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# Cupola practice in modern gray iron foundry

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# CUPOLA PRACTICE IN MODERN GRAY IRON FOUNDRY

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# Cupola Practice in Modern Gray-Iron Foundry

Cupola practice, as described in this paper, will include only the practical operation of a cupola and the details of the work necessary in daily routine, and very little of the theory of combustion,or history of cupola development, is presented.

A brief description of the cupola will give an idea of its construction, and the names of the parts may be found on the sketch herewith.

The cupola consists of a steel shell, cylindrical in shape, which stands vertically on four cast-iron legs, about four feet off the floor; it is open at the top, and has swinging cast-iron doors at the bottom. On the outside of the shell at the bottom is a second shell, about four feet high, and about two feet larger in diameter than the cupola proper, enclosed top and bottom; this is the wind-box, and leading from it, to the inside of the cupola,are the tuyere openings, through which the air is conducted into the cupola, under low pressure.

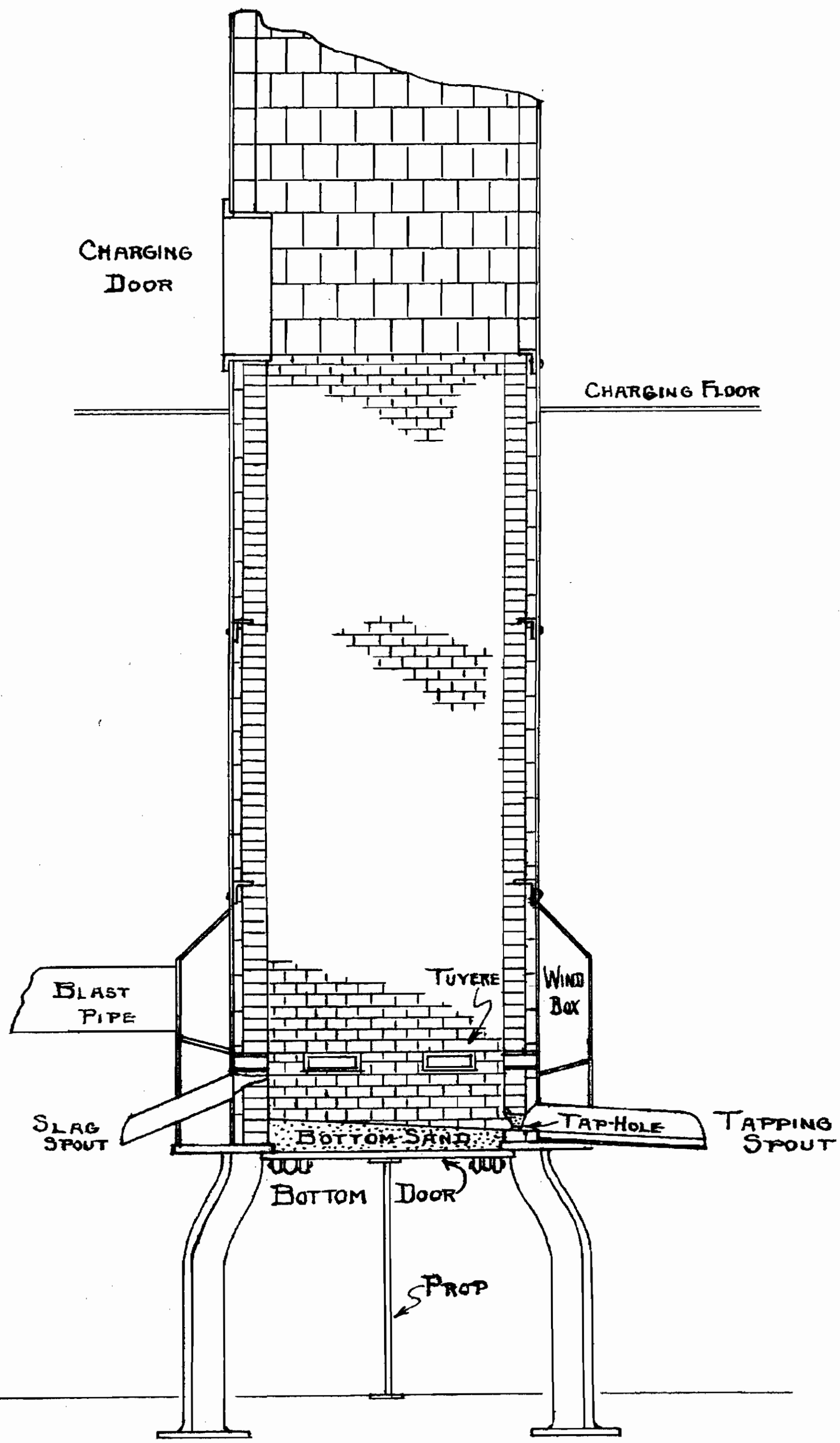
Also, at the bottom of the shell are located the tap-hole, in front, through which the molten iron is drawn, and the slag-hole, in the rear, through which the molten slag is conducted. Other parts, to be mentioned later, may be seen on the sketch, and are self-explanatory.

Before beginning the description of the detailed operation of the cupola, mention should be made of the various materials used in its maintenance and repair, as well as the lining.

The lining is made of fire-brick, and these brick should be of good quality, finely ground material, and burned hard, as well as being infusable up to a temperature of 2700 degrees F. The thickness of the lining depends on local conditions and the melting rate desired, but should not be less than about nine inches, when new, or re-lined.

Cupola blocks are made, for lining, by most fire-brick manufacturers, of sizes to fit practically any cupola, with diameter and thickness as desired. These cupola blocks are approximately nine inches square, with a thickness of four and one-half inches, or six inches; it has been found in practice by the writer, however, that the smaller cupola brick, about three inches high, and either four and one-half or six inches deep, give longer life to the lining, because the larger blocks crack, and larger pieces fall out, while the smaller brick have a tendency to prevent this.The lining of the cupola, well laid in, with a minimum of mortar in the joints, will last over a year, with good melting practice, using the small fire-brick between the tuyeres and the charging doors. It costs more in labor when the lining is made, but the difference in life of the lining more than justifies this expense.

# Modern Cupola in Cross Section



Next in importance to the lining is the material with which the lining is patched, in the daily repair work. This consists of equal parts of river or lake sand, coarse molding sand, or red sand, with considerable clay in it, and fire-clay, dry-milled. The clay gives a bond to the sand, makes a hard surface, while the sand furnishes the refractory qualities, and keeps the clay from cracking,under heat. This mixture is only one example; any number of sand and clay mixtures may be used, depending upon available material, but the patching material must have refractory properties, must stick to the lining, and be free from cracks when subjected to intense heat. In preparing this daubing mud, the dry materials are mixed in a flat box or pit, just enough water added to make it sticky, when well mixed, and then the whole mass allowed to stand about twenty hours, so that the water will be well worked into it. After a little further mixing, the mud will be ready for use.

The breast is made of the daubing mud, with an extra part of river sand added.

The material used for bodding up, or stopping up the cupola at the tap-hole is a mixture of fire-clay and red-sand in equal parts.

The sand for the bottom consists of burned molding sand, or gang-way sand; this is wet down just enough so that it will pack firmly together, about the same amount of water as required for molding sand.

The tools necessary for cupola work are not many, but they should be kept near the cupola, and maintained in good condition. One of the most important is the pointed stick to be used for forming the tap-hole; this should be of hardwood, about five-eighths to one and one-quarter inches in diameter, depending upon conditions in the foundry; this will be explained later. The stick used to make the slag-hole should be about twice the diameter of the tap-hole stick.

The bod-stick, with which the tap-hole is stopped up, on the end of which a lump of clay is held, is a straight stick of wood about eight or ten feet long, and about two inches in diameter; on one end a steel ferrule is driven; this end holds the bod.

Steel bars for chipping out and opening up the tap-hole may be two feet to four feet long, and one-half to one inch in diameter; there should be at least one bar of chisel steel with a bent chisel point.

For chipping out inside the cupola, a small pick and a brick-layers hammer are good tools for this work.

A soft brush, a rammer, and a ladder for going into the cupola from the charging doors are also necessary. Other tools may be added, but these listed are enough for the work.

The tools and materials all being on hand, the daily cupola operation may begin; it must be understood that this procedure is not arbitrary, but it is logical and has worked economically, and a cupola may be successfully operated with these general principles; assuming the cupola has been operated before, the "bottom" is lying where it was dropped, underneath the cupola; this consists of bottom sand, coke, slag, and unmelted iron, if any remained in the cupola when the bottom was dropped.

The first thing to be done is to haul out the mass of material dropped, separating the coke and iron, setting them to one side, to be used again, and hauling the remainder to the dump.

The melter should then go into the cupola and chip out the slag that is hanging on the sides and over the tuyeres, and chip out any rough projections left in the lining by the last heat. This work should be carefully done, so that the daubing operation is made easier. Any pieces of loose brick from the lining should be knocked out, so that the patched lining, when dried out, will not loosen up. The chipping out should include the slag-hole, tap-hole and breast, from inside and outside the cupola, and also both spouts.

The tapping-spout should be patched up, brushing off the dry sand and slag with a wet brush, before applying the daubing mud, or material for patching the lining. The tapping spout lining should be smoothed up with the brush, while still wet, and should have a slope of about three-fourths of an inch per foot, up toward the tap-hole.

The breast may be made next, of the special clay and sand mixture prepared for the purpose. The opening should be chipped out clean, at least the size of two fists, and wet with the brush, and then the material rammed tightly into place, from both inside and outside the cupola. With the plastic mud firmly in place, use the tap-hole stick for forming the tap-hole, wetting it, inserting the point, and running it backwards and forwards several times to insure a smooth passage for the iron when it is melted.

The size of the tap-hole depends on local conditions; that is, the size of the cupola and the character of the work cast in the foundry. If large castings are to be made, the tap-hole must be large, in order to hold large quantities of iron in the cupola, and then draw this metal off quickly when the proper time comes.

If the cupola runs continuously, though, the tap-hole may be small, in order to hold a head of iron in the furnace and keep back the slag from the tap-hole.

A safety tap-hole may be made above the regular tap-hole with about one inch space between the holes. This may be used for tapping out in case the lower tapping hole should freeze up; this device may save the whole heat from loss in case of trouble. The lower tap-hole will usually melt through a little later, and then may be used again.

While the clay is still soft, the breast should be scraped away to a thickness of about $2\frac{1}{2}$ or 3 inches; a small pocket about 3 inches deep, should be made inside the cupola, directly in front of the hole (see sketch). This should be about the size of a man's fist. Now the tap-hole stick should again be run through the hole several times, to insure it being smooth and firm, and the inside and outside of the breast smoothed off, leaving sharp edges on the hole.

A fire should be made on the spout, of small sticks, up close to the breast, to dry it our thoroughly; if a torch, or burner is available, this is still better for this work. The inside of the breast must be also dried out, with a torch, or small fire up against it; a small piece of sheet iron, a foot square, stuck between the bottom of the fire-brick and the cupola bottom-plate, is handy for this use; lay a few sticks of fine kindling on the sheet iron, and ignite them, drying the inside of the breast by the time they are burnt out.

After the wood burns on both sides, examine the breast closely for cracks, and if any are seen, daub up the cracks and dry it out again, This is very important, for the iron might leak out through these cracks, if not properly closed up before the heat is run. It must be kept in mind that the proper making and drying out of the breast are absolutely essential to successful melting. Many good heats are spoiled and much money lost in the foundry through the failure of the cupola breast during the heat.

This concludes the work on the breast, the next work is that of patching the inside lining with the daubing mud already prepared. The lining should be deeply scored, or cut away, only for one or two feet, with good melting practice; most of the lining should be about straight, except in the melting zone, about two feet above the top of the tuyeres.

In applying the daubing mud, it is thrown against the lining hard enough to make it stick; the mud should be of such consistency that it will stick without any trouble. After the lining is filled out, so that it is approximately straight again, with a slight overhang above the tuyeres as shown in the sketch, it should be smoothed up with a wet brush, to remove the irregularities. All this work must be very carefully done; the patching must stick well to the lining and be smooth when dried out by the fire.

When the melter is patching around the slag-hole, he should fill up the slag-hole opening with clay, and then make a new opening, through it, for the passage of slag. The slag-hole should be formed at this time, using a pointed stick like that used for making the tap-hole, but larger in diameter, in fact, about twice the diameter; the slag spout in the rear of the cupola, should now be lined, and smoothed up; it need not be dried, however, because the popping, or bubbling of the slag on the wet clay is of no consequence.

The bottom doors are then closed up and propped with one or two heavy steel bars, at least $1\frac{1}{2}$ inches in diameter, depending on the size of the cupola. The bottom of the bars should have a good foundation; if this is irregular, a steel plate should be placed under the props, with a little dry sand spread over the top of the plate. The space under the cupola should be cleaned up, and water used very sparingly there; if it is too wet, steam will be formed when the bottom is dropped, and a small explosion will be the result.

The sand for the bottom is dumped in from the charging floor, and the melter descends on a ladder hung from the charging-door opening; the bottom sand is spread out, and tamped in place with a rammer; it should be rammed about as hard as molding sand is rammed in the foundry, that is, firm enough to resist the pressure of the hand; the bottom must slope upward from the tap-hole, with a grade of about $\frac{3}{4}$ of an inch to the foot; the front should be exactly in line with the bottom of the tap-hole, and the small pocket on the inside of the breast. (See sketch)

The height of the slag-hole above the bottom sand in the back of the cupola depends on the class of work handled in the foundry. For very large castings, it is necessary to hold large quantities of iron in the cupola before tapping out, and hence, the slag-hole should be built as high as possible, except that it must be kept below the bottom of the tuyeres, or the slag will get into them. For continuous operation, where the iron is run out almost continuously, and only stopped for short periods, the slag-hole may be made close to the bottom, within two inches. The thickness of the bottom sand may be varied to get the same result, if the tuyeres are built for different operation than that desired. The minimum depth of sand should be about 5 inches, otherwise the iron may run through the bottom during the heat.

Before laying the fire-wood around the cupola, preparatory to lighting up, the melter should place some long pieces of coke, making a bridge around the tap-hole on the inside, building up the coke as a protection for the tap-hole, leaving a hollow pocket 4 or 5 inches deep, on the inside. This coke will remain through-out an ordinary heat unconsumed, and serve to keep the hole open.

Long sticks, four and five feet, should be placed against the lining, all around the cupola; this should be done carefully, to prevent injury to the green lining, or patching. Smaller sticks are laid below, and the melter ascends the ladder to the charging floor, pulling the ladder out afterwards.

To start the fire, a few pieces of oily waste or rags are lighted and thrown into the bottom, igniting the wood. Coke is added slowly, and all peep-hole doors are opened for draft, until the coke is well ignited. When the first layer of coke, about one foot thick, is burning through, add the whole bed charge, which has been previously measured.

The height of the bed of coke above the top of the tuyere openings is probably the most important thing to have correct around the cupola; accurate determination of the proper height of the bed, and keeping this constant throughout the heat practically decide the success or failure of the melting practice.

When previous operation of the cupola is unknown, it is best to make the bed high, that is, about 30" above the tuyeres, 24" being about average. After the cupola is properly charged, allowed to stand at least one hour, and the blast is turned on at full speed, time should be taken from the starting of the blower until the first iron runs over the tapping spout; this should be between 8 and 10 minutes-- if less than 8 minutes the bed is too low, if more than 10 minutes the bed is too high and fuel is being wasted. A good heat may be run off with a high bed, but it is an unnecessary waste of coke and in the next heat the bed should be cut down a few inches, and this continued until the proper height is determined.

The assumption is made here that the proper volume of blast and relation of tuyere area to cupola area, have previously been provided for. Reference may be made to the table, taken from Moldenke's, "Principles of Iron Founding".

| Cupola Diam. Inside Lining-In. | Tons of Iron Melted Per Hour | Cubic Feet of Blast Per Sec. |
|---|---|---|
| 30 | 3 | 25.00 |
| 36 | 4½ | 37.50 |
| 42 | 6 | 50.00 |
| 48 | 8 | 66.67 |
| 54 | 10 | 83.33 |
| 60 | 13 | 108.33 |
| 66 | 16 | 133.33 |
| 72 | 19 | 158.33 |
| 78 | 22 | 183.33 |
| 84 | 26 | 216.67 |
| 90 | 30 | 250.00 |

The volume of blast should be checked by calculation from the blower manufacturer's tables and the speed of the blower. The total area of the tuyeres should vary from one-fifth the cupola area for 36" cupola to one-tenth for 84" cupola, with intermediate ratios in proportion.

With the proper blast, the height of the bed can be permanently fixed; the next problem is keeping the bed at this height through the heat, thereby holding the melting zone in the same place during the run. It has been found in practice that the top of the bed should not vary more than 4 inches to get the best results; therefore,a layer of coke 4 inches thick, regardless of the diameter of the cupola, should be placed between each layer of iron in order that the bed may be held to the correct height by these successive 4 inch layers of coke passing downward and replacing the coke consumed in melting the previous charge.

This brings us then, to the proper size of the charge of iron for the cupola used. Moldenke recommends an easy method of determining this weight. Lay out a circle on the charging floor with circle brick, or cupola blocks, the inside diameter of which is just equal the inside diameter of the cupola. Build the brick up one foot high and fill the space within the circle with coke, leveling off the top as evenly as possible. Weigh this coke, divide by 3, to get the weight of a charge 4 inches high, and this will give the weight of the coke charge to be used.

Now the general average melting ratio, that is the weight of coke required to melt a given weight of iron (not including bed) is 10 to 1; hence, if the weight of the coke charge is multiplied by 10 the result will be the weight of the iron charge to be used. The nearest 100 pounds is close enough for this determination.

To return to our cupola operation, the bed charge is dumped on the fire and allowed to burn until red spots show through, and small flames appear. Charging should begin at this point--pig-iron, heavy scrap, light scrap, and then another layer of coke. The pig iron should be evenly distributed, no pigs crossed over each other, and the scrap charges must be kept level.

If the cupola is to run over half an hour, it should be slagged; to do this, flux should be added in charging. Limestone is the usual material used for fluxing, but this should contain over 95% calcium carbonate and magnesium carbonate or it will not give good results. The amount of limestone to be used depends on the amount of ash in the coke, the sand on the pig iron, the rust and sand on the scrap , and of course, the composition of the flux itself. The usual amount to be charged is from 1% to 2% but more may be necessary if the conditions require it.

The flux should be charged in small pieces, about egg size, and directly on top of each coke charge, spreading it evenly over the coke.

The charging is continued--layers of coke, then limestone, pig-iron and scrap, another layer of coke-- until the cupola has been filled to the charging doors. Charging is continued after the blast goes on and the burden begins to settle in the cupola. The same charges should be used as before, coke, flux, pig iron and scrap, in even layers, until the proper amount required for the foundry has been charged. The charging doors should then be closed for the balance of the heat.

Now the charged cupola should be allowed to stand at least one hour, preferably two hours, before blast is put on, to get all the charges warmed through. The peep-hole covers should be opened to give enough draft to the coke to keep it burning, but not enough to burn away an appreciable amount of the bed. If the coke is slow in burning, the blast may be turned on for a few minutes to give it a good start and then turned off as soon as possible, so that the bed will not be burned away.

When everything is ready in the foundry for handling the iron, the blast is turned on; this should be put on full at the beginning, and continued that way through the heat, unless the iron cannot be handled as fast as melted, or something happens to stop the operations, in which case the blower can be stopped, and the iron will stop melting.

The tap-hole should be open, and be kept open until the iron runs over the spout in a good stream. The time required between "blast on" and when the first iron runs over the spout should be checked to regulate the height of the bed to be used on the following day, as described before.

Allowing the hot gases to blow through the tap-hole also tends to dry it out good and make it hard.

When enough iron has run through the tap-hole to get a good stream, it should be plugged with a small bod of clay, mixed for the purpose. The "bod" is cone shaped, with the point to the front, and is placed on the end of the bod-stick. The melter holds the stick above the stream of iron, not parallel to it, but slanting downward; with a quick motion he jabs the bod downward and forward into the tap-hole, shutting off the stream of iron. The clay becomes hard just as soon as the iron comes in contact with it, sealing up the hole.

When enough iron has melted and collected in the cupola, to maintain a small head of iron on the tap-hole, the ladles should be brought up and the cupola tapped out.

In tapping out, the melter should pick away all ragged pieces of clay around the tap-hole with a short chisel-shaped steel bar; then dig out the clay from the tap-hole with a pointed bar, until the molten iron begins to trickle through;

then run a larger pointed bar into the tap-hole and out several times to remove all obstructions.

If the iron is frozen in the tap-hole, and it cannot be opened by repeated jabbing with the bar, then use the upper tap-hole, mentioned before, and break a hole throught it, using it as a tap-hole until the iron melts in the lower one. If no other tap-hole is available, a hole must be broken through the breast, close to the tap-hole, with a sledge and steel bar. This hole should be kept as small as possible so that the breast will not be torn away any more than necessary. If the breast is badly broken in doing this, shut off the blast, drain the cupola of iron, and build a new breast with a new tap-hole. A few pieces of fresh coke may be placed inside the breast to give a solid backing against which the clay may be rammed, in building the new one. The heat of the burning coke in the cupola dries it out at once, and operations may then be resumed.

After about 30 minutes operation, the slag-hole is opened, and the slag permitted to flow out of it; the hole should be kept open through the remainder of the heat by pulling away the chilled slag with a bar frequently to keep the hole open. The slag should be fluid enough to run out of the slag-hole when it is opened, and enough iron has accumulated to raise the slag to the level of the hole.

When all the iron charged has been melted, or if all the molds in the foundry have been poured off, and no more iron is wanted, the blast should be shut off and the cupola drained of all molten iron. The bottom doors should now be dropped by pulling out the props underneath. All the unburned coke, unmelted iron, and some slag, with the bottom sand, will drop down under the cupola. A stream of water should be turned on this hot mass to keep the coke from burning, and also to cool it off for removal the next day.

This completes the operation for one heat; and the cupola is ready for the next day's work.

If the melting practice is closely watched, and all work around the cupola is consciencciously done, the foundry should get clean, hot iron every day at a minimum of expense, and the defective castings due to poorly melted iron will amount to very little.

Probably it would be appropriate here to explain the calculation of the analysis of the castings wanted, from the analyses of the pig-irons and scrap used.

In foundries where castings of many different kinds are made, all from iron melted in one cupola, the usual method is to make an iron of such an analysis that it will answer the purpose for large and small castings alike, and be readily machinable and strong.

An analysis of this type would be approximately:

| | | | |
|---|---|---|---|
| Silicon | 2.20 | to | 2.40 |
| Sulphur | Under | | 0.05 |
| Phos. | .60 | to | .75 |
| Mn. | .50 | to | .60 |
| Total Carbon | 3.30 | to | 3.60 |

Suppose we had the following pig-irons available:

| Pile No. | Sil. | S. | Phos. | Mn. |
|---|---|---|---|---|
| 1 | 2.82 | .025 | 1.01 | .69 |
| 2 | 2.22 | .021 | .45 | .58 |
| 3 | 2.50 | .035 | .78 | .59 |
| 4 | 2.71 | .038 | .66 | .65 |
| 5 | 2.36 | .028 | .96 | .81 |
| Scrap Analysis | 2.35 | .060 | .70 | .56 |

In ordinary foundry practice the sprues, over-iron, and defective castings returned to the cupola for melting amount to about 25% to 35%. In usual practice 40% to 50% scrap is used in the charge with 50% to 60% pig iron so that some "outside" or foreign scrap is needed to make up the difference.

Suppose the cupola takes a charge of 2000 pounds, and 50% scrap and 50% pig iron are to be used. The calculation of the charge can be made with a table as shown herewith:

| Pile No. | Wgt. Each Charge Lb. | % Sil. | Lb. Sil. | % S. | Lb. S. | % Phos. | Lb. Phos. | % Mn. | Lb. Mn. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 200 | 2.82 | 5.64 | .025 | .050 | 1.01 | 2.02 | .69 | 1.38 |
| 2 | 200 | 2.22 | 4.44 | .021 | .042 | .45 | .90 | .58 | 1.16 |
| 3 | 200 | 2.50 | 5.00 | .035 | .070 | .78 | 1.56 | .59 | 1.18 |
| 4 | 200 | 2.71 | 5.42 | .038 | .076 | .66 | 1.32 | .65 | 1.30 |
| 5 | 200 | 2.36 | 4.72 | .028 | .056 | .96 | 1.92 | .81 | 1.62 |
| Scrap | 1000 | 2.35 | 23.50 | .060 | .600 | .70 | 7.00 | .56 | 5.60 |
| Totals | | | 50.72 | | .894 | | 14.72 | | 12.24 |
| Dividing by 20 | | | 2.536 | | .0447 | | .736 | | .612 |
| Subtract Si & Mn Add S | | | .253 | | .03 | | 0 | | .10 |
| Final Product | | | 2.28 | | .075 | | .74 | | .51 |

Multiply percent of each element by weight of each pile in the charge to get total weight in pounds of each element.

The silicon is decreased in the cupola about 25% through oxidation; the sulphur is increased from the sulphur in the coke, about 3 points or .03% with less than 1% Sulphur in coke, the phosphorus remains the same, and the manganese is decreased about 10 points of 0.10%.

The analysis of the final product, with losses and increases calculated, comes within the limits specified, and hence may be used in the proportions shown in the table.

If the analysis of the product, after casting, differs very materially from that calculated, the analyses of the different piles of pig iron should be checked, and also the amount of each actually charged into the cupola. The man preparing the charges may have made a mistake and put in the wrong proportion of each iron to make up the charge, which, of course, would change the analysis of the product.

In conclusion, it should be remembered that all the minute details of the cupola operation, including charging, must be closely supervised at all times to get uniformly successful heats, and if the results are not what they should be, a close study of the work being done during the whole day around the cupola, will usually reveal the source of the difficulty, and any efforts put forth by the superintendent, or plant engineer, in this direction will be well repaid.

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