

T H E S I S

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C O P P E R S M E L T I N G  
A S P R A C T I C E D A T  
D O U G L A S , A R I Z O N A

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Submitted by

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In partial fulfillment of the requirements

for the Degree of Master of Science

Colorado Agricultural College

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GRADUATE WORK

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER  
MY SUPERVISION BY David K. Ingman

ENTITLED COPPER SMELTING AS PRACTICED AT  
DOUGLAS, ARIZONA

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS  
FOR THE DEGREE OF Master of Science  
in Trade and Industrial Education

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David King Ingman

Douglas, Arizona

May 12, 1931

CHAPTER I  
PROBLEM AND OBJECTIVES

Copper was the first metal used by man in fashioning his implements of both peace and war. Thru the centuries of industrial development its uses have increased and been multiplied until today it holds a place of importance second only to the products of iron ore.

From the ship's bottom to its wireless antennae, from the depths of a mine to the observeratory atop the mountain, on land, on the sea, or in the air, copper plays its part.

This thesis gives an accumulation and compilation of facts concerning the art of copper smelting as practiced in the most productive district of the greatest copper producing State of the Union, Douglas, Arizona.

The material is presented with a four-fold objective:

For use in the study of copper production:

First: As an aid to those seeking information that will help in the selection of a life work.

Second: As an aid to those thinking of entering any of the numerous branches of the industry.

Third: For smelter employees seeking advancement in their work.

Fourth: As supplementary material for school studies in economics, in commerce and industry, and in the sciences.

It is then, the problem of this thesis to present a study of actual copper smelting. In order that the writer should be able to accurately present this work, and speak with authority concerning the processes involved, it was necessary to spend much time at the smelters watching and studying each operation. A period of employment as a mechanic at one of the Douglas smelters afforded excellent opportunity for observation of all phases of the operation of the plant. Conferences, on the job, with foremen and workmen brought out the details of the specific steps in the production of copper bullion from the ore. The available books on the subject are quite out of date, but much valuable information of a technical nature was obtained from magazines devoted to mining and smelting. After the thesis was complete it was

submitted to the Superintendent of the Copper Queen smelter for criticism and correction.

Before going into the study of methods of copper production it may be well to review some of the more outstanding uses of this metal. About 75 percent of American industry is electrified, and the use of electricity is directly dependent on copper. Among the non-precious metals, copper is the best conductor of electrical current for power and light. Banish copper and our cities and manufactories would be plunged in darkness; the wheels of industry would stop not only because of lack of power but because of the disappearance of the brass and bronze bearings supporting those wheels; lack of transportation facilities would precipitate the greatest famine of all time; and even our systems of water supply would fail. Turning to the telephone to inquire as to the cause of the failure of our accepted comforts we would find the telephone useless; no telegraphic reports of conditions in general would come to us; and it would be impossible to broadcast the news by radio. Given time our men of science would put into use substitutes for the red metal, but so far as we now can see the industrial world could never return to its present state of

efficiency.

Fortunately, however, we do not need to seek substitutes. Exploration work done by means of diamond drills indicates that we have in sight in the United States enough copper ore to supply our demands for some hundreds of years to come. And that means a lot of copper. The estimated consumption of copper in the United States for 1926 as compiled by the American Bureau of Metal Statistics, and quoted in the Encyclopaedia Britannica, shows some of the major industries using copper as shown on page 6.

**COPPER USED BY MAJOR INDUSTRIES IN UNITED STATES \***

Figures express tons of 2000 pounds

Electrical manufacturers	201,000
Light and power lines	117,000
Automobiles	102,000
Telegraph and telephone	90,000
Wire and rods	74,000
Buildings	50,200
Bearings and bushings	38,000
Valve and pipe fittings	26,000
Refrigerators, electric	15,000
Trolley wire	7,000
Wire cloth	7,000
Railway cars	6,150
Ammunition	5,700
Radio receiving sets	5,000

\* Encyclopaedia Britannica

6: 407. 1929. (14th ed.)

These and many other industries use copper that becomes an integral part of the finished product as well as using copper in the machinery of manufacture. There are other uses of copper that are not so evident because it is not contained in the finished article of commerce. In Canada there is one factory that makes paper in sheets more than 25 feet wide at the rate of about 1000 linear feet per minute. This sheet of paper is formed on a strip of brass wire cloth as wide as the paper and 90 feet long. Of course no copper or its alloys appear in the finished paper, yet the production of paper is dependent on these corrosion resisting materials. The printing industry uses thousands of tons of brass annually for matrices for linotype machines. Millions of pounds of copper are used each year by the manufacturers of dairy equipment. Manufacturers of sugar and candies use copper kettles and vats. The textile industries use copper and brass equipment in the processes of washing, bleaching, dyeing, drying, and printing cloth.

Arizona has long been proud of her pre-eminence in the production of a metal so useful to mankind. From 1845 thru 1930 the State produced 14,477,527,568 pounds of copper. # x

"Arizona is the most important copper-producing State, both in production for 1927 and in total production for the country from 1845 through 1927. In 1927 Arizona produced 681,168,117 pounds of copper, 40.45 percent of the total for the United States. --- Arizona's total production through 1927 is 12,350,131,354 pounds, 31.48 percent of the total United States production. --- The Bisbee district produced more copper during the period from 1845 through 1927 than any other district in Arizona." x

Copper ores mined in the Bisbee district are shipped by rail to the smelters near Douglas, Arizona.

Two smelters are located at Douglas. One is the property of the Phelps Dodge Corporation, the other belongs to the Calumet and Arizona Mining Company.

# Mining Jour. 14: 6-7. Ja 1931

x Julihn, C. E. and Meyer, Helena. Copper in 1927. (General Report). 696-697.

United States Government Printing Office.

1929

The Phelps Dodge Corporation smelter, known as the Copper Queen Branch, Douglas Reduction Works, and locally called "Copper Queen" or "Queen", began operation in March 1904.

The Calumet and Arizona Mining Company completed their first smelter at Douglas, in November 1902. In June 1914, the present "C&A" smelter was completed.

The original equipment of both smelters included blast furnaces. At that time it was thought that concentrates, precipitates, dust and fines could not be smelted in a reverberatory furnace. Sintering and briquetting were resorted to as a means of using these ores as charge for the blast furnaces, but results were not satisfactory and costs were high. With improvements in reverberatory practice it was discovered that the "reverberb" could handle all these ores including fines and the blast furnaces were abandoned for the more rapid and cheaper reverberatories.

From time to time both smelters have added improvements and made changes that enabled them to take advantage of more modern smelting methods.

The amount of copper produced from month to month and year to year depends mostly on the body of ore being mined and the market demands.

During the World War all units were pushed to their utmost capacity, and again during 1929 when copper reached the highest price in the history of smelting, every effort was made to market as much copper as possible. The rated capacity of the 2 smelters is the same, therefore a statement of production at one smelter shows approximately half the copper produced in the district. At the Copper Queen, "The total receipts of the metal bearing products of all kinds, received from all sources, at this smelter from 1903 to the end of 1929 were 21,950,000 dry tons containing 673,000 ounces of gold, 47,331,000 ounces of silver, 3,313,970,000 pounds of copper, and 39,057,000 pounds of lead, the latter representing somewhat less than three years' receipts. It may be interesting to express these quantities in other terms. If all this material was loaded in Bisbee dump cars, fifty tons per car, it would take 438,890 cars and make one train 2,778 miles long. The gold and silver would make 33 carloads, and the copper, if all made into standard long distance telephone wire, would encircle the earth 500 times or run 52 lines to the moon." \*

\* Bishop, H. J. Ore Buying At The Copper Queen Smelter. Paper read before The Copper Queen Smelter Club, Douglas, Arizona. 4 S 1930

The personnel of any organization capable of such vast production must, of necessity, include men of many trades and varieties of training. In actual copper production we find men all the way from the unskilled laborer who sweeps up ore laden dust to the college trained smelting engineer who has spent years on the job perfecting himself in the art of copper smelting. Then there must be a small army of artisans of every sort to maintain electrical and mechanical equipment and to repair furnaces. Records must be kept of the tonnage and richness of all ores; costs of materials and labor must be constantly available, and the paymaster, with the aid of his corps of assistants, must be ready to give each man his earnings semi-monthly.

Improvements in smelting practice and installation of labor saving equipment have materially reduced the number of men necessary to operate the smelters. When running at rated capacity of 12 million pounds of copper per month the Queen employs 300 in actual copper production, 115 in maintenance departments, and 85 in other lines of service. The C&A employs 401 in actual copper production, 118 in maintenance departments, and 38 in other lines of service.

At the smelters the work of the machinist, the electrician, the carpenter, and the many men employed in other lines of building and maintenance is not much different from that of the same trades in any other manufacturing concern. Their jobs have been studied and analyzed and a discussion of their trades is outside the scope of this paper.

## CHAPTER II

## COPPER ORES

The ores received at the Douglas smelters are classified as oxide ores, sulfide ores, silicious ores, concentrates and precipitates. The names of the oxide, sulfide, and silicious ores indicate their natures. Concentrates are ores from which a great deal of the worthless materials have been eliminated either by the flotation process or by washing. The precipitates are copper bearing materials recovered by leaching and cementation processes from low-grade ore, containing usually less than 1 percent of copper.

The concentrates and precipitates are normally quite wet when received at the smelters and appear to the novice to be nothing more than car loads of worthless mud. The appearance of the oxide, sulfide, and silicious ores is not much more encouraging. They look like a mixture of dirt and rock. Certainly only those with trained eyes would ever suspect the value of the incoming ores.

Most of the ores come from mines owned by the companies. The smelters receive some Custom ores, which are handled for the owner on a charge basis, but, these

form a very small part of the whole. Both companies have extensive holdings in and around Bisbee, Arizona, a picturesque town in the Mule Mountains, about 20 miles northwest of the site of the smelters.

The C&A also receives ore from its subsidiary the New Cornelia Copper Company at Ajo, Arizona, and the Queen receives some of its richest ores from a subsidiary, the Moctezuma Copper Company at Nacozari, Sonora, Mexico, about 80 miles south of Douglas, Arizona.

At present all mining is of the underground type. For some years the Phelps Dodge Corporation did open pit work on the famous Sacramento Hill in Bisbee. Where that mountain formerly stood there is now a yawning chasm and the remaining ore is being removed from underground passages.

Because of the mountainous nature of the Bisbee district and the consequent irregularities of the ore bodies, the mines assume shapes that would seem fantastic to those acquainted with the more regular formation of other mining properties. The Southwest tunnel might be cited as an example. Opening not far from where Brewery Gulch joins Tombstone Canyon in the heart of Bisbee's business district, the tunnel pierces the base of the mountain

horizontally and continues on that level for nearly three-fourths of a mile thru almost continuous solid rock. Here an elevator takes the workmen up to the various levels of the mine or out onto the side of the mountain some 1600 feet above.

Where ore formation is in the nearly solid rock very little timbering is necessary to protect the miners from rock falls. In other places much timbering is necessary.

The ore body is drilled with the aid of compressed air, and charges of powder used to loosen the ore so that it may be moved by hand shovel or drag line to shafts where it falls into bins below. In some of the mines it is necessary to raise the ore to the level on which the electric ore trains travel. In a mine similar to the Southwest gravity deposits the ore in the loading bins.

As various bodies are mined they are constantly being sampled to determine the type and grade of ore, and each car sent to the smelters bears a notation of the contents.

The ore trains operating in the mines are of the small narrow gauge type. For shipment the ore is loaded into standard 50-ton hopper-bottom steel cars.

Some of the extremely high-grade ores are shipped in cars equipped with a steel roof to prevent loss by wind or theft.

Typical assays of ores received at the Copper Queen smelter are given on page 17. The ores received at the C&A smelter are very similar in character.

Typical Assays of Ore Received at  
Copper Queen Smelter \*

Figures express percent

	Cu	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe	CaO	S
C.Q. flotation concentrates	13.40	8.2	2.9	32.6	0.4	40.1
C.Q. sand concentrates	9.35	6.8	1.8	36.8	0.4	44.6
Moctezuma concentrates	23.62	10.8	4.0	26.9	1.0	29.8
Sulphide ore	4.13	25.7	9.3	24.2	1.9	21.0
Oxide ore	5.93	20.6	7.0	24.8	8.2	1.8
Silicious ore	3.63	64.6	8.3	8.6	0.4	9.6
Precipitates	63.12	1.8	4.0	8.6	0.2	1.7

\* Mills, R. H. Flow Sheet of Copper Smelting

Douglas Reduction Works, Douglas, Arizona

Mining Congress Jour. 16: 532-534. Je 1930

### CHAPTER III

#### PREPARATION DEPARTMENT

As the ore trains arrive at the smelter, cars to be unloaded are run in on an elevated track and spotted over receiving bins built of steel and equipped with hopper bottoms. Each bin will hold from 100 to 500 tons.

Orders from the plant metallurgist or the superintendent's office determine what cars shall be unloaded into the bins, and in what sequence, so as to give the correct mixture for the desired smelting charge.

From the bottom of the receiving bins the ore falls onto a pan feeder, which is an endless belt of steel plates. The feeder is mounted on tracks and may be moved readily from one bin to another.

At a uniform rate of flow the pan feeder discharges the ore onto an endless conveyor belt. A conveyor belt is made of cotton fabric and rubber and travels on a series of rollers. Each roller is made of a number of shorter rolls the axles of the latter being set so that the belt takes a concave shape and is thereby enabled to carry a load without loss. The various belts are from one-half inch to three-fourths inch thick and from 24 inches to 42 inches wide.

There is nearly 10 miles of such belting in daily use at the 2 smelters.

Pieces of wood which may have come from the mine with the ore are removed by hand and an electromagnet suspended above the moving stream of ore picks up all tramp iron that would damage the crushing machinery.

The conveyor belt coming from the receiving bins discharges its burden onto a slanted grating of steel bars called a grizzly. Ore of two and one-half inch undersize passes thru and joins the ore coming from the crusher. The oversize ore drops into a Traylor jaw crusher where it is reduced to a two and one-half inch maximum size. This crusher, commonly referred to at the plants as a "bulldog crusher" has one stationary jaw and one movable jaw, the latter ponderously moving back and forth like some evil monster slowly devouring its flinty meal. The weight of the machine is 84 tons and it is driven by a 100 horse power electric motor.

The C&A uses a gyratory crusher for the first crush.

From the jaw or the gyratory crusher the ore passes by conveyor belt to the rolls plant for further crushing. As the name implies the ore is reduced

by passing thru crushing rolls fitted with steel shells, until the maximum size is from five-eighths inch to one-half inch.

A portion of the ore is automatically cut out for sampling, and the remainder travels by conveyor belt to the screening plant and is spread by pan feeders onto a Tyler vibrating screen. This screen is of one-half inch mesh and separates the ore in much the same manner as a man sifts sand from gravel with a hand screen.

Ore passing thru the screen is taken by conveyor belt to the ore beds. That which is too large to pass thru the screen goes over it and is returned to the rolls and again crushed. This is known as the closed circuit system.

Immediately after the ore leaves the screening plant on its way to the ore beds the concentrates and precipitates are added. These form from 30 percent to 60 percent of the tonnage, the amount being specified by the plant metallurgist.

At the C&A the concentrates and precipitates are carried from the receiving bins on a conveyor belt which runs at right angles to and ends over the belt from the screening plant. Thus as both belts move the concentrates and precipitates are spread evenly over the ore moving to the beds. The amount

delivered may be varied by the speed of the belt or the supply coming from the pan feeder.

At the Queen the concentrates and precipitates are unloaded from the cars by an electric pull shovel and dropped into a hopper. The hopper opening is about 14 inches above the plate feeder. This feeder is a cast iron disk 4 inches thick by 10 feet in diameter. Extending across the plate is an arm bearing shoes about 10 inches wide and set at such an angle that as the plate is revolved the ore on the plate is moved to the edge where it falls onto the belt carrying the crushed ore to the beds. The speed of rotation of this feeder is varied to give the desired mixture of the precipitates and concentrates with the less rich ores.

As the ore comes in at the head of the beds it again changes direction as it passes thru a tripper and is sent off at right angles down the length of the bed. Here it passes thru a second tripper and is dropped to the bed below. This tripper moves slowly and automatically up and down the length of the bed depositing a layer of ore less than one-fourth inch thick.

As stated before, the first unloading of the ore into the receiving bins is so governed as to

give the desired metallurgical charge for smelting. This unloading is by carload lots, however, and it is necessary to make the whole smelting charge as nearly uniform as possible. Bedding the ore is in reality a mixing operation, altho it also serves as storage.

As the ore is needed in the bins above the roasters, it is taken by the reclaimer and deposited on conveyor belts running up to the roaster building. The reclaimer is a machine which operates on the end of an ore bed moving a harrow like rake across the end of the bed, as at the C&A, or up and down the face of the end of the bed, as at the Queen. The rake causes the ore to cave down, where it is engaged by bucket-like plows and moved laterally to the conveyor belt.

The bins above the roasters hold approximately 150 tons each.

On August 29, 1930 the Queen smelter put into operation a new preparation plant similar to the one the C&A had been using for some years. They now have five beds of 11,500 tons capacity each, or a total of 57,500 tons. A list of the electric motors used will give an idea of the size of the preparation department and the power required for this part of the work.

There are nine 2300-volt A. C. motors from 30 to 100 horsepower, seventy-five 230-volt A. C. motors from 1 to 35 horsepower and 12 D. C. motors from 5 to 20 horsepower.

In the figuring of operating costs and profits it is necessary to know the amounts of the various elements contained in the ores coming to the smelters. In the case of custom ores, which are mixed with the company ores for smelting, the bullion obtainable from each shipment must be known in order that the shipper may receive pay commensurate with the true value of the ore. He may also receive a bonus for flux contained in the ore or be penalized for materials increasing smelting difficulties. It is necessary to know the various elements of ores received in order that the mixture may be so governed as to give the most effective smelting charge. To accomplish these ends a smelter must maintain an efficient sampling department.

The first sample cut is 5 percent of the whole and is taken automatically by means of buckets on the arms of a revolving shaft. As the ore comes from the second set of crushing rolls, where it was reduced to 1/2 inch size, the buckets cut thru the stream of falling ore and remove the sample. This sample is put thru rolls which reduce the size of

the ore to 1/4 inch, and 5 percent or 20 percent is cut out, the amount depending on the volume of ore being sampled. The finishing rolls reduce the sample to 1/8 inch size and it falls thru a bank of Jones dividers, or "splitters", until the total sample has been reduced to 200 pounds. One-half of this amount is termed the "floor sample" and is held for 30 days against the possibility of some circumstance arising which would necessitate a recheck of the final sample. The remaining 100 pounds is weighed, than dried for 24 hours in an oven at 200 degrees F. and weighed again. This gives the moisture content. The dry sample is reduced to about 20 mesh in an Englebach mill, or "coffee mill", put in an 18-inch cube mixer and thoroly mixed. After the mixing the sample is divided until there remains only enough pulp to take care of the desired samples, usually from 23 ounces to 40 ounces. The sample is next reduced on a bucking board, or by means of a McCool pulverizer until it will pass a 120 mesh screen. All custom, lease, spotty, or high value material is ground to 200 mesh. The final sample of about 16 ounces is sent to the assay laboratory.

The method of taking samples of concentrates and precipitates must of necessity be different from that used in taking samples of the mine-run ores.

Both are sampled from the car before unloading into the receiving bins. In the case of concentrates a hole is bored with a 1 1/4 inch auger and the displaced core removed as a sample. In a standard 50-ton car holes are bored in 3 rows of 15 holes each. This sample is then split until about 100 pounds remains. Precipitates are sampled by cutting a trench in each end and in each side of the car load, about 100 pounds being taken from each cut. This 400 pounds is reduced to 100 pounds by splitting. Both samples are sent to the sample room where they are dried and handled the same as other samples.

Accurate information concerning the properties of incoming ores is necessary for the ore buyer and the metallurgist who gives instructions for the mixing of the furnace charge.

The bulk of the work of the laboratory is the determination of samples from the preparation department. In order to make up a well balanced charge, one which smelts with the greatest ease and efficiency, it is necessary to know the amounts of copper, iron, alumina, sulfur, lime, and silica contained in the ore. In addition to these, determinations must be made of slag and matte, and the amount of gold and silver contained in the copper bullion.

Between 1500 and 2000 determinations are made each day in the laboratories of the 2 smelters. This includes determinations for silica, alumina, iron, lime, magnesia, manganese, sulfur, lead, zinc, gold, silver, acid soluble copper determination for ores and mill tailings, cyanide copper determination for ores, iodide copper determination for ores, slags, and mattes, electrolytic copper determination with rotating electrode for impure ores and pure ores, electrolytic copper determination with stationary electrode for slags, impure ores, pure ores, and bullion.

All of this work is classed as routine, and the processes have been so standardized that they can be handled by the less skilled of the laboratory employees. The method of procedure for each determination is placed in the hands of the workman, and as all the various branches of the company are supplied with these detailed instructions, uniformity of practice is insured.

As an illustration of the complete detail of these instruction sheets there is given here one furnished by the chief chemist at the Copper Queen smelter.

Iodide Copper Determination  
Ores #

For low grade ores under 1% Cu, use 2.0 gram samples; between 1 and 5% Cu, use 1.0 gram; above 5% Cu, use 0.5 gram.

Weigh the sample into 250cc beakers. Cover and add 5cc HCl, 7cc HNO<sub>3</sub> and 1cc bromine. Place on hot plate until decomposed, taking care not to run to dryness. Remove from hot plate and allow to cool for a moment. Add 5cc H<sub>2</sub>SO<sub>4</sub> and take to heavy fumes. Remove, cool and add 30cc water. Place on hot plate and allow to boil gently until all salts are in solution. Remove, filter through CS&S 597-11 cm paper and wash 5 or 6 times with hot water, receiving the filtrate in 250cc beakers.

Dilute the filtrate to about 175cc with cold water and add 10cc of a 20% solution of sodium thiosulphate (commercial grade filtered). To very high grade ores, add 15cc. Cover, place on hot plate and boil until precipitated sulphides turn dark and solution is nearly clear, then add 5cc more hypo and boil until solution clears up.

# Phelps Dodge Corporation  
Routine Laboratory  
Methods.  
8. 1 Ag 1926.

Filter through 597-12 1/2 cm paper and wash about 7 times with hot water, washing all trace of iron from filter paper and all hypo from top and sides of beaker. Fold the filter with the copper sulphide and place in a scorifier and ignite in a muffle at a low red heat.

To the beakers from which the sulphides were filtered, add 3cc HNO<sub>3</sub>, 3cc H<sub>2</sub>SO<sub>4</sub> and 15cc bromine water. Transfer the ignited precipitates to the corresponding beakers, place on mat on hot plate and take slowly to dryness (without covers). Remove, cool, take up in 10cc hot water, dilute to 30cc with cold water and add 5cc acetic acid. When cold, add 8cc KI solution (1 lb. per liter) and titrate with standard thiosulphate solution, using starch indicator.

Standard sodium thiosulphate solution contains 20.30 grams per liter.

1cc = .005 gram Cu.  
Standardize daily against pure copper foil.

Work which comes more rarely to the laboratory is classed as special and is usually handled by a trained chemist. Each case must have individual attention and often special apparatus is necessary.

The routine work falls under 3 general methods, the gravimetric which involves the formation of insoluble precipitates which may be filtered out, the filter ignited and the residue weighed, the volumetric, or iodide method, which depends on certain reactions in solution by which the desired element can be estimated, and fire assay for gold and silver.

The iodide method of determining copper is used for the daily ore samples, and altho not absolutely accurate it gives very satisfactory results.

All settlements for purchase and sale of ores or bullion are based on electrolytic copper determination.

## CHAPTER IV

### ROASTERS

The purpose of the roasters is to dry the ore, which normally contains from 4 percent to 8 percent of moisture, to drive off a part of the sulfur, and to heat the ore before it is delivered to the reverberatory furnaces.

The roasters are huge upright cylinders of boiler plate lined with a special insulating and heat-resisting brick. They are about 19 feet in diameter and 32 feet high, and contain 11 hearths and an outside drying hearth. Up thru the center of the roaster extends an air cooled column to which are fastened rabble arms extending over each hearth. On these arms are set teeth which, when the column is revolved, act as plows to move the ore slowly across the hearth. One set of rabble teeth are so placed that they move the ore toward the center shaft where it falls to the next lower hearth, then the teeth revolving above this hearth move the ore to the outside where it drops to the next hearth. The progress of the ore continues in this alternating manner until it passes the eleventh hearth and falls into a hopper below the roaster ready to be delivered to the reverberatory furnace.

The ore is fed onto the drying hearth at the same rate it falls into the hoppers after leaving the eleventh hearth. Thus there is a constant stream of ore passing thru the roaster. The time required for roasting a charge is about 3 hours.

As the ore passes over the first or outside drying hearth some of the moisture is driven off. On succeeding hearths the charge becomes drier and hotter until the sulfur in the ore ignites and furnishes fuel.

On the three lower hearths air that has been used to cool the center column and rabble arms is introduced. This preheated air more readily supports the combustion of the sulfur contained in the ore which is all the fuel used under normal conditions. In case of continued rain, and especially during the rainy season of July and August, some fuel oil must be used to maintain the proper heat.

By the time the ore has reached the last hearth in its downward progress thru the roaster it is red-hot, near 1000° F.

The roasted ore is known as calcine.

From the last hearth the calcine falls into hoppers from which it is taken to the reverberatory furnaces. At the C&A the calcine is carried in

hopper-bottom cars from the roasters to the reverbs. The Queen plant was rebuilt in 1926 and the roasters placed above the reverberatory furnaces, six roasters to each furnace. The calcine charge is fed to the furnaces by gravity. This method eliminates haulage and saves fuel oil as the charge is delivered to the reverbs with little loss of heat.

The ascending roaster gases, passing in alternate directions across the hearths above, transfer heat to the descending ore, and then pass into a horizontal flue which connects all the roasters.

These gases,, or smoke, are laden with dust that is relatively high in copper content and it is worth while to recover it. This is accomplished in the Cottrell plant which consists of about 1000 vertical pipes 8 inches in diameter thru which the dust laden gases, must pass. Thru the center of each pipe is a wire insulated from any ground and carrying from 50,000 volts to 75,000 volts of unidirectional rectified alternating electric current. The corona effect around the wire causes the dust to collect on the sides of the pipes and when the pipes are rapped vigorously with pneumatic hammers the dust falls to screw conveyors which carry it to hoppers from which it is delivered with the calcine

to the reverberatory furnaces.

The copper contained in a ton of the recovered dust is nearly twice as much as that contained in a like amount of calcine. When the Cottrell plants were built it was estimated that the cost of each, near \$1,000,000, would be saved in the first 4 years of their operation.

As the gases leave the Cottrell plant they pass into a balloon flue and are conducted to the stack which discharges them into the air. Each of the smelters has in use three large stacks, built either of brick or of boiler plate lined with brick. In January 1931 the C&A completed a new brick-lined steel stack for the roasters which is 18 feet in diameter and 270 feet high. The bell-like base is 24 feet in diameter. At the Queen the roaster stack is 17 feet in diameter and 351 feet high, built entirely of brick.

## CHAPTER V

## SULFURIC ACID PLANT

Sulfuric acid is a by-product obtained from the waste gases of the roasters. In March 1917 the C&A smelter put into operation an acid plant costing \$989,000. In 1930 they erected 4 Herreshoff 10-hearth roasters 19 feet 6 inches in diameter which are charged with sulfide ores for producing sulfur dioxide for the making of acid. This addition put the cost of the plant well above a million dollars.

The main building of the acid plant is a one-story brick structure 629 feet 9 inches long, 138 feet 8 inches wide, and 41 feet high on the inside. In this building are located the 6 large and 23 small chambers, the Glover tower, the Gay-Lussac towers, and the necessary fans, flues, and piping.

During normal operation 60 to 70 tons of ore is put thru each roaster per day. Gases containing from 5.5 percent to 6.5 percent of sulfur dioxide leave the roasters at a temperature of 1000 to 1150 degrees F. and pass thru a dust chamber where the heavier particles settle out. From this chamber the gases pass thru the niter flue and circulate about cast iron pots containing sodium nitrate and sulfuric acid.

The hot gases "cook" this mixture and cause the formation of sodium sulfate and nitric acid. The former is discarded and the nitric acid in the form of gas passes with the sulfur dioxide to the Glover tower, entering at the bottom.

The Glover tower is charged with acid from the chambers, and the gases now at the temperature of about 850 degrees F., concentrate the acid to 60 degrees Baume' which is the required strength for shipping. Contradictory as it may seem it is in the Glover tower that the first acid is formed and the acid concentrated to its final state.

Lead covered fans are used for moving the gases thru the whole system, in all 2000 tons of lead being used in the plant.

As the gases pass up thru the Glover tower they encounter a mixture of chamber acid and nitrous vitriol from the Gay-Lussac towers <sup>that are</sup> descending thru the open brick work of the Glover tower. Here the first formation of acid takes place and it amounts to about 20 percent of the total.

Passage thru the Glover tower has reduced the temperature so that the gases enter the chambers at about 180 degrees F. Here water is introduced by means of sprays and the acid formation continues.

After the gases have completed the circuit of the 27 chambers they enter the Gay-Lussac towers where the niter gases are recovered by bringing them in contact with cold 60-degree Baumé' sulfuric acid, forming nitrous vitriol.

The remaining gases pass to the atmosphere, The nitrous vitriol is pumped to the top of the Glover tower where it is mixed with chamber acid and the reactions start again.

In the complete cycle there is a loss of only about 5 percent of nitric acid.

Most of the sodium nitrate used comes from Chili and costs about \$50 per ton.

There is about a 95 percent conversion of sulfur dioxide into sulfuric acid, but only a very small portion of the roaster gases are now being used. The present plant is capable of producing 250 tons of acid daily.

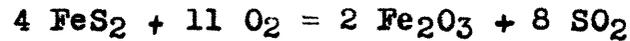
The finished acid is pumped to a 5000-ton storage tank made of Alleghany iron. Shipment is made in 50-ton steel tank cars. To avoid damage to the cars the acid may not be of lower strength than 60-degree Baumé', which is about 77.67 percent pure sulfuric acid.

Most of the acid is sold under large contracts at \$5.00 per ton to the New Cornelia Mining Company at Ajo, Arizona, and the Inspiration Mining Company at Miami, Arizona. These companies use the acid in the leaching process of recovering copper from low-grade ores.

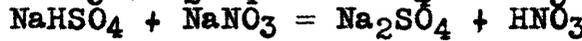
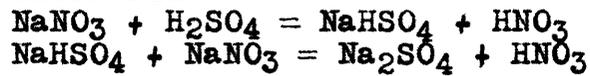
The Copper Queen smelter has no acid plant.

Reactions in the Manufacture of  
Sulphuric Acid #

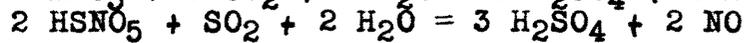
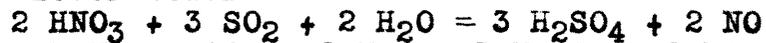
Roasters



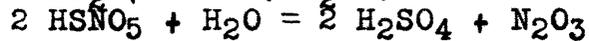
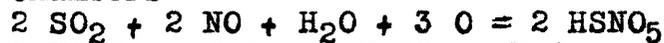
Niter flue



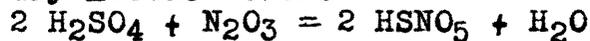
Glover tower



Chambers



Gay-Lussac towers



# Jacks, M. E. Calumet and Arizona  
Mining Company Sulphuric Acid Plant.  
Mining Congress Jour. 16: 615-630  
Jl 1930

## CHAPTER VI

## REVERBERATORY FURNACES

The roaster treatment of the ore is merely a preparatory step, smelting really beginning in the reverberatory furnaces.

The C&A has 4 reverberatories each 19 feet wide and 90 feet long. The newer plant at the Queen has only 2 but they are larger being 23 feet 6 inches by 96 feet. A reverberatory furnace is built of brick with reinforcing steel columns and overhead cross ties on the outside. The brick average in size about 3 inches by 6 inches by 20 inches, making a wall about 12 inches thick and the roof or arch about 20 inches thick. The roof is arched, entirely self supporting, and being only from 3 feet to 6 feet above the charge in the furnace reverberates the heat to the charge, hence the name.

The continued high temperatures gradually burn away the heat-resisting walls and arch of the furnace and make repairs necessary. If the portion of the wall to be repaired is not too large the work is done without cooling the furnace. If a large section of the arch falls in, as frequently happens, the furnace is partially cooled with water, carpenters build a substructure of wood on which the brick masons

proceed to place a new arch. Sometimes the furnace is cooled for only 6 to 8 hours and it is necessary to keep water constantly playing on the wooden framing to keep it from burning away. In case of very urgent need a steel substructure is used, the arch repaired without cooling the furnace, and the steel supports are destroyed when the burners are again turned on. Such procedure is avoided when possible because of the extreme discomfort to the workmen, and the higher cost of the repairs.

As the calcine comes from the roasters it is placed <sup>in</sup> /, or allowed to fall into, hoppers one on either side of the furnace. From these hoppers the calcine and silica flux pass thru 6-inch charge pipes and pile up along the side walls of the furnace. This helps to protect the walls and adds to their period of usefulness.

At the firing end of the furnaces oil burners are inserted thru openings about 9 inches by 15 inches 10 burners to each of the larger reverberatories. Each set of 10 burners requires about 425 barrels of fuel oil each 24 hours. Air under pressure (16 ounces at the C&A, 42 ounces at the Queen) is supplied for atomizing this oil. Auxiliary air to support combustion comes in thru the

openings where the burners are inserted.

The atomized oil burns with explosive fierceness and surges down the center of the furnace heating the banks of calcine on either side. As the temperature of the furnace is approximately 2400 degrees F. and the melting point of the charge only about 1900 degrees F. the whole mass is reduced to a liquid state in less than an hour. This liquid consists of matte and slag. The matte consists of copper, iron and sulfur, while the slag is mainly silicate of iron. The specific gravity of matte is about 5 while that of slag is about 3.5. This being the case the slag must of necessity rise to the top of the liquid mass and is drawn off at the end of the furnace opposite the oil burners.

The man in charge of drawing off the slag is known as a skimmer. He watches the furnace charge thru a peep hole about 6 inches by 6 inches, using a dark blue glass to protect his eyes.

The slag outlet in the reverb wall is placed above the bath line of the matte and skimming may be done at any time when the furnace charge is high enough to cause slag to flow. Usually skimming is being done about three-fourths of the time. If the furnace should become too full and matte should

begin to flow from the skimming hole the skimmer can easily see the mistake. Slag is sluggish and viscous in appearance. Matte sparkles and flows very readily.

When the charge is ready to be skimmed the skimmer uses a steel bar to knock out the fire clay that has been used to plug the skimming hole. The slag runs out and thru a cast iron launder from which it falls into a ladle of about 20 tons capacity mounted on a short railway car. When one slag pot has been filled it is necessary to stop the flow while another car is spotted under the launder. To do this the skimmer places a cone of fire clay on a rammer and packs it into the hole in the wall. An electric motor moves the slag car out to the dump where the pot is tipped and emptied of its molten burden.

The slag has little value except as ballast for railroad beds. The Southern Pacific uses it quite extensively for that purpose. It is too hard and glass-like to be used for highway building.

As a check on the judgment of the reverberatory foreman and the skimmer a sample is dipped from the flowing slag and sent to the laboratory. The report shows whether the charge was properly fired and whether or not the skimming was done correctly.

There is a slight loss of copper in the slag, less than one-half of 1 percent.

At the firing end of the furnace the copper matte is tapped off in much the same way that the slag was skimmed from the furnace charge. The important difference is that the matte is tapped off at a lower level than the slag.

An analogy may better explain the principle of skimming and tapping. Suppose a milk bottle equipped with a spigot 3 inches down from the top and another at the bottom. After the bottle had been filled with whole milk and allowed to stand until the cream rose to the top, the cream could be drawn off from the upper spigot and then the milk emptied thru the lower. In the case of the reverberatory furnace, however, it is the useless slag that rises, and the valuable and heavier matte that is drawn off from the lower opening.

The matte is also sampled as a check on the mixture and the handling of the furnace charge.

As the matte comes from the reverberatory furnace it flows thru launders and falls into ladles of about 30 tons capacity. These ladles are picked up by an overhead crane and their contents poured into converters for further refining.

As it leaves the reverberatory furnace the matte contains about 30 percent copper, 40 percent iron and 25 percent sulfur with small amounts of alumina, lime and silica.

Thru an uptake at the end opposite the oil burners the gases leave the furnace and pass into waste-heat boilers where their temperature of about 2000 degrees is used to generate steam for driving the machinery of the plants. When all the furnaces of the two smelters are in operation this recovered heat delivers about 10,000 horsepower.

Reverb dust is collected in the waste-heat boilers and in a dust chamber between the boilers and the stack which conveys the gases to the atmosphere.

Late in 1930 the smelters entered into a contract with the Western Gas Company to supply natural gas from the gas wells near Jal, New Mexico. This gas will supplant the use of crude oil fuel. It is expected that the pipe line will be completed in the summer of 1931.

In April, 1931, the C&A began the building of a new reverberatory furnace designed especially for using natural gas. This furnace is to be 26 feet wide by 106 feet long inside and will be capable of smelting 1000 tons of calcines per day.

At the Queen the present furnaces will be remodeled to some extent for the change of fuel. Present plans call for the installation of gas burners in a line down the center of the arch. Beginning at the firing end of the furnace there will be 10 burners spaced about 5 feet apart and set at a 45 degree angle, pointing toward the skimming end. This arrangement will concentrate the heat in one end of the furnace, as at present, and leave the other end less agitated to facilitate the separation of slag and matte.

## CHAPTER VII

### CONVERTERS

The most spectacular part of the smelter work is that performed in the converter aisle. The firing ends of the reverberatory furnaces are at one side of this aisle and the converters are on the other. High above on either side is the track on which is mounted the bridge work of the traveling crane. The crane moves up and down the aisle or across the aisle at the will of the operator who rides in a cab underneath the structure. The crane has a lifting power of about 75 tons thus allowing a wide margin of safety for handling the ladles of molten metal.

As the matte from the furnaces falls into the ladles there results a shower of bright red particles, and again when the converters are tipped and the charge of matte poured into them the aisle is filled with brilliant sparks, and clouds of suffocating gases surge from the converter mouth. At night the whole scene suggests some fantastic imitation of the nether world.

The Queen has eight converters of the Great Falls or upright type, 12 feet in diameter and about 15 feet high. They are made of boiler plate and are lined with 15 inches of magnesite brick.

The C&A discarded the upright type of converter late in 1929 and now has three of the Pierce-Smith or horizontal type, each of about 200 tons capacity. The difference in the two types is purely mechanical as each accomplishes the same results.

Along the bottom of each converter is a series of tuyeres thru which air under 15 pounds pressure is introduced. Above the mouth of the converter is a metal hood which catches the escaping gases and delivers them into a dust chamber from which they pass to the stack. The converters are mounted on trunnions, thus permitting turning the mouth from under the hood for charging or to pour out slag or copper. As the tuyeres are below the bath line, air pressure must be maintained at all times while the converter is in an upright position in order to prevent stoppage of the air passages. Despite the air pressure there is some tendency for the copper to collect in the tuyeres and impede the flow of the air. It is necessary, then, to continually clear the air passages by forcing an iron bar thru openings provided for this purpose. This process is known as punching converters.

When the craneman has carried the huge cauldron of matte across the aisle from the reverberatory furnace and poured it into the converter the air is

turned on, the converter is again brought to its upright position and the refining process continues. As in the case of the roasters, no fuel oil is necessary. The compressed air keeps the metal in a state of constant agitation permitting the oxygen to combine with the sulfur. This, of course, gives off heat. From time to time silica in the form of crushed rock or silicious ore is added to the charge. The iron and silica readily combine under the intense heat and form slag which is poured off into a ladle and returned to the reverberatory furnace. This slag contains nearly 3 percent copper and is too valuable to be discarded. In the furnace it mixes with the other charge and most of the copper is recovered.

While the slag is being poured from the converter mouth the operator makes repeated tests to determine when the charge has been completely skimmed. He does this by inserting the end of a long iron bar into the stream and then inspecting the resultant coating of slag or metal. Slag appears smooth and glassy while the metal presents a corded stringy appearance or, in smelter parlance, shows worms.

The time required for reducing the converter charge is about 6 hours.

Typical Analyses \*

Figures express percent

	Cu	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe	CaO	S
Ore beds	9.07	22.0	7.2	25.4	1.9	24.5
Cottrell dust	15.35	7.2	3.7	25.3	0.4	19.7
Calcines	9.48	23.8	7.1	28.9	2.1	13.3
Reverb slag	0.41	37.6	9.8	46.3	2.2	0.4
Reverb matte	30.24	----	---	39.6	---	25.7
Converter slag	2.76	19.4	---	54.7	---	1.5

\* Mills, R. H. Flow Sheet of Copper Smelting

Douglas Reduction Works, Douglas, Arizona

Mining Congress Jour. 16: 532-534. Je 1930

## CHAPTER VIII

### BLISTER COPPER

When the converter has received 4 or 5 charges of matte and discharged the slag from them a copper sulfide known as white metal remains. The charge in the converter is then blown with air until the sulfur has passed off as gas and there remains only the copper, gold, silver, and a very small amount of sulfur and oxygen. This is known as blister copper, the name being derived from the blistered appearance of the metal when cold.

If the copper is to be shipped to the refinery in blister bars it is poured from the converter into a ladle and carried by the crane to the holding furnace which is an oil-fired horizontal brick-lined vessel. The holding furnace also provides a means of pouring the copper into the moulds of the casting machine. This machine consists of a series of moulds mounted on the spokes of a large horizontal wheel. As a mould comes under the spout of the holding furnace the wheel is stopped and the mould poured full. The copper freezes quickly and before a mould returns to its position under the pouring spout it automatically dumps its load into a water bath and receives a lime spray to insure easy dumping of the next bar.

The blister bars are raised from the water by an endless belt traveling up an inclined plane. The rough edges are trimmed off by hand, and laborers truck them into railroad cars for shipment. Each bar weighs about 275 pounds.

There has been very little blister copper cast since the completion of the anode plants at both smelters in 1929.

## CHAPTER IX

## ANODE COPPER

Formerly it was the practice to ship blister bars to the refineries in the East. The present practice eliminates a loss of time and fuel oil by casting the copper bullion into anodes at the smelters.

In preparing the copper for casting into anodes the Queen uses two 15-ton cylindrical vessels lined with magnesite brick. The molten copper brought from the converters is poured into the stationary or oxidizing vessel and blown with air at 90 pounds pressure. This drives off the sulfur in the form of sulfur dioxide gas, but it also increases the oxygen content of the copper. The furnace is then tilted by hydraulic lifts and the copper passes out an opening in the end opposite the receiving end and flows down a short launder to the reducing vessel. This vessel is the same in construction as the oxidizing vessel but it is mounted on a carriage which travels along a track parallel to the line of moulds.

The reducing vessel is then moved to one side to permit poling. By means of a chain attached to an electrically operated hoist, a green/<sup>wood</sup>pole is inserted thru the mouth of the vessel and the outer

end raised until the pole is forced down into the liquid copper. Violent agitation accompanies the burning of the wood, and the oxygen in the metal passes off as carbon dioxide.

The bullion now assays about 99.65 percent copper.

The reducing vessel is moved along the track to the molds, tilted the same as the oxidizing vessel and the bullion flows into a cast iron spoon to facilitate filling the moulds. There are 50 moulds in line parallel to the line of travel of the reducing vessel and spoon.

After the anode has cooled a plunger lifts it sufficiently to allow a traveling crane to pick it up, immerse it in water, and place in on the platform for inspection. All rough parts are trimmed off with air-operated chisels and those passing inspection are trucked into cars for shipment to the refinery.

The mechanics of making anodes at the C&A is somewhat different from that at the Queen altho the results are the same. Here two revolving furnaces, each 13 feet by 20 feet, perform the oxidizing and reducing operations and the casting is done on a Walker casting wheel carrying 22 moulds. The reducing furnace and spoon are stationary and the wheel revolves bringing each mold under the spoon in turn.

The anodes are removed from the moulds by an overhead air hoist.

The electrolytic process of refining demands anodes of very exact size. Each one must be 1 3/4 inches by 36 inches by 36 inches and weigh 700 pounds with a tolerance of only 5 percent heavier or lighter. On each side at the top projects a lug about 5 inches long for suspending <sup>the anode</sup> in the electrolytic tanks. One of these lugs is cast with a Baltimore insert groove for attaching the cathode rod.

The gold and silver contained in the ore follow the copper thru the smelting processes and are recovered at the refinery. A typical analysis of anode copper shows about 99.65 percent copper with 0.44 ounces of gold and 18.06 ounces of silver per ton.

All anode bars from both smelters are shipped to the Nichols Copper Company refinery at El Paso, Texas.

On an average market each anode shipped from Douglas represents a value of about \$100 exclusive of electrolytic refining costs.

Typical Analyses of Bullion \*

Figures express percent or ounces per ton

	Cu	O <sub>2</sub>	S	Au	Ag
Blister copper	99.27	0.30	0.049	0.44 oz	18.06 oz
Copper from oxidizing vessel	99.15	0.65	0.005	0.44 oz	18.06 oz
Copper from reducing vessel	99.65	0.11	0.0013	0.44 oz	18.06 oz

\* Mills, R. H. Flow Sheet of Copper Smelting

Douglas Reduction Works, Douglas, Arizona

Mining Congress Jour. 16: 532-534. Je 1930

## CHAPTER X

## INVESTIGATION DEPARTMENT

Changes in copper smelting practice are usually slow. Old methods are not quickly discarded for the new. Too much money is involved. But in the history of operations at Douglas there have been radical changes from time to time and production and profits have been increased, often by seemingly small changes. The superintendent, the chemist, the metallurgist, and all foremen are constantly on the alert to devise ways and means of increasing tonnage.

Smelting practices that have been evolved or improved at one or the other of the Douglas smelters are now in common use thruout the world.

The C&A maintains no research or investigation department as such, but the Queen employs a number of men whose duty it is to be especially interested in increased production. The force has varied in number from 25 to 7 or less, depending on the work to be done and conditions of the copper industry in general.

Certain routine matters are handled by the department such as testing of gases heat and dust losses, brick for various purposes, oils and efficiency of oil burners, steels for specific uses, flotation reagents and the like.

The salaried men of the department are usually college trained chemists, but most of their specific training for smelter work has been gained while on duty at the plant, altho there is no organized system of training. The investigation department itself is a sort of training school for smelter men.

The department as such was not created by direct order but grew out of the gathering together of men of training and ability as problems were presented for solution.

A recital of the achievements of this group of men, their failures and successes, would make a most interesting chapter in the history of the art.

As a result of their study and experimentation, roaster capacity was increased from 60 to 350 tons in 24 hours, without increasing the diameter of the roaster. This was done by placing the hearths closer together and increasing the number of drop holes from 6 to 24. The capacity of the reverberatory furnaces was doubled by changes in the arch and in the uptake.

One smelter man states that a reverberatory furnace with superimposed roasters always had been a sort of metallurgical dream. The Queen smelter built such a plant in 1926 and its success is directly traceable to the research department.

It was then the only plant of its kind in the world. Since that time one other has been built in Canada.

The investigation department conceived the idea of placing the Cottrell plant above the roasters. An account of this one contribution to the industry illustrates the work being done by the department.

When the Cottrell plant had been placed above the roasters, unforeseen complications resulted. More dust was recovered than had been expected, and the hotter gasses caused the dust to burn and short out the treaters. It was <sup>evident that the gases</sup> / must be cooled. This could be done by removing <sup>the flue</sup> / insulation but the heat would be so intense that the plant could not be operated. A system of cooling with water was evolved, but it required expert handling and constant attention. Outside air was introduced but this increased the volume of gas by about 40 percent and consequently put a 40 percent overload on the system. An air cooling device carrying the gas thru a pipe which described a loop was finally installed. The loop or "cyclone" was used as a space saving device and as a modified type of cyclone dust collector. Experimentation was <sup>necessary to</sup> / determine whether there would be a sufficient amount of the sulfide dust settled out so that the dust passing on to the Cottrell

would not burn at the high temperatures of the plant. Tests proved that what dust remained would not burn at temperatures even higher than operating temperature, and there was no need for a cooling device!

And thus a problem that had been demanding the attention of the department since May 1928 was solved in February 1931.

Increased efficiency in handling ores, elimination of heat and dust losses, utilization of waste products, new and better fuels and fuel ratios, elimination of the clouds of sulfur smoke issuing from the stacks, these and many other problems await solution by the investigation department.

## CHAPTER XI

## WORKING CONDITIONS

The work day at the smelters is divided into 3 shifts of 8 hours each, beginning at 7 a. m., 3 p. m., and 11 p. m. The shifts are commonly designated as days, 3 o'clock, and graveyard. A change of shifts is made every 2 weeks. The men of the various maintenance departments work the day shift only unless some emergency demands overtime, for which they are paid "time and a half" or 50 percent additional.

Shift men work 7 days per week, maintenance departments 6 days per week, and the office force 5 1/2 days per week.

All employees not on shifts are at the plant 8 1/2 hours per day with 30 minutes for lunch at noon. The man on shifts must eat lunch while attending to their duties. The Queen maintains a lunch service where employees may buy food at the noon hour and at specified times thruout the day and night.

A visitor at the plant might be inclined to think of smelting as one of the hazardous occupations. High voltage power lines, massive machinery, and metal made liquid by heat are a bit disconcerting to the uninitiated. But both of the Douglas smelters have been remarkably free from serious accident.

Such accidents do happen, but almost invariably subsequent investigation <sup>has</sup>/disclosed the fact that the injured was acting in violation of orders or was "asleep on the job".

Each foreman is directly responsible for the safety of his men. He must instruct them in matters of safety and see that they obey his instructions. The discharge of the foreman may follow an accident. This being the case the foreman is given authority to enforce safety rules. If a man takes unnecessary risks or fails to wear safety appliances he is warned by the foremen. A repetition of the act may result in immediate discharge.

The only dangers encountered in smelting which are not common to all other large manufacturing enterprises are those from gas and burns. The sulfur dioxide fumes from the roasters, reverberatories, and converters, are at times disagreeable but could scarcely be classed as dangerous to the workmen. A burn caused by molten copper, in addition to being painful, is often very difficult to heal. But the work of the men handling the molten metal requires few quick and precipitate actions. They move deliberately and surely about their tasks, and where it is necessary that they remain close to the metal while it is being poured from one

receptacle to another they are well shielded from sparks and splatters.

The companies follow closely the safety recommendations of the National Safety Council and the Arizona Industrial Commission. To encourage elimination of accidents they strive to create a competitive spirit. Department is matched against department, shift against shift or mine against smelter. Various devices are used for advertising the fact that certain departments have had no lost-time accidents for long periods of time.

A lost-time accident is one in which the employee is unable to report for work on his next shift. If an accident is such that it interferes with the performance of duty, the workman is given medical attention and sent home for the remainder of that shift, for which he is paid in full. If he is able to return to the smelter for light duty his next regular shift, and able to resume his regular duties the third day, the accident is not a lost-time accident. Following an accident or surgical treatment a man must have permission from the medical department before returning to work.

Both companies maintain efficient medical and hospital service for employees. The Calumet Hospital

in Douglas is the property of the Calumet and Arizona Mining Company. The Copper Queen Dispensary serves Phelps Dodge employees. From the wages of married men there is deducted a \$2.00 per month medical fee. Single men pay \$1.00/per month at the Queen, \$1.50 at the C&A. This fee entitles the employee to all necessary medical and surgical attention, with the exception of treatment for venereal disease. There are some other exceptions prescribed by each company, cases which might arise from circumstances in no way connected with the company. Married men receive medical attention and medicines for their families, and in the event of need for hospitalization for a member of the family it is furnished at reduced rates. The regulations concerning medical care of an employee's family vary somewhat with the two companies but both give excellent service to their employees.

If hospital care is needed by an employee of the Queen smelter the Company pays the expenses at the Calumet hospital or takes him to their own hospital at Bisbee.

If an employee of either company so desires, the company will issue to him an insurance policy with liberal disability and death benefits. The premiums are nominal and are deducted from the biweekly pay check.

CHAPTER XII  
VOCATIONAL GUIDANCE SUGGESTIONS, AND CONCLUSIONS

Rapid advancement in the copper smelting industry is an exception rather than the rule. Most foremen and other men in places of responsibility have been engaged in smelting for a number of years. Many of them were first employed as helpers and in that way learned the fundamentals of the work in their particular departments.

But a knowledge of only one phase of smelting does not make a man the most valued employee. The work of the different departments is too closely interwoven. The successful handling of the reverberatory charge depends on the roaster treatment of the ore, and the converters will have difficulties if the reverberatories do not pass on to them a properly smelted charge. Such things are true of the whole plant, and in general the most valued man is the one who has a good working knowledge of the smelter as a whole and who is an expert in his particular department.

Most of the men in the higher positions are college men, either chemists or mining or smelting engineers. Their training and background give them an advantage over the untrained man. Their college

work did not fit them for the positions they hold, for smelting can be taught only in a smelter, but it did give them a training that enabled them to more quickly grasp the actual smelter operations, and more easily understand the reasons back of certain processes.

What if these men had not gone to college, but at the completion of a high school course had entered the smelter and concentrated their efforts on becoming efficient smelter men. Doubtless at the end of 4 years they would be much further advanced than the man who had spent that time in school, but it is problematical if they would be able to maintain their lead. If in addition to putting in 8 hours each day at the plant they would spend another 5 hours in study, making their day no longer than that of the <sup>a technical</sup> man in/school, their success would be assured. Unfortunately few men are willing to pay such a price.

If an employee is satisfied to continue year after year at a job which requires a minimum of mental effort that, of course, is his affair. There are many such jobs about a smelter. If on the other hand, he is desirous of bettering his condition that, too, may be accomplished, and the best place to begin is before entering the industry, or while yet in school.

The value of a high school course is frequently challenged and it may be worth while to check certain studies against the needs of industrial employees in general and smelter men in particular.

At the smelters elementary and advanced mathematics must be used for making such estimates as tonnage of ore beds, capacities of ladles, bins, and furnaces, percentages of metals and slags, ratios of fluxes, fuel mixtures, and power, stresses and strains of building materials, lifting power and margin of safety for cranes and hoists, costs, profit and loss, and many other items.

Without the work of the chemist and his qualitative and quantitative determinations the smelters would be working blindly and could not operate efficiently or profitably. The laboratory work is of a most highly specialized nature, and since able men with ample training are available the laboratory does not attempt to train men in the fundamentals of chemistry. One chief chemist states that only college trained chemists are considered when vacancies occur. Those with no more than high school training in chemistry are employed for routine work only and very rarely advance beyond that point.

Those who would make the greatest progress in any line of work must have a good command of the English language. No matter how much a man may know about his particular specialty he cannot rise to a place of preeminence unless he is able to express himself clearly and convincingly.

A study of civics, economics, and history has little direct bearing on the ability or promotion of a smelter employee. A knowledge of these subjects does make of him a more useful and valuable member of society.

At the Douglas smelters the laborers and most helpers are Mexicans. As many of them refuse to talk English, even when able to do so to some extent, it becomes necessary for all foremen handling them to be able to talk Spanish. The statement is often made that the Mexican language, and especially as used in the northern states, is not the same as the Castillian Spanish. Due to the Indian influence this is somewhat true. Nevertheless the Spanish vocabulary and grammatical construction are an asset to those who work with these people.

With the many types and varieties of mechanical appliances in use about the plants there can be no question as to the value of shop courses and physics.

Education is not necessarily the result of schooling, but the quickest and best place to get an educational foundation is in our public schools.

To those determined to succeed copper smelting offers an attractive field. There is no known substitute for copper, no metal so abundant, so cheap, and so durable. The position copper holds in the industrial life of the world assures the future of the industry.

"It is safe to say that the United States production will continue to be the chief item of world production for many years - - - -. Great reserves of proven ore exist in the United States to support its production of the near future, and there probably are also enormous quantities of very low-grade copper-bearing rocks that will become of economic importance as the relative high-grade ores of the world approach exhaustion some decades hence. " \*

But there is a copper-colored cloud which casts a sinister shadow on the industry in the United States--

\* Julihn, C. E. Summarized Data Of Copper  
Production. 30-31. United States  
Government Printing Office. 1928

the rich deposits in Africa and South America. Vast quantities of high-grade ores and cheap labor enable producers in these countries to market the red metal at figures which threaten our domestic copper interests.

Two solutions to the problem present themselves, one a tariff which would enable the mines and smelters to maintain wage schedules and make a profit, the other the development of methods which would lower the cost of production and make profitable the handling of low-grade ores. The latter constitutes a challenge to those now in the industry and to the most able of our young men who would choose copper as their field of endeavor.

Copper ranks high in a list of essential products, and altho the heat may be disagreeable, the dust unpleasant, and the gas annoying, at the close of the day the workman may well feel proud that he has been helping produce such a useful article as copper.

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ABSTRACT OF THESIS

COPPER SMELTING  
AS PRACTICED AT  
DOUGLAS, ARIZONA

\*\*\*\*\*

Submitted by

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In partial fulfillment of the requirements

for the Degree of Master of Science

Colorado Agricultural College

Fort Collins, Colorado

June 15, 1931

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## CHAPTER I

### PROBLEM AND OBJECTIVES

This thesis is presented with a four-fold objective:

For use in the study of copper production:

First: As an aid to those seeking information that will help in the selection of a life work.

Second: As an aid to those thinking of entering any of the numerous branches of the industry.

Third: For smelter employees seeking advancement in their work.

Fourth: As supplementary material for school studies in economics, in commerce and industry, and in the sciences.

## CHAPTER II

### COPPER ORES

Oxide ores, sulfide ores, silicious ores, concentrates, precipitates, and some miscellaneous

custom ores are handled at both smelters. The ores are mined at Bisbee and Ajo, Arizona, and at Nacozari, Sonora, and shipped to Douglas.

### CHAPTER III

#### PREPARATION DEPARTMENT

Incoming ore trains are unloaded into receiving bins from which the ore is carried by conveyor belts to the mill where it is reduced to about 1/2 inch in size. The concentrates and precipitates are added and the mixture dropped onto the ore beds.

As the ore passes thru the preparation department from bins to beds it is automatically sampled. The final sample is sent to the laboratory for assaying where determination is made of the various elements. Detailed work sheets, of which a sample is given, standardizes laboratory work. The routine work is divided into three general classes, gravimetric, volumetric, and fire assay. Electrolytic copper determination is the basis for purchase of ores and sale of bullion.

### CHAPTER IV

#### ROASTERS

From the beds the ore is transported by conveyor belts to the roasters. The sulfur contained in the ore supplies fuel for driving off the

moisture and eliminating a large part of the sulfur. When the ore, moved by rabble arms, has traversed the 11 hearths of the roaster it is known as calcine.

Much valuable dust was formerly lost in the roaster treatment. Cottrell plants now collect this dust by electrical precipitation.

#### CHAPTER V

##### SULFURIC ACID PLANT

Sulfuric acid is a by-product obtained from the sulfur dioxide gases of the roasters. The C&A smelter has an acid plant capable of producing 250 tons of 60-degree Baume' acid daily.

#### CHAPTER VI

##### REVERBERATORY FURNACES

Smelting begins in a low-roofed brick structure called a reverberatory furnace, or reverb. The charge is fed from superimposed bins thru charge pipes on each side of the furnace. Oil burners maintain a temperature of about 2400 degrees F. in the furnace and the charge is quickly reduced to a liquid state. The impurities rise to the top as slag and are drawn off and discarded. The matte is tapped from a lower opening and transferred to the converters.

Gases from the reverbs pass thru waste heat boilers and generate steam for the plant machinery.

In the spring of 1931 changes were begun for using natural gas as furnace fuel.

## CHAPTER VII

### CONVERTERS

An overhead crane picks up the ladle containing matte from the reverb and pours it into a converter. The Queen uses the Great Falls type of converter, the C&A the Pierce-Smith type. Thru a series of tuyeres in the bottom of the converter air under pressure is sent up thru the converter charge, No fuel is used. Silica is added thru the converter mouth and the sulfur, iron, and silica form slag. This slag contains about 3 percent copper and is returned to the reverb.

## CHAPTER VIII

### BLISTER COPPER

When all slag has been removed the copper sulfide is blown until there remains only copper, gold, silver, and very small amounts of oxygen and sulfur. This blister copper is carried to the holding furnace from which it is poured into moulds.

## CHAPTER IX

### ANODE COPPER

Most of the copper is further refined and cast into anode bars. The refining is accomplished in two stages, the blowing with 90-pound air which drives off the sulfur but increases the oxygen, and poling to reduce the oxygen. Gold and silver follow the copper and are recovered at the refinery.

## CHAPTER X

### INVESTIGATION DEPARTMENT

Both smelters are constantly making changes that increase efficiency. The Copper Queen employs a group of men whose sole duty it is to improve methods, and their accomplishments have proven their value to the corporation.

## CHAPTER XI

### WORKING CONDITIONS

Three shifts of 8 hours each, 7 days per week is the program of those engaged in actual copper production. Maintenance departments and office employees work the day shift only.

Safety rules are rigidly enforced and accidents are comparatively few.

Medical and hospital service is furnished to employees at a nominal rate.

## CHAPTER XII

### VOCATIONAL GUIDANCE SUGGESTIONS, AND CONCLUSIONS

Many of the men in the industry entered employment as helpers and gradually, tho slowly, advanced in the art. Promotion is more rapid for those having an educational background. Most men in the better positions are college trained chemists.

High school courses in chemistry, physics, mathematics, and shop work are most valuable to those thinking of entering the smelting industry, and a knowledge of civics, economics, Spanish, and English is a decided asset.

A genuine service to mankind is rendered by those engaged in the production of so useful a metal as copper.

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