each, but this is reduced to 300 lb. if the coke is of poor quality. In the specimen sheet the weight of each metal charge is 350 lb. ,each charge being proportioned in accordance with the Mixing Sheet.

CUPOLA CHARGE SHEET.

No. ....

Job Nos............ Cupola No............

Date of cast. ....

Charge No.:	1	2	3	4	5	6	7	8	9	Total Weights. Lbs.
Coke	400	40	44	44	44	44	44	30	—	690
Limestone	—	4	5	6	6	6	5	3	—	35
Hot Blast Pig ..	122	122	122	122	122	122	122	56	—	910
Cold Blast Pig ..	70	70	70	70	70	70	70	30	—	520
Pig Iron No. 4 ..	53	53	53	53	53	53	53	19	—	390
C.I. Scrap No. 2 ..	105	105	105	105	105	105	105	45	—	780

Tapping Times ..	1030,	1040,	1059,	1117,	1133,	1140
Weight tapped (cwts.)	1	$4\frac{1}{2}$	5	5	5	2

Lit fires..	0730	Weight of Iron	2,600
Started Blow	1015		
Melt per hour (cwts.) ..	16·3	Weight of Castings	2,380
		Pig iron and scrap made ..	120
		Melting loss	100
			2,600

REMARKS.

First tap rather dull-ran pigs.

First slag black and cindery, but improved later to a greenish-brown colour, thin and fluid.

Cupola lining to be repaired in the melting zone.

6. **The Cupola.**—The height of the cupola is measured from the tuyeres to the sill of the charging door, and is usually 3 to 5 times the internal diameter.

The cross-section of the blast air belt is about 50 per cent. greater than that of the tuyeres leading off from it.

The total area of the tuyeres at their smallest section is from 17 per cent. to 19 per cent. of the cross-section of the cupola at the level of the tuyeres.

The slag hole should be just below the lowest tuyere level but not too close to the tuyeres as this leads to chilling of the slag and possibly to choking of the air supply.

The Cupola Lining.—The firebricks are bedded on to a grouting of fireclay and crushed firebrick about $\frac{1}{2}$ in. in thickness. The bonding material is as used for boiler brickwork, and should be as thin as possible. Brickwork should be dried thoroughly before lighting fires for the first " blow." It is good practice to paint over the whole of the lining with a thin fireclay wash. A handful of salt in the water helps to produce a glaze on the brickwork.

After a blow, the lining should be carefully cleaned with hand picks, taking care not to spoil the glaze. Parts which require repair are covered with a thin fireclay wash, and rammed and reshaped with a facing mixture consisting of 50 per cent. fireclay and 50 per cent. crushed firebrick. The facing should be as stiff as possible with only sufficient water added to enable the mixture to adhere to the brickwork.

The Melting Zone.—This extends from about 6 in. above the tuyeres and upwards for from 10 to 14 in. in a small cupola up to 36 in. in a large one. It is essential to restore the melting zone to correct form after each blow. No abrupt changes in the internal diameter of the cupola should be allowed, and no part of the melting zone should be of smaller diameter than the adjacent parts of the lining. If the melting zone becomes unduly enlarged, blast air will escape between the charge and the brickwork and cause rapid scouring of the brickwork.

The facing mixing applied should not exceed ¾ in. in thickness at any part. Such a state indicates that the brickwork requires renewal in the worn section.

" Cupoline " may also be used for repairs to the lining.

At the end of a blow, the melting should show as a clearly defined scoured belt in the lining. An imperfectly defined zone indicates a high or fluctuating level of the coke bed, caused by variations in the weight of coke introduced between metal charges. Absence of scouring on part of the circumference of the melting zone may be due to a choked tuyere.

The Cupola Bottom.—The stays or dogs fitted to support the drop-bottom must be firmly secured on a solid foundation to prevent the least possibility of the doors partially opening during the melting operations. Door joints are covered with clay to prevent the sand running out when it becomes dry.

The strength of the same must be adjusted to give an easy and clean drop when the doors are opened at the end of the blow. If too weak or friable, the sand may be washed away by the flow of metal or by the force of the blast air, and if too strong or hard when baked difficulty may be experienced in breaking the sand bed to drop the residue of coke and slag.

The bed usually consists of old sand from the foundry floor strengthened by the addition of new loam sand ; about one-third of new sand being a common proportion.

The sand adjacent to the tapping hole may be dug out and replaced by a strong baked clay or loam core, which is better able to withstand possible damage from the end of the tapping bar and so helps to maintain an even flow of metal into the cupola spout. The sand is rammed to about the density used for an open sand mould, and has a gradual and smooth slope down to the tapping hole from all directions; the amount of the slope varying from ½ in. to 1 in. per foot.

If the cupola is a slow melter, or if irons are used which solidify quickly, it is well to use the steepest slope. This causes the iron to collect quickly at the breast in a hotter state. Excessive slope will lead to a swift flow of metal from the tapping hole, making it difficult to stop or " bot " again. When the cupola is fitted with a receiver, maximum slope is permissible, with a moderate slope on the floor of the receiver.

The periphery of the sand bed should turn up to the cupola lining with a good radius.

The Breast and Tapping Hole.—The space for forming the breast is about 8 in. square. This may be left open to supply natural draught to the cupola until the fire is well started, but if a low pressure air supply is available the breast may be completed before lighting the fire and air supplied by means of a flexible hose led to the tapping hole.

Various methods of completing the breast and tapping hole are adopted, those most generally in use being as follows :—

(*a*) The brickwork is brushed clean and slightly wetted with a fireclay wash, after which a handful of loam sand or ganister is daubed on to the bottom and a gate-peg or rod about ¾ in. to 1¼ in. in diameter is bedded in to the level of the sloping sand bed. (See Fig. 1.)

Pieces of coke 3 or 4 in. in length are bedded round the peg until the breast hole is filled. The peg is then withdrawn and the face and tapping hole dressed with a fireclay mixture or with ganister. The coke expands when heated and forms a tight and durable breast.

(*b*) A piece of board is placed across the breast hole flush with the inside of the cupola lining, and fireclay bonding material is rammed into the breast and around the gate-peg. The front is cut away, as shown in Fig. 1, to reduce the length of the tapping hole. A long hole tends to chill the metal and may cause trouble by choking during the tapping operations.

Instead of using a gate-peg the bonding material may be rammed around a hollow cylindrical baked loam core. This provides a strong and dry tapping hole.

(*c*) A rectangular loam brick or breast core, complete with tapping hole, is moulded to fit the breast. This is baked hard in a core-drying oven and bedded neatly into place with a thin layer of bonding material, the bottom of the tapping hole being flush with the sand bed.

This is considered to be the easiest and most reliable method, and a stock of spare cores can be kept ready for use.

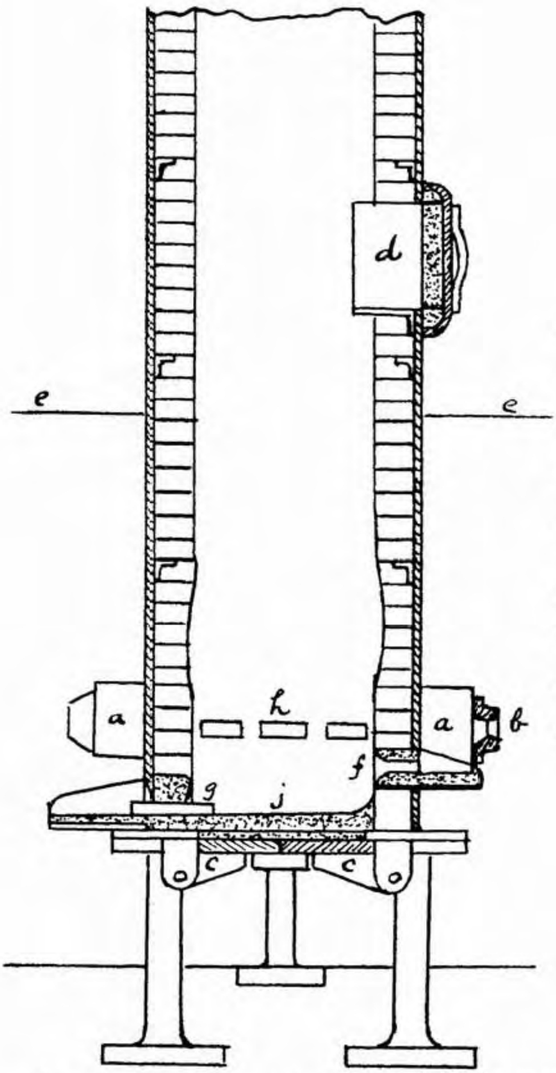

FIG. 1.

(*a*) Blast Air Belt.

(*b*) Tuyere sight doors.

(*c*) Drop-bottom doors.

(*d*) Charging door.

(*e*) Charging Platform level.

(*f*) Slag hole.

(*g*) Tapping hole.

(*h*) Tuyeres.

(*j*) Sand hearth.

In all the above cases the breast is strengthened by a steel cover plate cut away about the tapping hole and forming part of the cupola shell.

The Tapping Spout is lined with firebricks and a facing of loam or fireclay. The bottom of the channel should be narrow, as a wide spout causes the molten metal to wash over the sides.

Cupola Operation. Lighting-up.—The fire is started as in a coal-fired boiler, using as little wood as possible in order to reduce the amount of ash. Coke is added gradually until the full amount for the coke bed has been charged. The amount of coke required for the bed depends upon the height of the tuyeres and varies for different cupolas, but normal practice is to charge to a height of from 18 to 24 in. above the tuyeres. A high bed gives a hotter metal at the tapping hole, but the rate of melting is reduced, and an excessive charge may even stop the melting altogether until the coke has burned down to the proper level. It is, however, better to charge too much rather than too little, and until experience has shown the best height for the particular cupola in use a height of 24 in. above the tuyeres should be adopted.

This can be measured by sounding with a chain gauge from the sill of the charging door.

It is important to get the coke bed burning vigorously before the first metal is charged. The time required to get the fire in good condition for charging iron varies from 1½ to 3 hours according to the size of the cupola, using only natural draught through the breast, tuyeres and slag hole.

Blast air should not be used to force the rate of burning unless haste is imperative.

To increase the efficiency of the cupola it is sometimes found desirable to heat it initially before any metal is charged. This is done by blowing for 15–20 minutes and experience will show how much coke has to be charged to give a level at about the top of the tuyeres at the end of this preliminary blowing.

Coke is then charged to a height of about 18 in. above top of tuyeres, and limestone spread over, and the first charge of metal added.

By this superheating, the first charge comes down very hot and special metal for special work can be obtained, *e.g.*, nickel iron, uncontaminated by subsequent poorer quality charges.

It is essential that the Receiver should also be specially heated by means of a heavy wood fire assisted by blowing if necessary.

Charging. Coke-Iron Ratio.—Charging of either coke, metal, or flux should never be done by guesswork but always by properly weighing each charge. The weight of coke to be charged between the layers of metal depends entirely on the internal diameter of the cupola, the thickness of the coke layers being fixed at from 6 to 8 in. Metal charges are from 9 to 10 times the weight of the coke layers.

Limestone flux required with each charge varies from 10 per cent. to 15 per cent. of the weight of coke.

As an example, a cupola 22 in. in diameter with a melting rate of 18 cwts. per hour was charged as follows :—

Coke bed, 430 lbs. (22 in. above the tuyeres),
Metal charges, 350 to 400 lbs. each,
Coke charges, 40 to 45 lbs. each,
Limestone charges, 4 to 8 lbs. each.

Time does not usually permit of weighing each coke charge and it is more convenient to make a cylindrical sheet-iron tray, 7 in. deep and of the same internal diameter as the cupola, into which each coke charge may be measured before firing.

Metal and limestone charges sufficient for the day's melting should be weighed out and placed in convenient positions near the charging door, in correct order in accordance with the charging sheet.

When the coke bed is thoroughly burning the first metal is charged (Column 1 on the charge sheet), followed by a layer of coke and the limestone flux. The second metal charge is then added and the charging continued in the order coke-limestone-metal, as shown in the vertical columns of the charge sheet.

Pig iron should be broken into pieces not more than 8 in. in length, and evenly distributed over the coke, taking care not to leave gaps at the sides through which blast air may escape. Heavy pieces of metal should be reserved for later charges and not placed on the coke bed, as they may sink to the level of the tuyeres and partially choke the air supply.

The limestone should be evenly distributed in pieces about egg-size.

The cupola is kept filled to the sill of the charging-door until the final metal has been charged. This utilises as much as possible of the heat available for preheating the charge and also prevents fumes and flames affecting the men at the charging door.

Careful and regular charging is of first importance. It should be noted that the function of the coke layers is to replenish the bed and maintain it at the correct height above the tuyeres. Over-reduction of the coke layers will cause dull metal at the tapping hole, but the change in composition of the metal and the amount of carbon absorbed will be diminished by keeping the coke at the minimum amount required to give a high tapping temperature. Correct charging is indicated by uniform fluidity and speed of melting throughout the blow.

If time permits, the fully charged cupola may be allowed to " soak " under natural draught for an hour or so in order to ensure a hot and fluid iron at the first tapping.

The "Blow".—When the moulds on the foundry floor are ready for pouring, the slag and tapping holes are closed with clay " bots," the tuyere sight doors are shut, a heated ladle is placed in position under the cupola spout, and the blast air supply fans or blowers are started.

Molten metal will be seen at the tuyere sight doors in from 5 to 10 minutes. The capacity of the well and the rate of melting being known, a rough estimate can be made of the time required for the metal to rise to the level of the tapping hole. Constant watch must be kept through the sight doors, and at the first appearance of molten metal rising to the tuyeres the cupola must be tapped without delay.

If the first metal appears to be rather sluggish, it should be run into a small ladle and cast into pig-moulds. The castings should be poured as hot as possible and iron should not be left standing in the ladles for longer than is absolutely necessary.

The time taken from the starting of the blast to the first appearance of molten metal at the sight doors is a further indication as to the correct height of the coke bed. Assuming that the bed was well ignited before starting the blow, a greater time than 12 minutes indicates that the coke bed is too high. If the molten metal appears very quickly but is comparatively dull, the bed is probably too low.

Tapping the Cupola.—Several tapping bars and a quenching bath should be kept ready to hand as the ends of the bars may be quickly burned away. Tapping bars are of iron or steel from ⅝ in. to 1 in. in diameter and from 4 ft. to 10 ft. in length and are pointed at the tapping end.

A few bars should be made with chisel ends to deal with a badly choked tapping hole.

The " bot " is loosened by picking around its outer edge until the pressure of the molten metal is about to burst it outwards. A firm prise on the side of the bot will then easily remove it and leave a clean hole which may be readily stopped-up again when necessary.

Botting the Cupola.—The bot-stick consists of an iron bar with a disc about 1½ in. to 2 in. in diameter at one end, the clay plug or bot being pressed on to the disc by hand. The bot is rolled in blacklead before being secured to the disc, and a depression formed in its base to facilitate adhesion.

It should not be thrust directly forward against the stream of molten metal but held poised just above the metal near to the tapping hole and then rammed home by a downward and forward plunge.

To prevent the bots falling off it is very necessary to have a small projection, say ½ in. diameter by ½ in. long, on the bot side of the disc.

Slagging.—The flux most commonly used in the cupola is limestone ; but shells, calcite, marble chippings, etc., are also suitable. Fluorspar is a good flux but has a destructive effect on the brickwork. Sufficient flux must be used to make the slag thin and fluid, but an excess will cause rapid scouring of the lining.

The slag hole is broached when iron begins to flow freely past the tuyere sight doors and is temporarily stopped after each tapping in order to prevent loss of blast air. If an ample supply of blast air is available it is better to leave the slag hole open throughout the blow. Care must be taken to keep the slag hole free from obstruction to prevent choking of the tuyeres.

Observation of the nature of the slag gives useful information as to the working of the cupola, but it must be allowed to cool slowly and under the same conditions to permit of useful comparisons. The slag issuing from the cupola should be thin and fluid and of a greenish-brown colour. A yellow tint is sometimes obtained but this is merely the result of using pig-iron rich in manganese.

A very heavy slag indicates the presence of iron generally due to a shortage of flux or too much blast air.

A black or brownish-red colour denotes oxide of iron and may be caused by insufficient fuel or excessive blast air.

Too much limestone will produce a whitish appearance and a dull stoney fracture.

The Blast.—The weight of air required is a direct function of the amount of coke to be burned in the cupola. Volume meters are now generally fitted to measure the amount of air supplied. The pressure of the air supply is not a true indication of the amount of air supplied since the pressure is affected by the closeness of the charging, the amount of charge still remaining in the furnace and the state of the tuyeres.

This is particularly the case with fan-type blowers where an increase in the resistance of the charge means an increased pressure at the fan but a decrease in the amount of air supplied to the cupola. When a positive blower is fitted, the air supply varies with the speed of the blower and is not so much affected by the resistance of the charge. A pressure gauge is therefore suitable for use with a variable-speed positive type blower but with fan supply a volume meter is required.

Air supply should be at a maximum at the beginning of the blow, and may be reduced as the charge descends from the level of the charging door. Excessive blast at the end of the blow will result in heavy scouring of the brickwork at the melting zone.

With an 18 cwt. per hour cupola, the air pressure was varied from about 12 in. of water at the beginning of the blow, to 5 in. immediately before the last metal was tapped.

The blast is stopped when the final tap is made, and as soon as all the metal has been tapped the drop-bottom is opened to allow the residue of coke and slag to fall.

Blast air required per ton of metal melted is about 30,000 cubic feet at 60° F. When volume meters are supplied, this figure may be taken as a guide until experience has indicated the correct volume for the particular cupola in use.

8. **Cupola Troubles. Scaffolding.**—This occurs when the charge becomes wedged and hung-up in the cupola shaft. The charges

below the jam descend and leave an empty space beneath the "scaffold."

A scaffold must be broken quickly by ramming with a slice or iron bar inserted through the charging door.

Failure to break the jam involves complete failure of the blow.

Scaffolding may be due to one or more of the following causes:

(*a*) Uneven distribution of the charge, or charging of large or irregularly-shaped pieces of metal.

(*b*) The use of weak, friable coke which is easily crushed and blown out by the blast, so leaving a space which may become covered with a roof of chilled slag.

(*c*) Badly trimmed brickwork with projecting bricks.

(*d*) Cooling and solidification of the slag at a point just above the tuyeres. This may be remedied by temporarily closing the air supply to the tuyere affected and allowing the chilled slag to remelt; or small pieces of coal may be inserted through the tuyere to produce an intense local heat. It may sometimes be cleared by means of an iron bar inserted through the tuyere.

After a scaffold has been cleared it is advisable to charge a little extra coke to replenish the coke burned out of the bed during the hold up of the charge.

Dull Metal.—The first metal tapped may be sluggish, particularly if the coke bed was not burning vigorously before charging the metal, or if the blast was started too soon after charging. In this case the first metal should be poured into pig moulds. It is useless to pour dull metal into moulds for castings. A high pouring temperature is essential for the production of sound castings, and this can only be obtained by correct charging and strict adherence to the best coke-iron ratio and blast air volume as found by experience of the cupola in use.

Choking of the Tapping Hole or Tuyeres.—Choking of the tapping hole may become a serious trouble unless quickly cleared. The blast should be shut off immediately if a stoppage in the flow of metal or failure to remove the bot occurs, in order to retard the melting. Failure to clear the tapping hole within a few minutes will probably lead to an overflow of metal into the tuyeres, complete failure of the melt, and considerable damage to the cupola. The most probable causes are insufficient slagging, leading to an accumulation of thick slag at the tapping hole at the end of each tap, or to the use of a very strong bot.

Constant watch must be kept through the sight doors to avoid choking of the tuyeres by the rising metal and slag. It is a good practice to leave the slag hole open throughout the blow whenever possible.

Modern cupolas are rapid melters and efficient arrangements must be made for the transport of the molten metal, and a relay of heated ladles kept ready for use. Tapping of the cupola cannot be delayed.

9. **Use of Mild Steel Scrap.**—The use of mild steel scrap under proper conditions produces a tough close-grained casting with the graphite in a finely divided state. The amounts of silicon, phosphorus, manganese and sulphur are less than with ordinary cast iron made from the same pig iron mixture owing to the diluting effect of the steel. It should be noted, however, that an increase in the total carbon content of the mixture will occur, owing to the carburisation of the steel. For the purpose of calculating charges it is therefore usual to assume that the carbon content of the mild steel scrap is from 2·5 to 2·7 per cent.

The steel is preferably in the form of scrap from $\frac{1}{4}$ in. to $\frac{5}{8}$ in. in thickness, such as punchings, shearings, ends of anglebars etc. Borings and turnings are not suitable owing to rapid oxidisation in the cupola.

A high temperature in the cupola is necessary and the metal should be poured into the moulds as hot as possible.

Steel increases shrinkage, and gates and runners should therefore be large. Up to 10 per cent. of mild steel may be used in any cupola mixture without trouble, but more than this amount requires careful supervision of the melting conditions in the furnace and due allowance for shrinkage in the mould.

The increase in carbon content becomes a factor in determining the amount of steel which can be added to a pig-iron charge with improved results. When the pig iron is low in total carbon it is possible to use more steel than with high-carbon mixtures. For this reason cold blast pig irons are better than the hematites for "semi-steel" mixtures, since the hematites are generally high in carbon.

Castings of excellent quality are obtained by casting semi-steel mixtures in heated dry-sand moulds. If facilities can be arranged for heating the moulds to temperatures between 350° C. and 400° C. by means of gas-rings or coke fires, up to 40 per cent. mild steel scrap can be used without casting or machining troubles, and at the lower temperatures obtainable in moulds removed from a core-drying oven it is possible to use up to 20 per cent. of mild steel scrap.

10. **Use of Cast Iron Scrap.**—Scrap cast iron should be sorted into two kinds; arisings from the foundry, such as runners, risers and other pieces of which the analysis is known, and mixed scrap from other sources. The first kind is of great value and should be reserved for work which is to be cast to a specified analysis, but mixed scrap of unknown composition should be used only for unimportant work or else re-cast into pigs of which the analysis may be obtained.

11. **Use of Ferro-Alloys.**—Ferro-silicon or ferro-manganese can be used to adjust the composition of the charge if necessary, but it is better to use pig irons of analyses that will give the desired composition in the castings without such additions.

The chief value of these for ordinary foundry purposes arises when pigs are being cast to a specified analysis for re-melting in the cupola.

Average compositions of these alloys are as follows :—

	Mn.	Si.	P.	S.
80 per cent. Ferro-manganese	80·5	0·6	0·3	Trace.
25 per cent. Ferro-silicon ..	0·7	26·0	0·02	0·05
70 per cent. Ferro-silicon ..	0·4	70·0	0·03	0·02

12. **The Heat Treatment of Iron Castings.**—Heat treatments applied to iron castings are of two kinds.

(*a*) Low temperature annealing, for the purpose of relieving casting stresses.

(*b*) High temperature heat treatment, for the purpose of softening in order to obtain better machinability, or in order to modify the structure and physical properties of the iron, or to harden the iron by quenching and tempering.

Low Temperature Annealing.—The object is to relieve casting strains with the least possible reduction in the strength of the iron. The temperature to which the casting is raised must therefore be well below the critical temperature of the iron. The critical temperature depends on the composition of the iron and varies from about 730° C. to 760° C.

The time required to effect annealing at any given temperature depends on the shape and mass of the work, and is reduced when the original structure of the iron may be assumed to be fairly uniform, as in castings of constant cross-section. Slow cooling is essential. Average practice is as follows :—

Annealing temperature ..	350° C.	500° C.	600° C.
Time in hours	8	6	3

The Admiralty specification for the annealing of turbine casings states :—

> "Castings to be removed from the moulds before they have become entirely cold, raised to from 600° F. to 700° F. (320° C. to 370° C.) in an oven, and maintained so for about 8 hours. To be allowed to cool slowly in the oven. In addition, turbine casings for main engines are to be annealed after rough machining, as much material as practicable being removed before annealing."

This annealing may be carried out either in an annealing furnace, core oven or by means of steam, at a temperature not less than 175° C. for a period usually not less than 12 hours.

High Temperature Heat Treatment. Softening.—Castings found to be difficult to machine can be softened by raising them slowly to from 780° C. to 850° C., and maintaining this temperature for from 3 to 6 hours, according to the size and nature of the castings.

Hardening and Tempering.—Hardening and tempering operations are occasionally carried out with certain irons.

The hardening effect obtained by quenching cast iron in oil from temperatures above the critical point depends upon the composition of the iron.

Silicon and other elements which tend to produce graphitic carbon reduce the hardening effect, whilst manganese and sulphur increase it.

Quenching in oil produces a considerable decrease in tensile strength, but this may be recovered and increased by suitable tempering, to a value higher than that of the material in the " as cast " condition.

With compositions normally used, good results will be obtained by quenching from 840° C. to 860° C., and tempering at from 340° C. to 360° C. for a period of 15 to 20 minutes.

The table shows the results of hardening and tempering a cast-iron quill ½ in. in thickness and about 8 in. in diameter. The quill was heated to 850° C. in an electrically heated muffle furnace fitted with pyrometer temperature control, quenched in " Quenchol " and allowed to cool in the oil, and tempered in an electrically heated bath of molten tempering salts at 350° C.

The analysis of the quill was as follows : Graphitic carbon 2·75 per cent., combined carbon 0·6 per cent., silicon 1·8 per cent., manganese 0·95 per cent., sulphur 0·09 per cent., phosphorus 0·6 per cent.

	Brinell Number.	Tensile Strength. Tons/sq. in.
As cast	240	15·9
Heated to 850° C. and quenched in oil	490	
Tempered at 350° C. for 20 minutes	380	18·8