1908

Copper smelting in a rotary furnace with pulverized charcoal

Elmer Cooper Heck

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COPPER SINTERING IN A ROTARY FURNACE
WITH
PULVERIZED CHARCOAL.

This process is in use at the Verde Grande Copper Company's plant, located thirty-two miles north west of Hermosillo in the state of Sonora, Republic of Mexico, and is yet experimental.

The process is, in general, as follows: The ore and lime-rock are crushed to pass 1" bar openings and stored in bins to be used when needed, the charcoal to pass 3/4" to 1" openings, and the slag broken to from 2" to 3" size.

The charge is made up of ore, lime-rock, charcoal and slag by weight and dumped into a charge bin just above the charging door of the furnace. From the bin the prepared mixture is charged into a rotating furnace through an iron chute. The smelting is done in this rotating, cylindrical, fire-brick lined furnace, of 2 1/2 to approximately 3 ton capacity, by pulverized charcoal ground in a tube mill to such a fineness that 96 per cent will pass 100 mesh screen. The pulverized charcoal is blown into the furnace through and by means of a blower under a little less than 1/2 oz. pressure. The charge is smelted, with occasional rabbling, through a small door placed in the charging door, in approximately 3 1/2 hours.

When the rotating of the furnace is stopped the furnace, which rests in a steel frame, the frame being supported by trunnions, somewhat similar to a converter, is then tipped down for the settling and collecting of copper at the top hole. After approximately ten minutes time is allowed for settling, the furnace is tapped, running the copper into moulds forming bars of 93 to 96 per cent fineness ready for shipment.
The slag is run into pots where it is allowed to chill, having sufficient pots to hold one furnace charge, and then wheeled to a near by dump, dumped out of the pots, broken up and thrown over the dump. By these means, considerable copper, which settles to the bottom of the pots, is saved. More time is not given to the furnace for settling when rotation is stopped on account of the blast melting off or the draining off all the slag which adheres to the brick long enough during rotation, to protect them, such seems to considerably increase the time of the use of the brick in the furnace.

The patent of this class of furnace is owned and the furnace is manufactured by The Miners Smelting Furnace Company of New York.

The mines from which the ore is taken for smelting are owned by the company and consist of three separate workings from a mile to a mile and a half from the plant. The plant is so located as to give about an equal haul from the three workings. The workings are the Verde Grande, Cobriza, and Verde Chico.

ORE:

The ore is practically free from smelter interfering elements with the exception of some of the Verde Chico ore which contains Arsenic and Antimony. On account of these elements entering the copper bullion to some extent, the copper bullion produced was proportionately lower in fineness. Such ore was used in small amounts in charge, thus working up the objectionable ore and avoiding as much as possible the penalty on bullion when sold.

The Verde Grande carries less than one per cent ZN.

The ore consists of some oxide of copper, though most of the copper is in the form of carbonates, as Azurite and Malachite.

The silver is part native; and part cerargyrite, the latter greatly predominating.

The gold is in a free state.
The ore is decidedly "spotted" in silver and gold and for such reason difficult to get an average sample; in copper the ore assays very even.

OCCURRENCE OF ORE:

The ore occurs in deposits in an altered lime with a garnet gangue, twenty-five to one hundred feet from a granite-lime contact.

This applies especially to the Verde Grande on which considerable development work has been done and several thousand tons of ore blocked out.

The workings consist of a tunnel with cross-cuts and an upraise. The tunnel cuts the ore body securing about two hundred feet depth.

The Cebriza has only surface workings and such has exposed small but rich deposits.

The Verde Chico is near and somewhat similar to the Verde Grande though the latter carries no Arsenic or Antimony. Considerable surface work has been done on this property.

Sulphides will probably be found with depth, as a property thirteen miles to the north and one seven and a half to the south with similar surface showings have sulphides at about four hundred and fifty feet depth and one hundred and seventy-five feet depth respectively.

The country rock has been considerably broken up and in the basins of the folded lime which are comparatively soft and somewhat shattered, occur the copper deposits.

The three workings lie in the same mineral belt extending north west and south east.

The ore is mined and trammed to bins near the workings at the Verde Grande and Cebriza, from where it is hauled to the Smelter in large wagons of four to six tons capacity, drawn by twelve mule teams. These workings are reached by a good wagon road. The Verde Chico is reached by burro trail over which the ore is packed by burros to the Smelter.
The delivery of all ore is paid for by weight.

The lime rock for flux is quarried near the Smelter and hauled in carts.

The ore is stored in bins or piled on the dump above the Smelter to be used as needed. As there are from four to five consecutive months of dry season and cheap Mexican labor is available, storage bins are not an important factor.

CHARGE:

As black copper varying from 93 to 95 per cent fine is produced in the furnace, at one operation, the slag calculation is a very simple matter, merely balancing the SiO2, FeO and CaO in the proportion that will effect the greatest saving, and also commensurable with the capacity and ratio of available ores.

The slag was calculated for the following ratio:

<table>
<thead>
<tr>
<th></th>
<th>SiO2</th>
<th>FeO</th>
<th>CaO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>44</td>
<td>18</td>
<td>28</td>
</tr>
</tbody>
</table>

ORE ANALYSIS:

<table>
<thead>
<tr>
<th></th>
<th>SiO2</th>
<th>FeO</th>
<th>CaO</th>
<th>Al2O3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verde Grande</td>
<td>35.1</td>
<td>11.5</td>
<td>22.2</td>
<td>7.1</td>
</tr>
<tr>
<td>Cobrizo</td>
<td>39.0</td>
<td>10.2</td>
<td>20.0</td>
<td>6.4</td>
</tr>
<tr>
<td>Lime Flux</td>
<td>18.1</td>
<td>1.3</td>
<td>40.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Calculating for slag of the above ratio, it is found that 2/3 Verde Grande to 1/3 Cobrizo is the proportion, and for a charge there is use for 3740 lbs. of Verde Grande to 1868 lbs. of Cobrizo with 220 lbs. of lime rock for flux. Slag and Charcoal are also used in the charge, slag to assist fusion, etc, and the charcoal to reduce the copper oxide, which forms on the disassociation of the carbonates by heat; preventing the copper from entering the slag as the oxide and causing copper loss.

It was assumed in the slag calculation that the SiO2, FeO, CaO of the slag would sum up to 90 per cent. This was after proven by slag analysis to be practically correct.
The following table was found convenient both in checking slag calculation and changing charge to different slag ratio of SiO2, FeO, and CaO.

Can also be used in a tentative way for slag calculation.

<table>
<thead>
<tr>
<th>Ore</th>
<th>lbs. ore</th>
<th>%SiO2</th>
<th>lbs. SiO2</th>
<th>%FeO</th>
<th>lbs. FeO</th>
<th>%CaO</th>
<th>lbs CaO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verde Grande</td>
<td>3740</td>
<td>35.1</td>
<td>1313</td>
<td>19.3</td>
<td>654</td>
<td>23.2</td>
<td>868</td>
</tr>
<tr>
<td>Cobriza</td>
<td>1868</td>
<td>39.0</td>
<td>728</td>
<td>10.2</td>
<td>191</td>
<td>20.0</td>
<td>374</td>
</tr>
<tr>
<td>Lime-rock flux</td>
<td>220</td>
<td>16.1</td>
<td>40</td>
<td>1.3</td>
<td>3</td>
<td>40.0</td>
<td>88</td>
</tr>
</tbody>
</table>

\[
\text{SiO}_2 + \text{FeO} + \text{CaO} = 4732 \text{ lbs. of SiO}_2, \text{FeO} \text{ and CaO in the slag. Since this is 90\% of the slag, 4732 divided by 90\% equals 4732 lbs., weight of slag per charge of 5828 lbs. of ore and flux of lime-rock.}
\]

Then 2081 lbs. of SiO2 divided by 4732 equals 44\% SiO2

\[
\begin{align*}
848 & \quad \text{FeO} \quad 4732 \quad 18\% \text{FeO} \\
1330 & \quad \text{CaO} \quad 4732 \quad 28\% \text{CaO}
\end{align*}
\]

The ash from charcoal being small was neglected.

Note: The FeO, Al2O3 and CaO occurring with garnet, a large part especially Al2O3 and CaO are in combination with the Silica in the form of a Silicate, hence the high slag ratio to the pounds of charge.

The following full charge was made up.

<table>
<thead>
<tr>
<th>Pounds.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verde Grande ore</td>
</tr>
<tr>
<td>Cobriza</td>
</tr>
<tr>
<td>Lime-rock</td>
</tr>
<tr>
<td>Slag</td>
</tr>
<tr>
<td>Charcoal fines to 1&quot; size</td>
</tr>
</tbody>
</table>

A large excess of charcoal was used to insure total reduction of copper oxide, while this amount is greatly in excess of the theoretical amount necessary to reduce the copper oxide present in the charge, a series of experiments varying the amount of charcoal, other conditions
remaining the same, gave the best results from the above proportion, the amount of charcoal varied with the amount of copper in the charge, the more copper in charge the more charcoal is needed.

The charcoal also served as a reducing agent for the silver chloride. All the charcoal is not available for reduction as some is burned and some is consumed by the lime rock. The charcoal is well mixed with the ore in the charge by the rotation of the furnace thus giving favorable conditions for reduction, being brought in contact and thoroughly mixed with the ore. This probably prevents loss of silver due to volitilization of silver chloride. The low blast being less than 1/2 oz. pressure is also favorable to lessen loss by volitilization and flue dust.

Time for treating a charge and Charcoal used:

Under the most favorable conditions it will take four hours to charge furnace, smelt, and discharge; each charge being the maximum of 2.8 tons of ore. Allowing thirty minutes for charging, rabbling, and topping would leave three hours and a half of continuous blast and charcoal feed. Using 8 lbs. of charcoal per minute would require 1680 lbs. of charcoal per 2.8 tons of ore treated, or 600 lbs. per ton.

Proportion of Charcoal to air in blast:

One pound of charcoal of 80% carbon, feed into furnace, with blast, through the blower requires theoretically, for complete combustion to burn all C to CO2, about 122 cu. ft. of air; to burn all C to CO about 61 cu. ft. of air.

With 100 cu. ft. of air delivered per pound of charcoal, for 8 pounds of charcoal feed to the furnace per minute, would be required 800 cu. ft. of air per minute.

The blower delivers just a little more than 800 cu. ft. of air at 1200 revolutions per minute. This gives theoretically a fairly
strong reducing atmosphere and in connection with the 165 lbs. of charcoal in charge, has been found to work satisfactorily.

Note: No correction was made for altitude and temperature in calculating proportion of charcoal and air.

A higher proportion of air might give a higher heat but the reducing atmosphere would become more feeble in proportion, so the increase.

SLAG:
While a basic slag smelts more easily and gives larger tonnage by being more fusible and running readily, it has a feeble reducing action and though by such action giving a pure black copper almost free from iron, which is desired, these conditions may be dearly bought.

A more acid slag and a more powerful reduction in the furnace lessens the loss of copper in the slag as Cu2O and is more than enough to compensate for the reduced iron which may enter the black copper.

The silicious slag is also lighter thus giving a better separation of the slag and metallic copper.

The average in per cent of FeO slag is as follows:

<table>
<thead>
<tr>
<th>SiO</th>
<th>FeO</th>
<th>CaO</th>
<th>Al2O3</th>
<th>Cu</th>
<th>ZnO</th>
<th>MgO</th>
<th>MnO</th>
<th>Ag</th>
<th>AN</th>
</tr>
</thead>
<tbody>
<tr>
<td>44.2</td>
<td>18.0</td>
<td>28.5</td>
<td>6.5</td>
<td>0.44</td>
<td>1.0</td>
<td>0.6</td>
<td>0.5</td>
<td>0.9</td>
<td>oz./ton</td>
</tr>
</tbody>
</table>

The ore treated averaged:

8.73% Cu, II.66 oz. Ag per ton, 0.055 oz. AN per ton.

Giving a saving of 86.4% Cu
92.3% Ag
98.0% AN

As 5828 lbs. of ore, neglecting the lime-rock, will give
4732 lbs. of slag, a slag of this ratio assaying 0.9 oz. Ag per ton on II.66 oz. Ag per ton ore gives a loss of ag. in the slag of 6.2% or a saving of 93.8% of the silver. 92.3% of silver was saved thus leaving 1.5% Ag loss due to volitilization and mechanical cause. The flue
dust loss is very low due to low blast.

The average in % of Met. slag is as follows:

<table>
<thead>
<tr>
<th>%SiO2</th>
<th>%FeO</th>
<th>%CAO</th>
<th>%Al2O3</th>
<th>%Cu</th>
<th>%Zno</th>
<th>%Mgo</th>
<th>%Mno</th>
<th>%Ag</th>
<th>%An</th>
</tr>
</thead>
<tbody>
<tr>
<td>44.8</td>
<td>17.8</td>
<td>27.9</td>
<td>6.6</td>
<td>0.52</td>
<td>1.3</td>
<td>0.6</td>
<td>0.4</td>
<td>0.8</td>
<td>tr.</td>
</tr>
</tbody>
</table>

The ore treated averaged:

6.3% Cu, 8.5 oz. Ag per ton, 0.034 oz. An per ton.

Saving in Cu 85.5%

Ag 90.0%

An 95.8%

Though the average of the Met. slag is close to that of FeO, by adding an ore higher in Silica, some charges were run up much higher in Silica than the average, and then by changing to a more basic ore the Silica ran as low as 42.5%.

It appears that the average loss in value in slag is about the same as the above charges; but on a low grade ore the per cent of loss is correspondingly increased, as the ore decreases in value, with the same per cent and oz. loss in slag as on a high grade ore.

The following is a number of analyses of slag during March:

<table>
<thead>
<tr>
<th>% SiO2</th>
<th>%FeO</th>
<th>%CAO</th>
<th>%Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>46.8</td>
<td>18.0</td>
<td>27.5</td>
<td>0.46</td>
</tr>
<tr>
<td>46.4</td>
<td>18.0</td>
<td>26.8</td>
<td>0.48</td>
</tr>
<tr>
<td>46.7</td>
<td>17.3</td>
<td>26.7</td>
<td>0.49</td>
</tr>
<tr>
<td>48.2</td>
<td>15.3</td>
<td>26.0</td>
<td>0.54</td>
</tr>
<tr>
<td>48.8</td>
<td>15.2</td>
<td>25.9</td>
<td>0.74</td>
</tr>
<tr>
<td>47.6</td>
<td>15.5</td>
<td>26.6</td>
<td>0.65</td>
</tr>
<tr>
<td>47.0</td>
<td>15.2</td>
<td>27.3</td>
<td>0.53</td>
</tr>
<tr>
<td>47.7</td>
<td>15.4</td>
<td>26.1</td>
<td>0.54</td>
</tr>
<tr>
<td>42.8</td>
<td>19.3</td>
<td>28.5</td>
<td>0.42</td>
</tr>
</tbody>
</table>
The high silicious slags did not give a liquid fusion, were thick and ran slowly, also considerable mush slag was drawn at the last when the furnace was tapped. The "mush" slag analyzed as follows:

<table>
<thead>
<tr>
<th>%SiO2</th>
<th>%FeO</th>
<th>%CaO</th>
<th>%Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>42.5</td>
<td>19.6</td>
<td>28.5</td>
<td>0.43</td>
</tr>
<tr>
<td>42.6</td>
<td>19.2</td>
<td>28.7</td>
<td>0.42</td>
</tr>
<tr>
<td>43.5</td>
<td>18.6</td>
<td>28.8</td>
<td>0.43</td>
</tr>
<tr>
<td>43.5</td>
<td>18.4</td>
<td>28.9</td>
<td>0.43</td>
</tr>
<tr>
<td>42.0</td>
<td>18.9</td>
<td>29.2</td>
<td>0.36</td>
</tr>
<tr>
<td>42.1</td>
<td>19.0</td>
<td>29.4</td>
<td>0.36</td>
</tr>
<tr>
<td>43.0</td>
<td>19.2</td>
<td>28.6</td>
<td>0.42</td>
</tr>
<tr>
<td>43.1</td>
<td>18.7</td>
<td>28.8</td>
<td>0.44</td>
</tr>
<tr>
<td>42.7</td>
<td>18.5</td>
<td>28.9</td>
<td>0.36</td>
</tr>
<tr>
<td>43.5</td>
<td>18.2</td>
<td>29.0</td>
<td>0.39</td>
</tr>
</tbody>
</table>

This slag which amounted to about 200 lbs. per charge was recharged, from time to time, with a charge giving a more basic slag, which worked satisfactorily, giving a good fusion and a clean slag.

Slags containing over 45% SiO2 did not yield to acid treatment but had to be fused with Na2CO3 for accurate determinations.

A fusion was made on the SiO2 of a slag of the following ratio:

<table>
<thead>
<tr>
<th>SiO2</th>
<th>FeO</th>
<th>CaO</th>
</tr>
</thead>
<tbody>
<tr>
<td>43.9</td>
<td>19.4</td>
<td>25.9</td>
</tr>
</tbody>
</table>

All ores for accurate SiO2, FeO and CaO also Al2O3 determinations had to be fused as part of the FeO CaO and Al2O3 are combined with the SiO2 as Silicates. Charges for this reason being high in SiO2 and CaO also having 5 to 6% Al2O3 are difficult to fuse.
APRIL SLAGS:

Up to date these slags analyzed as follows:

<table>
<thead>
<tr>
<th>SiO₂</th>
<th>FeO</th>
<th>CaO</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>42.0</td>
<td>19.6</td>
<td>28.8</td>
<td>0.4</td>
</tr>
</tbody>
</table>

The slag flows readily and is then of sufficient light sp. g to give a good separation.

Slags running as follows:

<table>
<thead>
<tr>
<th>SiO₂</th>
<th>FeO</th>
<th>CaO</th>
</tr>
</thead>
<tbody>
<tr>
<td>44.0</td>
<td>18.0</td>
<td>28.0</td>
</tr>
</tbody>
</table>

with a high heat gave as low as .28% Cu in the slag.

Theoretically this approaches very nearly the ideal conditions as an excess of charcoal was used in blast in attempting to get a high heat for considerable time, thus giving a strong reducing action with a silicious slag. The blower was also run at greater speed. However, such was anything but ideal from a commercial point of view.

All conditions being considered, it is found that the ratio:

<table>
<thead>
<tr>
<th>SiO₂</th>
<th>FeO</th>
<th>CaO</th>
</tr>
</thead>
<tbody>
<tr>
<td>42.0</td>
<td>20.0</td>
<td>28.0</td>
</tr>
</tbody>
</table>

gives the best satisfaction metallurgically though commercially such is not always possible.

The records show charges run on the following ratio in the slag:

<table>
<thead>
<tr>
<th>SiO₂</th>
<th>FeO</th>
<th>CaO</th>
</tr>
</thead>
<tbody>
<tr>
<td>36.0</td>
<td>33.0</td>
<td>12.0</td>
</tr>
</tbody>
</table>

the slag ran from 2 to 3 % Cu and in some cases no copper was produced. The latter condition was due, no doubt, to lack of sufficient difference of sp. g between metallic copper & the slag, due to high iron in slag. The former condition to give a separation was probably due to lack of sufficient reducing action in the furnace.
II.

FUEL FOR FURNACE.
The fuel is pulverized charcoal, the charcoal is obtained by burning iron wood and mesquite in adobe kilns.

The wood is cut and delivered by Mexican ranchers and is paid for by weight per cord.

The weight of a cord of each kind of wood was found by close piling of exactly a cord of wood, by measure, and then weighing same, giving for iron wood 4400 lbs. and for mesquite 3600 lbs. By these means the cost was saved of piling the wood for measurement which in careful work is no small item but cheaper by far than paying for wood loosely piled, the sticks being crooked, also the business relations with the Mexican wood men proved more satisfactory.

The wood consists of sticks 2 to 2 feet in thickness and is piled as closely as possible consistent with rapid work in filling the kiln, the crooked sticks being cut so as to take up as small amount of space as possible. The kilns are 12 ft. by 50 ft. by 10.6 ft. high with a three foot segment for a roof. With a 56 cord space, 48 cords is the greatest amount of wood that can be piled in the kilns consistent with rapid work. This amount of wood yields about 35 to 36 tons of charcoal. The wood is burned in the ratio of 10% mesquite to 90% iron wood. A cord of wood yielding 1500 lbs. of charcoal weighing about 29 lbs. per bushel.

Kilns:
The kilns are 50 ft. by 12 ft. by 10.6 ft. with a three foot segment for a roof making about 12 ft. in height. There are two kilns completed and two being built.

The kilns now being built are of the same dimensions but have a semi-circle formed roof which will lessen the pressure on the side walls and decrease their tendency to crack.
The kilns are built of adobe sun dried brick and adobe mud, on a rock foundation. The walls are 18" thick and the roof 8". The kilns are braced with nine 8" by 6" posts set at the side and tied at the top just above the roof with 1/2" iron rods and hooks.

At the bottom of the kilns there are, on each side, eight 6" by 6" openings and two in each end, while five feet from the bottom there are eight 2 1/2" round openings and two in the end, while five feet above these there are the same number "docked" in position. In regard to the former, these are for draft and to control the rate of burning by stopping them up in case of too rapid burning.

There are three openings in the top of the kiln 8" by 8".

**Filling the Kilns.**

Just under each opening of the top the wood is built up of large sticks in the form of a crib about 1 1/2 ft. by 1 1/2 ft. square. The wood is piled in the beginning at one end and working to the other end as the kilns are filled. The crib work is built up as the openings are reached. This crib or chimney extends from the floor to the roof under each opening, in the roof. When full the doors are stopped up with adobe brick and adobe mud and later when dry are plastered over with mortar.

**Firing the Kilns.**

When the kilns are filled and the doors closed up, fire is dropped through the openings of the roof to the floor inside the chimney or crib where it ignites with the kindling previously placed at the bottom of the crib. In about two hours the burning of the wood is well begun. The draft which governs the rate of burning is controlled by closing the 2 1/2" opening on the sides and ends of the kilns. At the bottom, on sides and ends the 8" by 8" openings are closed just as soon as the first ashes appear. All openings are ready to be closed air tight with adobe and adobe mud when the bottom openings are closed.
The slow fire with drafts carefully regulated burns for about four days and then all openings are closed air tight and after drying are plastered over two or three times with mortar from time to time to insure the kilns being air tight. In about ten days, the fire is smothered and the charcoal is ready to be taken out and spread to cool in the charcoal yard. In case the fire has not been completely smothered and starts into a blaze on opening the kiln, it is put out with the smallest amount of water possible. A small amount of water used after the charcoal is thoroughly dry does not seem to interfere with the subsequent effective burning of the charcoal in the furnace. The fire brands or unburned pieces of large sticks of wood are piled into the next kiln which is filled.

When the charcoal is cool, it is ready to be hauled to the charcoal storage room which is 60 ft. by 30 ft. by 25 ft. It is never filled, as in case of spontaneous combustion due to the fine dust accumulating, it is necessary to dig down to the place of the fire and put it out.

**MAKING OF ADOBE BRICK.**

These bricks are made of adobe earth mixed with water to the consistency of a medium stiff mud, mixing in two or three handfuls full of dry grass or straw to each brick for binding. They are then shoveled into a wooden mould 4" by 8" by 18" and pressed down and smoothed off on top by hand. The wooden frame contains three moulds. The frame is carefully removed so as not to break the brick. The bricks are left until sufficiently dry, which takes about 1/2 day, to set up an end for more rapid drying. After this is done in three days of dry weather and sunshine, the bricks are ready to use. The adobe mud, used as mortar in laying the brick, is made by screening the adobe earth through a 1/4" screen rejecting the part that is too coarse to pass the screen.
The fine material is mixed with water to the right consistency when ready for use and the adobe bricks are laid in the mud. Such make fairly strong and lasting walls.

A good adobe earth is light, consists of a fairly good clay that will give adhesion with little or no iron oxide and enough sand and gravel to prevent cracking.

VALUE OF THE BY-PRODUCTS FROM CHARCOAL BURNING.

One cord of hard wood will yield by destructive distillation fifty bushels of charcoal. At $30.00 a bushel, 10 gallons of alcohol (crude) containing Acetone, 200 lbs. of acetate of lime, and about 20 gallons of tar. This will give a gross value for the by-products, excluding charcoal, of about $9.00 a cord.

CRUSHING OF CHARCOAL.

The charcoal is now crushed to about 3/4- to 1" size by Mexican laborers with a kind of tamping bar with a broad heavy circular flange on the tamping end about five feet in diameter. Such work being necessary until the preliminary crusher arrives.

A screen test of the charcoal passing through a pulverized crusher has been made and is given below.

The preliminary crush in conjunction with the tube mill will pulverize over 20 tons of charcoal in twenty-four hours and such is more than ample to keep four furnaces running.

PULVERIZING IN TUBE MILL.

The charcoal crushed by hand is now carried up to a bin and dumped, from the bin it is fed into an adobe tube mill by an automatic feeder. The tube mill makes 27 revolutions per minute and uses 20 horse power. On coarse material the mill grinds enough charcoal in eight hours to keep a furnace continually running. The screen shows that 96% of the charcoal coming from the tube mill will pass a 100 mesh screen. The charcoal coming from the tube mill is screened and an
Elevator carries the fine to a storage bin, from where it empties direct into one specially constructed charcoal bin and into another is conveyed by a worm conveyor. From these specially constructed iron bins the charcoal is fed by means of a worm feed, the speed of which is regulated by cone pulleys, into a blower which with the air blast is forced into the furnace through a rubber hose of 8" diameter.

The rubber hose permits the furnace to be tipped up for charging and down for tapping.

The special charcoal constructed bins were designed to prevent packing of the charcoal and give fairly good satisfaction.

# I. SCREEN TEST OF CHARCOAL:

Preliminary crusher, with 1/8" bar openings.

- Passing a 100 mesh screen: 22.9%
  - 90 ": 30.5%
  - 80 ": 31.0%
  - 60 ": 31.8%
  - 40 ": 38.8%
  - 30 ": 49.0%

All would pass an 8 mesh screen.

#2 Preliminary crusher with 1/16" openings.

- Passing 100 mesh screen: 27.4%
  - 90 ": 30.0%
  - 80 ": 33.7%
  - 60 ": 37.0%
  - 40 ": 44.7%
  - 30 ": 59.1%
#3. Tube Mill screw test charcoal 1/2"-1" size feed.

<table>
<thead>
<tr>
<th>Mesh Size</th>
<th>Passing (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>96.0%</td>
</tr>
<tr>
<td>90</td>
<td>97.1%</td>
</tr>
<tr>
<td>80</td>
<td>98.6%</td>
</tr>
<tr>
<td>60</td>
<td>99.1%</td>
</tr>
<tr>
<td>30</td>
<td>99.9%</td>
</tr>
</tbody>
</table>

FURNACE FOUNDATION:

There are now two furnaces installed and room for two more. The foundations are of cement set on bed rock, with stay-bolts passing through the cement and anchored in the bed rock; the dimensions of the foundations are shown in the drawing.

CONSTRUCTION OF FURNACE:

The furnace, a shell, is constructed of 1/2" steel which forms a horizontal cylinder and is lined with fire brick 8" thick. The cylinder is 7 ft. in diameter and 9 ft. in length, with steel heads at the ends, and is encircled with two 2" rails which rest upon anti-friction rollers that are attached to a steel frame in which the cylinder rests.

The steel frame is attached to two trunnions, on each side, which resting upon two legs support the entire structure similar to a converter. A bevel gear in a gear housing is attached to one of the legs of the furnace and a pulley attached to this gearing is connected to a counter shaft pulley by a belt which serves to tip the furnace up to receive the charge and down to pour the copper and slag.

Attached to the lower part of the frame is a gear for revolving the cylinder. The gearing consists of a worm wheel which turns a cog wheel with angle set cog to fit the worm and is operated by sprocket wheel or pulleys and a sprocket chain. The cog wheel is keyed to a shaft which in rotating turns the two anti-friction rollers which are also keyed to the shaft, and upon which the cylinder rests on one side, thus rotating the furnace.
The sprocket chain is connected to a counter shaft on which is an "Idler" by which the rotating of the furnace can be started or stopped instantly.

The furnace is held in position in tipping up for charging and down for pouring by four rollers, two of which are attached on each side of the cylinder to a frame near the trunnions in counter position; and by a rail which is attached to and encircling the furnace which runs between these rollers. The furnace is constructed for 2 1/2 ton capacity.

WATER JACKET:

Is placed in the center of the back end of the cylinder and remains stationary while the cylinder revolves. The jacket is supported by two braces attached to the frame and the top of the chimney, the chimney being attached to the water jacket, and by a series of rollers and riding rings.

The tuyere enters the cylinder through the water jacket and is contracted above and below and widened at the sides, giving 9" by 6" dimensions. This tends to spread the blast on entering the furnace. Just above the tuyere is an approximately semi-circle shaped opening 6" high and 15" wide which opens into a chimney.

CHIMNEY:

The chimney which is 4 ft. in height is made of sheet-iron and lined with fire brick giving 15" by 24" dimensions inside the brick. This chimney carries the flame and gases to the stack. The stack in use for experimental work is 2 1/2 ft. in diameter and twenty feet high. A down take may be used or a passage for conducting the flame and hot gases to the boiler, thus utilizing the waste heat to make steam. Whether the hot flame and gases carrying dust would cause this passage also tubes in boiler to clinker or not and if so to what extent, would necessitate the experiment to obtain such information.
THE LINING OF THE FURNACE.
The lining is made of the most refractory brick, high in silica and low in base, such being necessary on account of the slag running high in silica, as such slag would take up the bases in the brick causing the brick to wear rapidly.

The lining is the most expensive part of all the repairs about the plant, as such being brought from the United States with freight, duty and original cost makes it prohibitive only for experimental work.

The bricks are 8" thick and made to fit the shape of the cylinder.

There is plenty of shale and an almost pure quartz ledge near the plant, and with clay at $12.00 a ton a lining with a brick machine can be made and put in the shell for $20.00 per lining.

The head lining upon which the blast is impinged lasts from ten to twelve days of six charges of 2.8 tons each. The side and back end last from twenty to twenty-two days.

At the end of such time, the brick become thin and permit so much radiation of heat that it is necessary to re-line the furnace.

The copper in settling will chill when the brick are thin thus leaving considerable "mushy" copper in the furnace when the furnace is tapped also increasing the loss in slag.

OPERATION:
The charging end has two doors, a large door and in center of this large door is a small door.

In charging, the furnace is first heated, then the blast and charcoal blown through the furnace with the small door open until the brick becomes hot enough to ignite the coal when blown in with the blast. The door is then closed and the furnace is heated up to a good light red heat. The large door of furnace is then opened and the furnace tipped up and the charge previously made up by weight and dumped into
a charging bin with a pointed bottom, is then run into the furnace thro.
a sheet iron chute. The cold charge being suddenly added the furnace is chilled so it is necessary on closing the large charging door to open the small door like in the first heating up and allow the blast and charcoal to pass through the furnace until the brick are sufficiently heated to cause a continuous combustion, when the blast and charcoal are impinged upon the head of the furnace with the small door closed. This prevents "puffing" in the furnace and blowing back the charcoal and blast through the blower from the sudden expansion of air from intermittent combustion.

The furnace is started to rotating as soon as 2/3 of the charge is put into the furnace.

When the end is sufficiently heated, the small door is closed and the ore smelts until it begins to form a fairly liquid slag when the small door is again opened and the slag thoroughly rabbled, breaking up all lumps or balls that occur from unfused parts becoming coated with slag and "balling" due to the rotation of the furnace.

This takes only a few minutes and the slag is then ready to draw in twenty minutes after the rabbling under favorable circumstances. The blast and charcoal is again turned on after rabbling and is continued up to and during part of the drawing of the charge.

When a good fusion, which takes from 3 1/2 to 3 3/4 hours of continuous blast and charcoal feed, is secured the rotation of the furnace is stopped and the furnace tipped down for tapping or drawing the charge.

The furnace charge is now allowed to settle from 5 to 10 minutes so the metallic copper will precipitate to the bottom of the hearth and collect at the tap hole.

The lute in the tap hole is broken through with an iron bar, and in case the copper is chilled by the bar preventing a flow of the
copper into the mould placed under the tap. A pointed stick of hard wood is inserted to increase the size of the opening and break the crust of chilled copper. The copper flows from the furnace into the mould which has been previously heated and coated with a mixture of ashes and adobe thin mud. This prevents the metallic copper sticking to the mould. After all the copper has run out of the furnace about an inch of slag is permitted to run into the mould covering the copper then it is allowed to cool somewhat and dumped from the mould into water. The sudden chilling causes the slag to fall away from the copper leaving the bar a bright copper color.

The bars are then weighed and piled ready for shipment.

When all the copper has run out of the furnace, on tapping, the flow of which is told by its bright color and rapid running, the slag follows having a darker red color and slower flow.

The slag is run into slag pots and rolled to one side and allowed to chill then is wheeled to a near by dump and the cone of the chilled slag dumped, broken up and thrown over the dump. Considerable copper is in this way saved by the settling in the pots. A large slag pot holding a full charge would no doubt effect a better saving as thus could save the slag shell as well as the copper settling to the bottom. Close examination of the slag in the pots shows that nearly all the "shot" copper collects, on account of the attraction of the iron, at or near the iron sides of the slag pots or within 1/4 to 1/2" of the iron.

This shell of slag could be from a large pot easily saved and charged back into the furnace in place of the slag now used.

With a track and a mule the cost of disposing of the slag would be considerably less.

When the slag has all flowed out of the furnace, the charging door is opened, the chimney cleaned, any accretions that may be adhering
to the water jacket "barred" off, furnace tilled up ready to receive
the next charge.

POWER:

Steam power is used, two Allis-Chalmers Company's engines,
one with a steam cylinder of 5" by 12" making 150 revolutions, the other
with a steam cylinder 12" by 16" making 150 revolutions per minute,
taking steam from one of the two tubular fire return boilers fired
alternately of estimated 100 horse power steaming capacity, furnish the
power.

The small engine furnishes power to run an 8" by 12" Dodge
rock crusher requiring 8 H.P.; I set of 12 1/2" by 12" rolls requiring
3 1/2 H. P.; I set of 24" by 10" rolls requiring about 8 H.P.; I sample
requiring 2 H.P.; giving 21.5 H.P. for the small engine rated at 25 H.P.

The large engine furnishes power to run the tube mill requiring
20 H.P.; elevator requiring 3 H.P.; two furnaces requiring about 8 H.P.
each; two feed conveyors 1/2 H.P. each; two buffalo #5 blowers 2 H.P.
each making a total of 44 H.P.

Three and a half cords of wood are used per twenty-four hours.

WATER SUPPLY:

A well 90 ft. deep, 4 ft. by 4 Ft. inside curb measurements
supplies an abundance of water for camp use, boilers and Smelter, besides
irrigating about an acre of garden and watering possibly seventy-five
head of stock per day. A #6 Cameron pump with about 60 gallons per
minute capacity pumps the water from the well into four storage tanks.

A tin tank of 12,000 gallons capacity is located on a hill
just back of the Smelter giving sufficient head to deliver water all over
camp by pipe line. Another tin tank of 6000 gallons with two wood tanks
of 8000 and 4000 gallons capacity each store water for the boilers and water
ejacket.
Two to three gallons are used per minute by the water jacket, running into a sump from the jacket discharge from where it is pumped back to the tanks, the such water is first pumped into a kind of cooler allowing the water to trickle down into the tanks for cooling. There are two feed water pumps for the boilers, also a heater.

With four furnaces allowing installed giving a daily capacity of 45 tons, allow one furnace to be out of commission for repairs necessary to the furnaces from time to time, have the following estimated cost; Estimated cost of complete plant $35,000.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated cost of treating I ton of ore in plant</td>
<td>$4.45</td>
</tr>
<tr>
<td>&quot;&quot; mining I ton of ore in plant</td>
<td>$3.00</td>
</tr>
<tr>
<td>&quot;&quot; hauling I ton of ore in plant</td>
<td>.75</td>
</tr>
</tbody>
</table>

Interest on the investment per ton 40

Total cost of treating I ton of ore $8.60

The above process is only applicable to isolated mining camps where cost of transportation of ore to Smelter or coke to the mine is prohibitive.

The small capacity makes the process expensive in comparison to the water jacket blast furnace, tho on a carbonate ore producing blister copper at one operation the loss in the slag is much less than that of the blast furnace.

The above is submitted to the FACULTY OF THE SCHOOL OF MINES for degree in Mining Engineering.

E. C. Neely
June, 1908.