CHAPTER VI

ZINC SMELTING (continued)

By-products in the Smelting of Zinc

Sulphuric Acid

Not the least important of the varied problems that present themselves in the extraction of zinc from its ores is the disposal of the sulphur dioxide resulting from the roasting of blende. Not only has this to be considered on the ground of health and the preservation of vegetation, but there is the further important economic consideration of utilising the sulphur gases for the manufacture of sulphuric acid, and thus securing a valuable product that is not only essential to chemical industry, but one that also plays an important part in many other industries.

As previously pointed out, where the manufacture of sulphuric acid is one of the objectives, certain conditions are imposed upon the roasting of blende, the most important of which is the conducting of the operation in muffle furnaces, as the sulphur fumes must not be contaminated and diluted with fire gases.

Most zinc ores are free from arsenic, consequently the sulphuric acid made from blende roasting usually commands a higher price than that made from iron pyrites, which almost invariably contains arsenic. On the other hand, zinc ores frequently contain fluorine, as calcium fluoride (fluor spar), which flotation and other concentrating methods have, unfortunately, not, up to the present, been able to separate effectively. Calcium fluoride is decomposed in the roasting furnace in the presence of silica and forms silicon fluoride, which is subsequently decomposed and causes the brickwork in the furnace to be appreciably attacked unless special precautions are adopted.
THE ZINC INDUSTRY

When the sulphur dioxide from blende roasting is converted into strong sulphuric acid of 60° Bé, the yield from 1 ton of 40 per cent. zinc blende amounts, on the average, to 80 to 90 per cent. Whilst the old-established English lead chamber method of sulphuric acid manufacture has to meet the increasing competition of the newer contact processes, these up to the present have found but little application in this country in connection with zinc ore roasting, although contact processes are in use in America and in Germany.

The lead chamber process, when working with hand-rumbled roasting furnaces, has to be carefully watched because of the irregular evolution of sulphur dioxide in consequence of intermittent rabling of the ore. In Germany it has been usual to reduce this difficulty by arranging for the furnace hands working on the different furnaces to start their shifts at different times, but, in spite of this, it is not possible to obtain a continuous current of uniform gas throughout the twenty-four hours, and, unless the process is watched carefully, loss of nitre will result.1

With modern mechanical furnaces this difficulty is completely overcome. Apart from some increase in the manufacture of sulphuric acid from blende roasting, there has been a large increase in the operation of contact plants for sulphuric acid production in this country since the outbreak of war, both as regards extension of existing works and the erection of new ones. Acid production was considerably increased in 1915 and 1916, and further small increase is in prospect. The importance of contact processes is therefore claiming the attention of British sulphuric acid manufacturers.

The contact process consists essentially in bringing about the combination of sulphur dioxide and oxygen by contact with heated finely divided platinum (hence the name "Contact process") and hydrating the sulphur trioxide so produced in the presence of strong sulphuric acid.

Hitherto the recovery of the sulphur from blende roasting has not received in this country the attention its great importance demands, and in this respect the British smelters are behind those on the Continent and in America, who have for some years given considerable attention to the production of sulphuric acid as a valuable secondary product of zinc smelting. As recently

ZINC SMELTING

pointed out by Moulden, it is now the practice in most European and many American works to carry on the blend roasting in conjunction with the manufacture of sulphuric acid, and this for two main reasons: (1) the restriction imposed by legislation in most thickly populated districts upon the discharge of sulphurous gases into the atmosphere, and (2) the value of sulphuric acid in such localities, due to the fact that they are consumers of the acid, and it therefore pays to utilise the sulphur.

It is not uncommon in Europe to find the roasting and the manufacture of sulphuric acid carried on in one district where the call for the acid is considerable, and the roasted ore distilled in another where conditions as to fuel, clay and labour are the more favourable. Economic considerations govern, of course, each individual case, and this system has reached its greatest development in Belgium and Germany, largely owing to the abundant and cheap facilities for transport afforded by the various canal systems.

**SULPHURIC ACID PRODUCTION IN UPPER SILESIA**

<table>
<thead>
<tr>
<th>Year</th>
<th>Metric tons</th>
<th>Metric tons</th>
<th>Total marks</th>
<th>Metric ton of 50º Be acid</th>
<th>Marks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1887</td>
<td>54,882</td>
<td>21,011</td>
<td>470,900</td>
<td>22.81</td>
<td></td>
</tr>
<tr>
<td>1891</td>
<td>66,230</td>
<td>20,076</td>
<td>749,900</td>
<td>22.85</td>
<td></td>
</tr>
<tr>
<td>1895</td>
<td>84,857</td>
<td>14,229</td>
<td>778,000</td>
<td>24.41</td>
<td></td>
</tr>
<tr>
<td>1899</td>
<td>121,002</td>
<td>16,091</td>
<td>1,071,000</td>
<td>16.77</td>
<td></td>
</tr>
<tr>
<td>1903</td>
<td>187,506</td>
<td>104,628</td>
<td>1,728,000</td>
<td>16.62</td>
<td></td>
</tr>
<tr>
<td>1907</td>
<td>14,045</td>
<td>100,840</td>
<td>2,187,000</td>
<td>15.65</td>
<td></td>
</tr>
<tr>
<td>1911</td>
<td>413,352</td>
<td>213,417</td>
<td>3,025,000</td>
<td>14.18</td>
<td></td>
</tr>
<tr>
<td>1912</td>
<td></td>
<td>254,008</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To illustrate the importance of the utilisation of the sulphur of zinc ores, Ridge gives the above figures for the output for Upper Silesia prior to the war. In normal times this district produces about 60 per cent. of the spelter made in Germany, but a considerable amount of calamine ore is still
THE ZINC INDUSTRY

available there, so that the maximum production of sulphuric acid from blende has not yet been reached; the tonnage of calamine treated is, however, steadily decreasing, but this is compensated for by an increase in the amount of blende treated, and permits of an increasing spelter and acid production. The last figures available are for 1912, and the table on page 113 shows the results for every fourth year since 1887.

The rapid annual increase in the production of sulphuric acid in the Upper Silesia district in recent years is shown by the following statement. In 1900 the production of sulphuric acid per ton of crude zinc produced amounted to only 0·08 metric ton; in 1905 it had increased tenfold to 0·85 metric ton, and in 1913 it still further increased to 1·34 metric tons.

"Prior to the war six works in Silesia still used their old reverberatory furnaces, so that not all the sulphur could be utilised, but for some years factory legislation has prohibited the emission of noxious fumes, and as the plants become worn out they have to be replaced by modern installations. The fumes from the reverberatory furnaces are scrubbed with milk of lime which is sent to waste. Five plants have lead chambers and make acid of 50 55° Bé.; this is generally concentrated in cascades or Kessler apparatus and in recent years largely in Gaiard towers. Three works have contact plants as well as lead chambers. There was in 1912 a total of 48 lead chambers.

"Of the total production of acid,

\[ 41,055 \text{ metric tons was sold as acid of } 50^° \text{ Bé.} \]
\[ 114,346 \text{ metric tons was sold as acid of } 50^°-60^° \text{ Bé.} \]
\[ 42,349 \text{ metric tons was sold as acid with } 98-100 \text{ per cent H}_2\text{SO}_4 \]
\[ 216 \text{ metric tons was sold as oleum with } 20 \text{ per cent } \text{SO}_3 \]
\[ 4,774 \text{ metric tons was sold as } \text{SO}_3 \]
\[ \text{and in addition } 2,855 \text{ metric tons of liquid } \text{SO}_3 \text{ was made.} \]

"The acid is used for making superphosphates, sulphate of ammonia, dynamite, and guncotton, and for refining mineral oil. It is distributed by rail over a wide area, some going into Russian Poland, Austria-Hungary, and even to Roumania.

"The position in the zinc smelting districts in Western Germany is analogous, but the make of acid there is larger in proportion to the production of spelter, because there is no local supply of calamine. The newer smelting works have been placed on navigable waterways so that freights on raw materials and finished products are low. The chamber process is used in all
the works except one, which has a contact plant; there is also
one installation making liquid sulphur dioxide.

"In 1913 in Germany 554,760 metric tons of blende was
roasted for making sulphuric acid; of this 87,439 tons was
imported from Australia and 50,181 tons from other countries.

"In Belgium blende is mainly roasted by the chemical manu-
facturers, who retain the sulphur and receive from the zinc
smelter in addition a payment of 6 to 8 francs per 1,000 kilos.
for roasting the ore. This was facilitated by the low freights
on the canals, which reduced transport charges to a very low figure.
In Belgium 65 per cent. of the total production of sulphuric acid
is made from blende, the amount of zinc acid is nearly 400,000
tons." 1

In America, fourteen zinc smelters make sulphuric acid,
mainly by the contact process. With the movement of the
zinc smelting industry to the eastward, which has taken place
in recent years in America, the separation of blende roasting and
zinc distillation has become more pronounced, as it has been for
a long time in Europe.

It is now regarded as good practice to roast the blende at some
convenient centre for the distribution of the sulphuric acid, and
then to reship the roasted ore to a suitable place for zinc distilla-
tion. This is now being done by many of the larger concerns.

The American production of sulphuric acid from blende,
calculated as 60° Bé. acid, in modern times is as follows 2:

<table>
<thead>
<tr>
<th>Year</th>
<th>Production in short tons (2,000 lb.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1911</td>
<td>250,943</td>
</tr>
<tr>
<td>1912</td>
<td>292,977</td>
</tr>
<tr>
<td>1913</td>
<td>299,218</td>
</tr>
<tr>
<td>1914</td>
<td>441,044</td>
</tr>
<tr>
<td>1915</td>
<td>484,942</td>
</tr>
</tbody>
</table>

The average price realised in 1915 was 8.85 dollars per short
ton. The use of the contact process for the treatment of the
sulphur fumes from blende has made its biggest strides in the
United States because the smelters are largely able to rely for
their ore supplies upon the produce of one or more home mines,
and are not dependent upon small lots of ore shipped from various
parts of the world, as has been the case in this country and on
the Continent. Consequently, the American smelters have been

1 Ridge.  2 *ibid., loc. cit p. 683
THE ZINC INDUSTRY

able to make provision for eliminating any harmful ingredients which may be present in the ore which they expected to be treating over a long period. The American smelters also have the advantage of having practically no hand-rabbled furnaces, all the blende roasting being done in the Hegeler furnace.

In the United Kingdom, sulphuric acid has hitherto only been made from zinc ore roasting in three plants, and it is estimated by Ridge that their combined output of acid does not exceed 25,000 tons of 140° Tw. acid a year. This amount corresponds with a production of about 10,000 tons of virgin spelter, which is approximately one-third the production of spelter in this country in 1913. Part of this metal was made from calamine, but since the available supplies of this ore are steadily decreasing, it is only a question of a comparatively short time before the whole of the virgin spelter will have to be smelted from zinc blende. This country has suffered badly in the past from the existence of wasteful and harmful metallurgical processes in certain areas, and especially in the treatment of zinc ores it has been customary to roast the sulphide ore in reverberatory furnaces from which the sulphur fumes cannot be used, so that the sulphur is wasted and the atmosphere polluted. While it is true that there has been some increase in recent years in the utilisation of the gases from blende roasting for the manufacture of sulphuric acid, it is much to be regretted that the Inspector of Alkah Works has had to report that considerable extensions of roasting plants for zinc ores were erected during 1915, and that arrangements had actually been made for further extensions in 1916, in which no provision whatever had been made for the recovery of the sulphur.

It is very desirable that such a procedure should be prohibited by legislation. That the matter is, however, receiving some attention is evident from the Inspector's latest report, in which it is stated that further progress has been made in the utilisation of the sulphur fumes from blende roasting for producing sulphuric acid, in spite of difficulties connected with the working of mechanical roasting furnaces and the scarcity of suitable labour for working the necessary hand furnaces. In the newest installations, the mechanical reverberatory Ridge furnaces have been adopted with satisfactory results.

It is necessary to remember that in 1913 the total consumption
of zinc in this country amounted to no fewer than 224,000 tons, of which 74 per cent. was imported.

After allowing for the metal produced by the British smelters, the imported metal was about 106,000 tons of spelter in addition to zinc in other forms. If, as pointed out by Ridge, this quantity were all made from blende, the roasting fumes could be used to produce annually 400,000 tons of 140° Tw. acid. There is no reason why this should not be done and the corresponding quantity of brimstone and non-cupreous pyrites, and pyrites with small copper content, now used for sulphuric acid production, displaced. Before the war the cost of making 140° Tw. acid from zinc ore roast gases in this country was only between 8s. and 9s. per ton, so that the operation is remunerative. Zinc ore must be heated because spelter is required, and if the roasting is not done here it will be done elsewhere. Cheap sulphuric acid has always been an important factor in the chemical industries, and the resources of the Empire should be used for its production within the Empire.

Although the main commercial use for the sulphur fumes from blende roasting is the manufacture of sulphuric acid, they are also utilised to a limited extent for making sulphates and liquid sulphur dioxide.

"Aluminium sulphate has been made at Flone in Belgium by passing the roaster gases into large chambers excavated in the hill-side and filled with alum shale." At Aumspn this method was also used for making alum with gas from reverberatory furnaces; it seems that sulphite is first formed, and this readily oxidises to sulphate.

"The manufacture of liquid sulphur dioxide was started by Grillo at Hamborn in Westphalia, because the fumes from the roasting furnaces were low in sulphur dioxide, and it was, at that time, considered impossible to utilise them for making sulphuric acid. The furnace gases pass to a scrubbing tower sprayed with water, which dissolves the sulphur dioxide, and the liquor gravitates to a series of pans, which are placed over the burners, the heat of which is sufficient to drive off the sulphur dioxide gas, which, after being cooled, is compressed and liquefied at a pressure of 7 atmos. In Germany two plants are in operation, viz., one at Hamborn and another at Lipine in Silesia, but, in this country, the method has not been employed on the

1 Ridge, loc. cit. p. 682.
THE ZINC INDUSTRY

fumes from zinc ore. The demand for liquid SO₂ is limited."

Lead and Silver.—These metals form important by-products in the smelting of zinc-lead ores, such as the Broken Hill concentrates, to which reference has already been made (p. 53).

When the ores contain much lead and silver, practically the whole of the silver and most of the lead will be found in the residues, which in this case are of commercial value.

They are usually concentrated, after grinding, by simple water-concentration in jigs and on tables, and the enriched material sold to lead smelters. The presence of lead is necessary in residues containing silver, as it acts as a collecting agent for the silver, consequently the lead content, as well as the silver, is taken into account when determining the price to be paid for the zinc blende. A deficiency of lead reduces the value of the ore because it causes loss of silver.

Zinc Fume.—This is another important by-product in zinc smelting, and consists of a mixture of finely divided zinc and zinc oxide. In America, zinc fume is called "blue powder." This product has increasing commercial value and its utilisation is dealt with later (p. 171).

Cadmium.—This metal is also obtained as a by-product. Cadmium occurs in small quantities, usually less than 0·5 per cent., in many zinc ores, such as the sulphide and carbonate, and practically all the cadmium of commerce is obtained from such ores. The metal is reduced by carbon and carbon monoxide at a lower temperature than zinc; consequently, in the process of extracting zinc from its ores, the cadmium, is obtained in the first portions of the product of the distillation, partly as metal and partly as oxide. It collects in the condensers and prolongs during the first two hours, and the product may contain from 5 to 8 per cent. of cadmium. This is submitted to redistillation to obtain the metal of commerce. Upper Silesia is the chief centre of cadmium production; some is produced in Great Britain, and a small quantity in the United States. The amount capable of being produced in Upper Silesia is comparatively large, but there has never been an important demand for the metal, and consequently its recovery has been undertaken by only a few concerns, and in limited quantity, most of the product from which it might be obtained being permitted to remain in the spelter. The consumption of the metal is small.
ZINC SMELTING

Its chief use is in the preparation of certain " fusible " alloys, in which advantage is taken of its low melting point. It is also used to a limited extent in electroplating. The metal possesses some very useful properties, and its electrodeposition may in the future find a more extended application. Compounds of cadmium are used in photography and also as pigments.

Owing to the limited demand, the metal is comparatively high in price, but as it occurs fairly abundantly in nature, this would doubtless be reduced if the demand increased.

Residues from Retorts. The exhausted residues drawn from the retorts are, in the case of clean ores, usually sufficiently free from zinc to be thrown away. The composition of these residues naturally depends, of course, on the composition of the ores, and with average ores they may be said to contain as a rule from 4 to 8 per cent of zinc. They contain carbonaceous matter in sufficient quantity to permit of profitable utilisation, and attention has already been drawn to the attempts that have been made in America to turn them to account.

When the ores contain much lead and silver, practically the whole of the silver and most of the lead will be found in the residues, which in this case are of commercial value.

They are usually concentrated after grinding by simple water-concentration in jigs and on tables, and the enriched material is sold to lead smelters, who also value them for the iron they contain, which acts as a flux in smelting.

The carbon content in the lead residues or slack is also a cheap reduction material.

The Cost of Zinc Production

The combined cost of roasting and distilling zinc ore necessarily varies in different smelting centres, as such conditions as character of ore, cost of raw materials, labour, fuel, distance from market, etc., differ with locality. The output, or works capacity, also has an important bearing on the cost of the metal produced. Practically two and a half tons of ore give one ton of spelter.

Pre-war British practice was to roast blende in reverberatory hand-rabbled furnaces at a cost of 118. to 125. 6d. per ton of ore.

This figure compares very favourably with Continental practice.
in modern mechanical furnaces, as shown by the working costs given below.

In the larger installations in the Swansea district the pre-war smelting charge of £2 15s. od. to £3 0s. od. may be taken as the inclusive cost, and as covering the roasting of the ore.

The following approximate figures have been given by J. Gilbert,\(^1\) as the average cost of smelting one ton of ore at modern works on the Continent.

The cost of roasting one ton of blende is:

<table>
<thead>
<tr>
<th>Item</th>
<th>Per ton of unroasted blende</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superintendence</td>
<td>9 d</td>
</tr>
<tr>
<td>Rolling, &amp;c</td>
<td>3 d</td>
</tr>
<tr>
<td>Roasting furnace work</td>
<td>1 d</td>
</tr>
<tr>
<td>Coal</td>
<td>2 d</td>
</tr>
<tr>
<td>Repairs</td>
<td>2 d</td>
</tr>
<tr>
<td>Sandfines</td>
<td>9 d</td>
</tr>
<tr>
<td>Various contributions</td>
<td>6 d</td>
</tr>
<tr>
<td>Crushing, &amp;c</td>
<td></td>
</tr>
<tr>
<td><strong>Total cost</strong></td>
<td>10 d</td>
</tr>
</tbody>
</table>

Details.—From 2,300 to 2,500 tons of crude blende produced 2,000 to 2,200 tons of roasted ore. Fuel consumption was 23 to 25 per cent. of furnace coal per ton of roasted blende. The cost of one ton of coal was 12s, on the basis price given below. Loss of metal in roasting, 0.05 to 1.0 per cent. Maximum value of sulphuric acid realised 9s. Actual cost of roasting, per ton, 1s. 7d.

The above figures refer to Rhenish roasting furnaces producing about 8 to 8.5 tons of roasted blende when working normally. With crude ore containing from 23 to 25 per cent. of sulphur and about 0.5 per cent. of lime, and returning after roasting about 1.1 per cent. of sulphur, the yield of sulphuric acid from the extractable sulphur is from 85 to 92 per cent., normally about 90 per cent.

Cost of distillation of zinc ore at a modern Rhenish works with a producing capacity of 10,000 to 12,000 tons per annum:

## Zinc Smelting

<table>
<thead>
<tr>
<th>Description</th>
<th>Per ton of ore treated (£d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management, office, &amp;c</td>
<td>0.90</td>
</tr>
<tr>
<td>Generators (wages, coal), reductive coal</td>
<td>0.17</td>
</tr>
<tr>
<td>Repairs of furnace</td>
<td>0.1</td>
</tr>
<tr>
<td>Fireproof material, tempering</td>
<td>0.05</td>
</tr>
<tr>
<td>Zinc stores and sieving of zinc dust</td>
<td>0.06</td>
</tr>
<tr>
<td>Various contributions to funds, &amp;c</td>
<td>0.01</td>
</tr>
<tr>
<td>Sundries (water, light, &amp;c)</td>
<td>0.02</td>
</tr>
<tr>
<td>Ore mixing</td>
<td>0.0</td>
</tr>
<tr>
<td>General expenses</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Each ton of ore treated: total actual costs: 0.10

### Details

- Ore treated 2,000 to 3,000 tons per month. Production, 1,000 to 1,400 tons of spelter and 100 to 140 tons of zinc dust monthly. Percentage of zinc contained in the roasted ore, 50 to 51 per cent. Loss in smelting (ore poor in lead), 12 per cent. Durability of retorts, forty to forty-five days. Coal, furnace, and tempering, 115 to 120 per cent. on ore weight, at 10s. 6d. to 10s. 9d. per ton delivered at works. Basis price main coal, 13s. 9d. delivered at works. Reduction coal, 40 to 45 per cent. of weight of ore.

- The ordinary life of a zinc furnace is about six years, but some regenerative furnaces have given good results, even after eight or ten years.

- The costs of repairs vary from £150 to £300.

- Considerable discussion has taken place since the outbreak of war as to the possibility of smelting a large proportion of the Broken Hill zinc concentrates in the United Kingdom.

- Without entering into the many problems involved, the following estimate for the treatment of the concentrates in Swansea recently put forward may prove to be of interest; an allowance, equivalent to one-half of the cost of roasting, is made in this estimate for the recovery of the sulphur as sulphuric acid.¹

- The estimate is based on a recovery of 85 per cent. of the zinc, 60 per cent. of the lead, and 50 per cent. of the silver from concentrates containing zinc 47 per cent., lead 8 per cent., and silver 10.5 oz. per ton. On this basis, the spelter recovered would be 0.4 ton for each ton of concentrate treated.

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¹ Quoted in the Bulletin of the Imperial Institute, 1916, vol. xiv, p. 68, but original source not given.
## The Zinc Industry

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost per ton of ore (L s. d.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roasting</td>
<td>3 9½</td>
</tr>
<tr>
<td>Furnace labour</td>
<td>12 2</td>
</tr>
<tr>
<td>Fuel and reducing coal</td>
<td>1 0 5</td>
</tr>
<tr>
<td>Retorts and condensers</td>
<td>4 8½</td>
</tr>
<tr>
<td>Repairs</td>
<td>1 2</td>
</tr>
<tr>
<td>Administration and overhead charges</td>
<td>2 0½</td>
</tr>
<tr>
<td><strong>Cost of concentrates at works</strong></td>
<td><strong>2 4 3½</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4 15 10</strong></td>
</tr>
<tr>
<td>Deduct value of residue less treatment costs</td>
<td>7 0 1½</td>
</tr>
<tr>
<td><strong>Net total</strong></td>
<td><strong>26 7 5½</strong></td>
</tr>
</tbody>
</table>

### The Conditions of Labour in Zinc Smelting

The work connected with the distillation of zinc is very arduous, and considerable skill is required in conducting the process, especially in charging the retorts, an operation which needs great dexterity.

In the chief zinc-smelting centres the workmen are specially trained, and in many cases the knowledge required for the more important parts of the process has been handed on from father to son through several generations of workers. On the Continent, special provision has been made to train the men required so that the output shall not suffer from lack of skilled workers.

There is a general agreement that the labour conditions in this country, as compared with the Continent, are detrimental to output. It is not, however, suggested that this is due to inferiority of the men individually.

Unquestionably the most difficult part of the problem connected with the development of the British industry is the training and organisation of the labour required for the smelting process. Difficult though these are, they should be undertaken without delay, for America has shown that they can be done, and done rapidly when necessary.

The system of payment of wages adopted in this country differs from that in use on the Continent. In the British spelter works the Datel system is in use, a fixed rate of wage being given per shift, according to the duties to be performed.
On the Continent the system of giving premiums has been attended with marked success.

At the great Belgian zinc works of La Vieille Montagne, the smelters and mill men receive, in addition to a fixed wage, a premium calculated on the output, and a special premium is also given for unusual energy. In some cases the firemen receive a similar premium, based on the time their furnace lasts without repair. In other cases, the workmen receive a premium when they obtain from the ores a greater amount of metal than that which they are calculated to yield. Two-thirds of this premium is paid periodically with the regular wage. The remaining third is retained until the end of the year, and it is not paid then unless the workmen have worked regularly throughout the year.

In some of the German works additional premiums are paid on the production of zinc dust, of metallic lead recovered from the distilling furnace, and the life of the retorts.

The tendency of zinc smelters within recent years has been to substitute, as far as possible, mechanical labour for manual labour. Especially is this the case in regard to roasting furnaces, but in the case of the distillation process, although mechanical charging and discharging appliances have been introduced, they have only been adopted to a very limited extent. The various operations connected with the distillation process do not lend themselves readily to mechanical devices. However, attention is being given to the possible application of mechanical appliances to the manipulation of zinc distillation furnaces, and a certain amount of success has been attained, more particularly on the Continent and in America.

As previously stated, machine-made retorts have now very largely replaced those made by hand, thus effecting a considerable saving in manual labour.
CHAPTER VII

OTHER METHODS OF ZINC PRODUCTION

The Electric Smelting of Zinc Ores

Whilst practically the whole of the zinc of commerce is produced by distillation, great efforts have been made in recent years, and large sums of money spent, in the endeavour to simplify, expedite, and cheapen extraction, and in particular to render the process of zinc production continuous.

It is recognised that the distillation process leaves much to be desired, because the heat is applied uneconomically, as it has to pass through the walls of the retorts, and in consequence these retorts must be relatively small, restricting the output of metal, and much hand labour is required in treating the ore.

Of all the various newer processes that have been devised and experimented with for the extraction of zinc from its ores only two may be said to have approached commercial success, viz.: (1) electro-thermal methods, or electric smelting, and (2) hydro-metallurgical methods. In the electro-thermal methods the distillation is continuous, the reduction and distillation being effected by heat produced within the reducing vessel or furnace itself, and in hydro-metallurgical, or wet methods, the zinc is first dissolved and then recovered from solution by electrolysis.

Both these methods have been applied to the recovery of the metal in low grade ores and in ores which cannot be satisfactorily treated by the usual distillation method. The electro-thermic production of zinc in the electric furnace was first attempted, in 1885, by the Brothers Cowles, who developed the resistance type of furnace originated by Despretz in 1849, in which a core of carbonaceous material in the charge itself carries the current in a horizontal direction. In 1901 C. P. G. De Laval erected the first electric furnace for smelting
OTHER METHODS OF ZINC PRODUCTION

zinc on a commercial scale, and four years later works were erected in Sweden to carry out his process. Since that time a considerable amount of attention has been given to electric furnaces for smelting zinc ores.

As pointed out by Professor Gowland, the chief drawbacks that impede the commercial success of the application of the electric furnace to the smelting of zinc ores are the cost of the current and of the electrodes, the loss of metal and the difficulty of obtaining a fair proportion of the zinc as metal and not as oxide, which has to be re-treated.

In spite of these drawbacks, the electric smelting of zinc ores has held the attention of metallurgists for a long time, and during recent years a large amount of work has been done on the problem of treating, not merely the high grade ores that are easily distilled in the ordinary retort furnaces, but also the low grade and complex ores that can hardly be treated at all by existing methods.

In discussing the electric smelting of zinc ores, Prof. A. Stansfield considers that the first point to make clear is the great difference between the old practice and the methods attempted by the electro-metallurgist. In the usual retort, the charge of roasted ore and coal is heated gradually for a number of hours, driving off first the moisture and the hydrocarbons from the coal, then the carbon dioxide resulting from the reduction of easily reducible metals such as iron and lead, and finally, when a temperature of more than 1000° C. has been reached, the zinc vapour itself with its equivalent of carbon monoxide.

Under these conditions the condensation of the zinc vapour is satisfactory, and a large proportion of the metal is obtained in the molten condition. This operation could no doubt be reproduced in an electric furnace, and would have the advantage that somewhat larger retorts could be employed, but the electric furnace inventor is not content with so moderate an attainment; he wishes to change the whole process from the present step by step method to a continuous smelting operation in which the ore and reducing carbon shall be fed into the furnace at one point, the zinc flow out of the condenser, in the molten state, at another point, the slag be tapped off from a third point, and lead bullion,

1 "Metallurgy of Non-Ferrous Metals," 1st Edn. London 1914, p 396
THE ZINC INDUSTRY

carrying any gold and silver values, shall flow out at a fourth opening in the furnace.

The task thus set is by no means easy; if the ore mixture goes without preparation into the smelting chamber, the moisture, hydrocarbons and carbon dioxide will come off in admixture with the zinc vapour and carbon monoxide, and the zinc will condense from this mixture mostly in the form of a blue powder. By a preliminary heating of the ore mixture in a separate chamber the moisture, hydrocarbons and carbon dioxide can be removed to a large extent, but it is difficult to effect their complete removal.

Thus it appears that there are considerable difficulties to be overcome before a successful electric furnace process can be developed.

One difficulty, inseparable from the ordinary process of zinc smelting, is the need for an almost perfect roast of the sulphide ore, as a preparation for the distillation process.

Stansfield considers that the electric furnace process, on the other hand, holds out the hope that this roasting operation can be dispensed with, or at least that it need not be nearly so thorough. This possibility depends on the removal of the sulphur in the electric furnace in combination with metallic iron, or more cheaply with calcium supplied in the form of lime.

This latter reaction has been studied by O. W. Brown and W. F. Oesterle, who find that it takes place very completely, in the electric furnace, according to the equation

\[ \text{ZnS} + \text{CaO} + \text{C} = \text{Zn} + \text{CaS} + \text{CO} \]

Early experimental work by W. R. Ingalls at the McGill University confirmed the opinion that, if electric smelting is to offer any advantages over distillation in retorts, the process must be continuous, and all modern furnaces are constructed on this principle. In many of the electric furnaces now in use the energy is applied with great ingenuity and high efficiency is obtained, whilst efforts are made to reduce the electrode consumption to a minimum.

The reduction in the electric furnace seems to take place more rapidly than in retort smelting, but the reaction between the carbon and carbon dioxide does not appear to occur to such an extent in the former as in the retort. Hence the electric furnace

\( ^{1} \) "The Electric Smelting of Zinc," Transactions of the American Electrochemical Society, 1905, vol. viii, p. 171
OTHER METHODS OF ZINC PRODUCTION

contains an atmosphere comparatively rich in carbon dioxide, so that a larger amount of fume (blue powder) is formed than when the retort furnace is employed.

Cote and Pierron, Johnson and others have attempted, with some success, to solve the carbon dioxide problem by such means as passing the gases through columns of incandescent carbon. But while progress has been made, the discovery of how to avoid oxidation of the zinc deposits, as formed under the conditions prevailing in electric smelting, is still the problem which metallurgists have to solve in connection with this method of zinc smelting.

The continuity of operation in the electric furnace implies discharging the residue as a slag that will flow, and there has been a tendency for inventors of electric zinc furnaces to render the charge fusible, so that fluid slags may be tapped as from cupolas. This condition, however, prohibits any great excess of carbonaceous material in the charge, and accounts for the higher percentage of carbon dioxide frequently found in continuously operated furnaces.

Among the various types of electric furnace now in use, those of De Laval, Cote and Pierron, and Johnson may be mentioned. The first two may be selected as typical, and as involving the two types of electric furnace; De Laval employs the electric arc, and Cote and Pierron slag resistance, as means for converting electric energy into heat.

The De Laval process, which has been carried out commercially for some years at Trollhattan and Sarpsborg, in Sweden, develops heat by means of the arc, current being generated from water power at prices variously given as from 38s. to 50s. per electrical h.p.-year. The works are equipped for 18,000 electrical horse-power and produce over 6,000 tons of refined zinc annually.

The process is conducted in two operations, the first being the smelting of the roasted ore in an arc furnace for the production of a coarse metal containing zinc, lead and other metals, and the second the refining of this coarse metal by distillation in another arc furnace.

Much of the zinc is obtained as fume or dust.

The furnaces are of the resistance type, with one large vertical carbon electrode passing through the roof, the other electrode being a carbon block in the bottom of the furnace. Each furnace

\footnote{Salman, loc. cit.}
has a capacity of about 3 metric tons and smelts nearly 3 tons of ore in twenty-four hours.

The complex argentiferous zinc-lead sulphide ore is first roasted to expel most of the sulphur. The roasted ore containing about 7 per cent. to 8 per cent. sulphur is then mixed with anthracite or coke and flux and charged through a hopper into a closed electric "melting" furnace, where most of the zinc and some of the lead are volatilised, and condense chiefly as crude spelter high in lead, and partly as blue powder, which has to be re-treated.

The other part of the lead is reduced to metal and is tapped out with the slag. It contains a considerable proportion of the silver present in the ore. Some matte (fused sulphides) is formed, and this and the slag contain some of the lead, zinc and silver. The crude spelter containing lead passes to the electric refining furnace, where the zinc is distilled, producing, on condensation, spelter of high grade, and a further quantity of zinc dust, leaving the remainder of the lead and silver as base bullion. Two melting furnaces supply one refining furnace.

The company owning these Swedish works reported recently that its smelting operations have not yet proved commercially profitable, considerable progress has, however, been made and it is hoped that things will eventually turn out well. About half the cost of smelting is for electric current, and it is thus evident that very cheap electric power is essential for the commercial success of the process.

It would appear that the solution of the difficulties connected with the condensation of the zinc are to be sought, not in the condenser proper, but in the character of the gas delivered to it. The attempt to condense a commercial proportion of the vapour resulting from the reduction of zinc oxide has so far failed, this being the crucial point of electric zinc ore smelting.

On the basis of ore alone the consumption of power at Trollhättan, according to report, was 2,078 kilowatt-hours per 100 kilograms of ore, but for every ton of ore smelted about two tons of zinc powder had to be resmelted.

The smelting of 1,000 kilograms of ordinary zinc ore (25–30 per cent. zinc) is reckoned to require from 900 to 1,000 kilowatt-hours. Each furnace smelts about 2,800 kilograms of ore in twenty-four hours.

The Cote and Pierron process is carried out on a small scale in France, notably at the Arundy Works in the Pyrenees, which
OTHER METHODS OF ZINC PRODUCTION

have been in operation since 1904; experimental work with this process has also been carried on since 1914 at Ugine and Iperre, in Savoy, and at Quenean in Belgium.

An important feature of the process is the melting of blende in the raw state, that is, without previous roasting to remove sulphur. Whilst simplifying the metallurgy of the process, this method increases the difficulties of operation of the electric furnace. The Cote and Pierron process is based on the fact that iron replaces lead in lead sulphide at a comparatively low temperature, and zinc in zinc sulphide when the temperature is increased. It is claimed that the process effects a complete separation of the zinc and lead. The furnace is a combined arc and resistance furnace. It is circular, with sides and bottom lined with graphite, thus giving a conducting lining; the roof is a low dome of fire brick. A carbon electrode, which can be raised or lowered, passes through an opening in the centre of the roof; the other electrode, a cone of graphite, projects from the hearth. The furnace is charged through the roof, and the lead, slag, and iron sulphides are tapped through an aperture in the side. The volatilised zinc passes through an outlet in the upper part of the furnace to the condenser, which consists of a cylindrical, shaft-like chamber of firebrick filled with coke or anthracite, and provided with a taphole at its base for the discharge of the condensed zinc.

The charge, consisting of a mixture of 200 kilogrammes of ore with iron turnings, and lime as flux, is introduced into the hot furnace, and the first reaction of iron on lead sulphide is effected at a relatively low temperature. The resulting lead is then tapped. The temperature is now raised and the decomposition of the zinc sulphide by the iron brought about. The zinc distils over, and is condensed in the condenser, the carbon in the upper part of which is kept at a red heat, to prevent as far as possible the formation of zinc fume. Finally, the iron sulphide and the slag are run out. At the Arundy Works a furnace of 350 kilowatts, with alternating-current at 55 volts, treats one ton of blende (35 per cent zinc) per 95 to 100 horse-power-days.

It is claimed that not more than 2 per cent. of zinc remains in the slags.

In America a considerable amount of experimental work has been done with W. McA. Johnson's electric furnace at Hartford,
THE ZINC INDUSTRY

Connecticut, and it is stated that arrangements have been made to erect a 100-ton commercial plant at Keokuk, Iowa, for the treatment of very complex ores. This is a continuous process with furnace of the resistance type, in which the charge carries the current.

The charge is heated to about 900° C. in a continuous pre-heater before reaching the furnace. To prevent the formation of blue powder, the carbon dioxide formed in the smelting zone is rendered innocuous by passing the gases from the furnace through an electrically-heated carbon filter, whereby the carbon dioxide is converted into harmless monoxide.

This process has been investigated by the Dominion Government with a view to its application in British Columbia, but apparently complete success has not yet been reached.

Another process that is claiming attention is the Snyder process, which has been applied to the treatment of argentiferous zinc-lead ores. The ore is roasted to oxide, and fluxes added so that the mixture will melt at about 1100° C. The molten mixture is then treated in an electric furnace and results in the reduction of the metals present. The lead, alloyed with the silver, collects below the slag, and is tapped off, and the zinc which is oxidised and volatilised is condensed in brick chambers.

Although electric zinc smelting has now passed beyond the experimental stage and become a commercial process, it is being continually investigated by those especially interested in this method of smelting zinc ores. An expert on zinc production, J. C. Moulden, has recently expressed the opinion that, given favourable primary conditions and the inevitable improvement to be brought about by experience, the electhermic method of distillation will in the future substantially influence the production of zinc.

_Hydro-metallurgical Processes of Zinc Production_

Since Parnell took up the question of treating complex zinc-lead ores at Swansea in 1881, many wet methods of zinc extraction have been suggested and experimented upon, but until quite recently none have met with commercial success owing to their inability to produce metallic zinc.

2 _Ibid._

130
OTHER METHODS OF ZINC PRODUCTION

Unlike most metals, zinc cannot be precipitated from its solutions by common metals, and if other precipitants are used and it is obtained as oxide, this must be mixed with carbon and treated by a distillation process in order to obtain the zinc as metal. Thus Parnell's process consisted in roasting the ore to sulphate, leaching with water, evaporating the purified zinc sulphate solution to a paste and adding powdered zinc blende. This mixture was then heated to produce zinc oxide, which was reduced in retorts and distilled. The argentiferous lead residue left in the vats was sold to lead smelters for the extraction of the lead and silver.

The difficulty of obtaining the zinc in the metallic state has been the main reason for the slow development of wet methods of zinc production. However, where formerly it did not pay to leach out zinc in the form of sulphate, owing to the limited market for the salt and the prohibitive cost of converting it into oxide, the growing demand for white pigments free from lead has made it possible to avoid the necessity of extracting the zinc as metal by crystallising the dissolved zinc as sulphate.

Thus, as the result of the increasing demand for zinc sulphate for the production of "lithopone," to which reference is made on p. 193, the unit of zinc in crystalline sulphate has a considerably higher market value at present than a unit of zinc in the form of oxide for smelting purposes.

More recently, hydro-metallurgical processes have been devised in which the zinc after having been obtained in solution, either as sulphate or chloride, is precipitated in the metallic state by electrolysis, but while the difficulties which formerly attended the precipitation of electrolytic zinc have so far been overcome as to form the basis of recent methods, the high cost of electric power has operated against the commercial success of most of these processes.

Létang was one of the earliest workers in the production of zinc by electro-deposition, in his process the crushed blende was carefully roasted at a low temperature to produce zinc sulphate, which was dissolved with dilute sulphuric acid. The solution was then electrolysed, using an anode of lead (or carbon) and a cathode of zinc.

Electrolytes of zinc chloride solution are said to be more economical in electric current than solutions of zinc sulphate, the electromotive force necessary for the decomposition of the
THE ZINC INDUSTRY

former being less than for the latter. In practice, however, it has been found to be more satisfactory to extract the zinc as sulphate than as chloride, and in most of the wet processes now in use the electrolyte consists of zinc sulphate.

Considerable attention has been given during the past few years to the electrolytic separation of zinc from its ores, especially so-called complex ores, and a specially pure zinc is now being satisfactorily produced by this process.

Compared, however, with smelting, the amount of zinc produced by electrolytic separation is very small, though the importance of the latter process is gradually increasing in districts where the special nature of the ore renders the application of hydro-metallurgical processes on a commercial scale possible. There is, however, little prospect that wet methods of zinc production will be sufficiently successful on a commercial scale to enable them to compete with the distillation processes.

The only commercial processes in the electro-metallurgy of zinc by direct wet methods appear to be those of Nahmsen, of Hoepfner, and of Dieffenbach.\(^1\)

The Nahmsen process has been employed at Lipine, Silesia, since 1893, the electrolyte used being a solution of the double sulphate of zinc and magnesium. The Hoepfner process is in operation at Duisburg, in Germany, and two plants were erected in 1914 at Kristiania and Balestrand, in Norway, for the treatment of Broken Hill flotation concentrates.

A modification of the method originally devised by Hoepfner has been employed with considerable success in the United Kingdom at the works of Messrs. Brunner, Mond and Co., near Northwich, Cheshire, where considerable quantities of zinc of high grade are now made and employed for the manufacture of brass for cartridge cases and other articles requiring a highly ductile alloy.

The ore is roasted to convert the zinc into oxide, which is then transformed into zinc chloride by carbon dioxide and a solution of calcium chloride, waste calcium chloride liquors from the Solway ammonia-soda process being used for the purpose. This results in the solution of the zinc as chloride and the precipitation of calcium carbonate. The zinc solution is purified by a series of operations analogous to those devised by Hoepfner.


132
OTHER METHODS OF ZINC PRODUCTION

The iron and any manganese are precipitated by means of chloride of lime and calcium carbonate, and the other metals, copper, lead, etc., by the addition of zinc fume to the clear solution. The purified solution is electrolysed, using revolving iron disks as cathodes and carbon anodes enclosed in cloth diaphragms, a current density of 30 amperes per square foot of cathode surface being employed. The solution for electrolysis should contain from 0.08 to 0.12 per cent. of free hydrochloric acid.

The products of electrolysis are metallic zinc and chlorine, the latter being subsequently converted into bleaching powder. The recovery of such a valuable by-product as chlorine from a waste material is a very important factor in the economic success of this process at Messrs Brunner Mond's works. The zinc produced has a purity of about 99.90 per cent.

The Dieffenbach process is applied to a Westphalian iron pyrites, containing 8 per cent. of zinc, which is converted into chloride by roasting with sodium chloride, and extracted by leaching with water. The residue, which is said to contain only 0.5 per cent. of zinc, is smelted for iron, whilst the aqueous solution of zinc chloride is electrolysed in double-compartment vats, the anode compartments being completely closed. The liberated chlorine is employed in the manufacture of calcium hypochlorite.

Since the outbreak of war there has been a very important development in the electrolytic production of zinc in America, especially at Anaconda and Trail. The processes being used in American plants are based on sulphuric acid leaching, and subsequent electrolysis of the zinc solution, using lead anodes.

The largest American plant for electrolytic zinc production is that of the Anaconda Company, at Great Falls, Butte, which when complete will produce 35,000 tons of electrolytic zinc annually. The ore is concentrated, chiefly by flotation, and is then roasted until the sulphur content is 2 or 3 per cent., mostly as sulphate.

The temperature must not exceed 732° C., in order to avoid the formation of zinc ferrite. The roasted residue is leached with spent electrolyte to which a sufficient quantity of sulphuric acid has been added. A little manganese dioxide, followed by

THE ZINC INDUSTRY

powdered limestone, is added to remove iron, arsenic and antimony. Lead, silver and gold remain in the residue, and the only impurities in the filtrate are copper and cadmium, which are precipitated by metallic zinc. Formerly zinc fume was used to precipitate the cadmium, but difficulties were encountered, and the plan now adopted consists in running the clear solution through tube mills containing zinc balls.

After filter-pressing, the solution is electrolysed with lead anodes and aluminium cathodes. The current density is 20 to 30 amperes per square foot of cathode surface (220 to 330 per sq. m.), and the current efficiency 93 to 94 per cent. The cathodes, which are stripped every forty-eight hours, are melted and cast into ingots. The process is said to be particularly suitable for the fine concentrates obtained by flotation, which are troublesome to treat in retorts.

At the Welland plant, Ontario, recently erected by the Weedon Mining Company, the solution of the zinc and electrolysis of the solution are performed in the same vat, the cathodes being enclosed in canvas bags. Other works adopt the arrangements at Anaconda.

It is proposed to use the method employed by the Anaconda Copper Company, described above, for the treatment of the complex zinc-lead sulphide ores which occur in large quantities in the Mount Read district of Tasmania. In these ores the metals are found in such an intimate state of fine division as to render concentration almost impossible. After much experiment, chemical treatment has been found to be the only feasible and economic method of dealing with such ores, and after trying several methods of wet extraction it is proposed to use the Anaconda method as stated. This has been rendered possible by the electric power scheme of the Tasmanian Government which has been in operation since May, 1915. The main water-storage basin is the Great Lake, and the present output is about 10,000 horse-power, but this can be very considerably increased in the future. The probable consumption of hydro-electric power in Tasmania in the near future for zinc ore reduction processes is estimated as 2,500 horse-power.1 The electrolytic production of zinc is proposed by several companies.

OTHER METHODS OF ZINC PRODUCTION

In the Gillies process, the zinc sulphate is electrolysed between a rotating cylindrical zinc sheet as cathode and lead anodes, with a woollen diaphragm for separating the gases.

The bisulphate process is another wet method of zinc extraction which has been tried in several localities, including Tasmania, for the treatment of complex sulphide ores containing zinc. In this process the roasted ore is pulped with water and sulphur dioxide gas passed through the mass, resulting in the zinc passing into solution as the soluble bisulphite, \( \text{ZnH}_2(\text{SO}_4)_2 \). This solution is pumped into another tank where the mono sulphate of zinc is precipitated, and this yields the oxide on roasting in a muffle furnace.

The sulphur dioxide evolved at two stages in the above process is added to the roaster gases, which are in turn employed as the source of the sulphur dioxide used in the initial leaching process. A certain quantity of sulphate of zinc collects in the leaching solution, and this is periodically recovered by crystallisation.

The "French" process of zinc recovery, which is in operation at Silverton, British Columbia, has several points of interest. Roasted zinc blende is treated with a solution of sodium bisulphate (nitre cake) containing a small quantity of a manganese compound, usually manganese sulphate. After about an hour the solution has extracted almost the whole of the zinc, whilst the iron, lead and silver remain in the insoluble sludge.

The liquor from the first extraction is run on to a second charge of ore in order to neutralise its acidity, and when this has taken place the clear solution is run into vats and the zinc recovered electrolytically, using lead and zinc electrodes. Any manganese present is deposited on the lead as manganese dioxide, which is redissolved and used over again, whilst the zinc is deposited on the zinc electrode. As the zinc is electrolytically deposited, the sodium bisulphate is regenerated, and when all the zinc has been removed the solution is again ready for use and is employed in re-treating the charge of ore previously used to complete the neutralisation of the solution. It is stated that the process can be employed equally well for low or high grade ore, although in the former case the cost of treatment is somewhat higher.

In the opinion of W. R. Ingalls, the electrolytic refining of zinc is an established process.\(^1\) Bulletin of the Imperial Institute, 1916, vol. xiv, p. 60. \(^2\) Loc. cit.
THE ZINC INDUSTRY

zinc is only practicable where power is very cheap, or where other conditions are exceptionally favourable, such as a readily soluble ore, as at Anaconda, or one high in silver.

The crude zinc ore at Anaconda lends itself very successfully to treatment by the flotation process, which gives a high-grade concentrate. This is of such a nature that by roasting and leaching with weak sulphuric acid the percentage of zinc extracted as sulphate is unusually high.

This is not often the case with ordinary ores, which very frequently contain sensible quantities of iron and manganese which form troublesome compounds in roasting and lower the percentage of zinc recoverable by lixiviation.

The recovery of silver from zinc ores, which is only 65 per cent. in the distillation process, amounts to 90 or even 95 per cent. in the electrolytic process.

The concentrated ore at Anaconda contains 20 oz. of silver per ton.

The zinc produced is of high purity, and in view of the increasing demand for pure metal for alloying purposes the electrolytic methods of zinc extraction are receiving renewed attention, especially in connection with the recovery of the metal from by-products and residues, etc., containing zinc. The prospects of electrolytic zinc in relation to distillation methods of zinc extraction have been very ably dealt with by W. R. Ingalls in a recent paper on "Electrolytic Zinc," 1 to which all interested in the subject are referred.

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2. Loc. cit.

135
THE ZINC INDUSTRY

to a temperature of from 100° C. to 150° C., after which treatment it retains its malleability when cold sufficiently to admit of being rolled into thin sheet or drawn into wire. On a large scale, however, the metal is rolled hot. At a temperature above 205° C. zinc again becomes so brittle that it may be pulverised in an iron mortar. In common with other metals, zinc is hardened by mechanical treatment, such as rolling, and requires annealing at a low temperature to restore its malleability. It has been shown by T. K. Rose\(^1\) that, in the case of pure sheet zinc 1.25 millimetres thick, softening is nearly completed in about half an hour at a temperature of 125° C.

Zinc is less tenacious than most metals in common use, its tenacity, according to Karmarsch, being 2,809 lb. per square inch when cast, and between 18,703 lb. and 22,188 lb. when in sheets or wire.

Measurements of the tensile strength of rolled zinc have been made by H. F. Moore,\(^2\) which show that zinc, either in the cast or rolled state, has no definite yielding point. The breaking load of thin rolled zinc (not more than 0.015 inch thick) was found by Moore to be about 24,000 lb. per square inch, and its tensional modulus of elasticity 11,500,000 lb. per square inch. Rolled zinc is somewhat stronger in tension across than with the grain. The stress developed in punching or shearing the rolled plates is about 40 per cent of that developed with mild steel plates.

The sheets are more ductile with the grain than across it. Results obtained by T. K. Rose\(^3\) show that zinc hardened by rolling is in an unstable condition at the ordinary temperature and undergoes a gradual change to the soft state. Thus the scleroscope hardness of rolled zinc was found to be 30, and after ninety-seven days the hardness had fallen to 3.2. Zinc may be granulated by pouring the molten metal into water. In hot water it is obtained in the form of small globules, known as bean-shot, and in cold water flakes are produced, known as feathered-shot metal. Both these forms of granulated zinc are prepared commercially.

The density, or specific gravity, of cast zinc ranges from 6.9 to 7.2, according to the temperature at which it has been

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\(^1\) *Journal of the Institute of Metals, 1912*, vol viii, p. 114.


THE PHYSICAL AND CHEMICAL PROPERTIES OF ZINC

cast and the manner in which it has been cooled. By rolling the metal its specific gravity is increased to about 7.25.

The electrical conductivity of zinc is 25.6 to 29.9, according to the determinations of several observers, and its thermal conductivity 28.1, compared in both cases with silver as 100.

The atomic weight of zinc is 65.37 (taking O = 16), and its symbol is Zn.

Zinc melts at a comparatively low temperature, its melting point being 419° C., it boils at 950° C., the vapour burning in air with a characteristic brilliant bluish-green flame, and the production of zinc oxide, a soft, white, flocculent substance resembling wool, and formerly known as philosopher's wool, or "flowers of zinc." According to Ingalls, zinc burns in the air at a temperature as low as 500° C. It can be distilled in quantity at a bright red heat, and on cooling condenses in globules which coalesce, when a reducing atmosphere is maintained.

When it passes from the cold solid to the molten condition zinc increases in volume 11.1 per cent. It contracts but slightly on cooling from the molten state, and is thus well adapted for castings. The molten metal retains a small quantity of zinc oxide, which separates on solidification, presenting very thick crystal boundaries when examined under the microscope.

Zinc expands 4/10th of its length by heating from 0° C. to 100° C.

The metal is not affected by pure dry air or by oxygen at the ordinary temperature, but under ordinary moist atmospheric conditions it gradually acquires a coating of the greyish-white basic carbonate which protects the metal from further corrosion. In consequence of this property, zinc is used in the form of sheets for roofing purposes, and is also employed as a protective covering for iron, which when thus coated is said to be galvanized, a term that is somewhat misleading, since the iron is not ordinarily coated by electrical deposition, but by dipping the iron into a bath of molten zinc. The industrial value of zinc is largely due to this protective property.

Pure zinc is scarcely acted upon by pure sulphuric or hydrochloric acid, either dilute or strong. The presence of small quantities of impurities, however, determines the rate of solution of the metal. Hence ordinary commercial zinc is readily attacked by these acids with rapid evolution of hydrogen, and on this account the metal is used as the positive element in electric batteries.

139
THE ZINC INDUSTRY

When zinc is brought into contact with mercury, zinc amalgams are formed which are only very slowly acted upon by dilute sulphuric acid; therefore, by the superficial amalgamation of the zinc plates used for electric batteries, the same result is obtained as though the zinc were perfectly pure, and no solution of zinc takes place until the electric circuit is closed. Amalgamation protects zinc from corrosion by acids, because the discharge potential of hydrogen on mercury exceeds the potential of zinc.

Sulphuric acid dissolves zinc appreciably more slowly than hydrochloric acid with an equal concentration of hydrogen ions.

Owing to the differences in the crystalline structure of the metal, cast zinc is less easily acted upon than rolled zinc by dilute acids. The dark grey residue obtained on treating the commercial metal with acids consists chiefly of lead.

Both pure and commercial zinc are dissolved readily by alkalis.

Water has no action on zinc at the ordinary temperature, if air is excluded, but at a red heat the metal readily decomposes the vapour of water and is converted into oxide.

Carbon dioxide very readily oxidises zinc vapour with the production of carbon monoxide and zinc oxide. This reaction, as previously pointed out, is of considerable importance as it constitutes a decisive factor in the metallurgy of zinc, and confines within very narrow limits the methods that are applicable, on a commercial scale, to the extraction of the metal from its ores.

Zinc is strongly electro-positive and readily precipitates most other metals from their solutions. In this connection it finds industrial application; e.g., it is in extensive use for precipitating gold from cyanide solutions in the cyanide process of gold extraction.

Zinc unites with most of the common metals to form a number of useful alloys, the most important of which are the various forms of brass. The zinc alloys, and also a number of zinc compounds, of value in the industries, are discussed under the "Industrial Applications of Zinc" (see p. 161).

The Micro-structure of Zinc

The evidence afforded by the microscope, in relation to the constitution of metals and alloys, has been of such value that the systematic study of the micro-structure of commercial
samples of zinc and its alloys is now very generally undertaken. In particular, the systematic study of brass and of nickel silver as revealed by the microscope has claimed a considerable amount of attention in recent years.

The rapid growth of this new science of metallography, and the attention paid to it by both manufacturers and users of metals, is a cause for much satisfaction, as it evidently indicates that those connected with the British metal industries are beginning to recognise the fact that any advance in purely scientific knowledge of metals is capable of being turned to practical advantage.

The chief points ascertainable by the use of the microscope are the crystalline state of the metal or alloy, and changes in the general structure due to varying mechanical or heat treatment, and the constitution of the material, that is to say, the differentiation of the various constituents which enter into the composition of the alloys. This is one of the most important points connected with the modern study of alloys, and much valuable information has now been obtained by this method of investigation.

As regards crystalline structure, attention may be directed to the distinction between the grains of which a mass of metal is usually composed and the crystallites which compose each grain, the latter constituting the true crystalline structure. In each grain the crystallites are arranged in a definite direction or orientation. When, therefore, the surface of any pure metal, after having been carefully polished, is lightly etched with a weak acid or other reagent and examined under the microscope, it is seen to be composed of a number of separate grains, irregular in size and shape. If the etching be made deeper it is found that the grains, besides differing in size, differ also in texture, reflecting at different angles light thrown upon them.

Examination of the strongly etched surface under a higher power shows that this difference in texture is due to a number of small facets in each grain. The facets are oriented, but in any one grain they are similarly oriented, so that the general surface of the grain reflects light in a particular direction. Each of these grains has the uniformity of internal structure characteristic of a crystal and is, in fact, a crystal. With this fundamental fact established, the cause of the behaviour of metals under different conditions, under strain, for example, can be explained,
THE ZINC INDUSTRY

but much remains yet to be investigated. In particular, no completely satisfactory explanation of the manner in which the individual crystalline grains are cemented together has yet been obtained.

Well-defined or idiomorphic crystals are seldom found in the structure of cast metals, while crystallites or the incipient forms of crystals are predominant. On annealing, however, this crystallitic structure is replaced by a well-defined crystalline structure.

Various etching reagents are in use for developing the structure of zinc and its alloys. For etching the surface of zinc Timofeev recommends a mixture of 94 per cent. nitric acid and 6 per cent. chromic acid, a few drops of this mixture being added to 50 or 100 cubic centimetres of water before use. This reagent is also recommended by Desch, and has been found satisfactory in practice.

Iodine is found by Gulliver to be most suitable for alloys rich in zinc or cadmium. He uses a solution of 1 part iodine and 3 parts potassium iodide in 10 parts of water.

Caustic potash and caustic soda are used for zinc and aluminium and alloys rich in these metals. When caustic soda is used for etching alloys of aluminium with zinc, a black deposit is often left on the etched surface. This can be very satisfactorily removed by dipping the specimen in a solution of chromic acid in water.

The strength of the caustic soda reagent varies from 5 to 20 per cent. A 10 per cent. solution of chromic acid etches zinc, cadmium and many alloys of these metals, whilst a highly concentrated solution of chromic acid is, according to Czochralski, suitable for developing the internal crystalline structure of zinc.

The micro-structure of pure cast zinc consists of comparatively large grains, often showing a cross-hatching upon their surfaces, presenting a structure analogous to that of martensitic steel. A photomicrograph of cast zinc, etched with very dilute nitric acid, and magnified 100 diameters, is shown in Plate 1. Another

1 "Revue de Métallurgie," 1914, No. 1, p. 127.
4 Photomicrographs taken for the author by Dr. F. C. Thompson, University of Sheffield.
Photomicrograph of cast zinc.
Magnified 100 diameters.

Photomicrograph of cast zinc (showing twinning).
Magnified 100 diameters.

Plate 4.
CHEMICAL PROPERTIES OF ZINC

Photomicrographs of the same metal, treated as before, is also shown in Plate I. In this latter case the structure consists of allotropic-morphic crystals with twinning, which is of somewhat rare occurrence in metals in the cast state.

When the zinc is contaminated with zinc oxide, which is usually the case with commercial samples, the oxide tends to separate at the crystal boundaries, giving rise to very thick boundary lines.

The changes in structure of hard worked zinc on annealing are discussed by G. Timofeev. Cast specimens of zinc were prepared and strained in compression. The micro-structure of zinc crushed in a vice becomes homogeneous, no crystals being visible under very high magnifications. The hardness increases considerably. Recrystallisation takes place, however, very readily on annealing the metal, a very slight rise in temperature effecting a noticeable change in the micro-structure of the strained metal. The etching of the samples was effected with Timofeev's reagent given above. The strained specimens were annealed at different temperatures ranging from 65°C to 360°C.

The photomicrographs showed that the average size of the crystal grain in the annealed specimens increases uniformly with the annealing temperature, the hardness suffering a corresponding decrease in value, until it finally reaches the same figure as that found for the cast metal. It was found in all cases that the size of the grains was greater at the edges than in the middle of the specimens; this is ascribed to the greater amount of plastic strain at the edges of the specimens during deformation by compression.

It is concluded that the velocity of recrystallisation depends both upon the temperature of annealing and upon the severity of plastic strain; the final size of the crystalline grains when annealing at a given temperature is limited by the duration of heating. Under slight shock the large individual crystals composing cast zinc became striated, this effect being produced even by removing the ingots from moulds, if special care is not taken.

The micro-structure of zinc containing lead indicates that at the freezing point of zinc the still molten lead is rejected and forms minute globules occupying often the cleavage cracks caused by the contraction of the crystalline zinc during solidifica-
tion. This separation of lead is well shown in Plate 2, which in
the lead appears as isolated dots within the zinc crystals. The
cast zinc contained about 3 per cent. of lead, and the structure
was developed by etching with very dilute hydrochloric acid
with the addition of a few drops of a solution of zinc chloride.
The magnification is 100 diameters.

Iron is a frequent constituent of commercial zinc, and when
present above 0.1 per cent. it forms distinct crystallites which
are readily discernible under the microscope, and, as already
stated, are doubtless the cause of the light specks on the crystal
faces of fractured spelter. Hard zinc, containing about 10 per
cent. of iron, presents a characteristic structure in which the
crystals are well defined even at a low magnification of about 30
diameters.

The microscope affords a very ready means of controlling the
annealing process for brass and other zinc alloys, and has been
adopted for that purpose in several large works. After every
stage of the process samples are taken, rapidly polished, etched
and examined under the microscope. From the size of the
crystals it is easy to determine whether the alloy has been in-
sufficiently, correctly, or over annealed.

The accompanying photomicrographs of brass, containing
60 per cent. of copper and 40 per cent. of zinc, are given as
illustrations of the study of the constitution of brasses by means
of the microscope.

Plate 3 represents the brass (copper 70, zinc 30) as cast,
while Plate 4 shows the appearance of the metal after annealing
for one hour at 750° C. The magnification in each case is 80
diameters.

The etching-agent was a 10 per cent. solution of ammonium
persulphate.

For further examples of the micro-structure of brass and other
alloys containing zinc reference must be made to the researches
on the subject that have been published in the Proceedings
of the scientific societies, notably in the Journal of the Institute of
Metals, and several of which have been mentioned in the Bibliog-
graphy appended.
Photomicrograph of cast zinc with 1% of lead
Magnified 400 diameters

Plate 2
Biscoe (70 to 80% copper, 0% zinc) as cast, showing cored structure. Magnified 80 diameters. Etched with 5% solution of ammonium persulphate.

Photomicrograph by Dr. E. C. Thompson,
University of Sheffield

PLATE 5.
Braze (70% copper, 30% zinc) after annealing for one hour at 750°C showing crystalline structure. Magnified 80 diameters. Etched with 5% solution of ammonium persulphate.

Photomicrograph by: In H. Thompson, University of Sheffield.
Impurities in Commercial Zinc

Owing to the fact that zinc possesses so powerful an alloying affinity for other metals, and even metalloids, e.g., arsenic, the commercial metal produced by distillation is invariably contaminated with impurities, the amount of which varies according to the composition of the ore from which the spelter is produced.

The most frequent impurities in spelter are lead, iron, cadmium and arsenic. From the table of typical analyses given on p. 149 it will be seen that the chief impurities to be guarded against are lead and iron.

The variations in the lead and iron content in different brands of spelter examined by R. T. Rolfe¹ during the years 1913–1916 were as follows:

<table>
<thead>
<tr>
<th>Brand of Spelter</th>
<th>Lead per cent.</th>
<th>Iron per cent.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crown</td>
<td>1.52</td>
<td>0.08</td>
</tr>
<tr>
<td>De Boom</td>
<td>0.31</td>
<td>trace</td>
</tr>
<tr>
<td>Nouvelle Montagne</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>Revi</td>
<td>0.26–1.74</td>
<td>0.04–0.09</td>
</tr>
<tr>
<td>S.S.</td>
<td>0.22–3.43</td>
<td>trace</td>
</tr>
<tr>
<td>Ste. de Boom</td>
<td>0.65–2.03</td>
<td>trace</td>
</tr>
<tr>
<td>Vieille Montagne</td>
<td>1.47–1.49</td>
<td>0.04–0.07</td>
</tr>
<tr>
<td>Vivian &amp; Co.</td>
<td>0.81–1.32</td>
<td>0.08–0.12</td>
</tr>
</tbody>
</table>

Lead.—The lead does not usually exceed 2 per cent., although some spelters are placed on the market containing as much as 3 per cent. It is usual, however, to refine such impure metal before marketing, since, as already stated, the quantity of lead present very largely determines the market value of the spelter.

In spelter intended for rolling, a small percentage of lead is desirable, and up to 10 per cent. it has no injurious effects on the malleability or ductility of the metal.

When, however, the spelter has to be used for making brass which has to undergo severe mechanical treatment, as, for example, the manufacture of cartridge cases, the presence of lead exceeding 0.1 per cent. is very undesirable, the metal being often somewhat brittle and liable to crack. When present in quantities greater than 0.7 per cent., lead tends to produce bad cracking in spelter castings.

THE ZINC INDUSTRY

Any cheap and readily applicable method for the elimination of lead from spelter, short of redistillation, would, in the opinion of Moulden, find both world-wide application and substantial remuneration.

Iron: Iron is a very frequent impurity, the amount passing into the spelter depending more on the method of smelting than on the ore employed.

When over 0.1 per cent., its presence is indicated by the grey appearance, and by the presence of a number of black specks (crystallites) on the crystal faces of the fractured spelter, while the pure metal exhibits clear, brilliant crystal faces on fracture.

The zinc may be freed from this impurity by redistillation, the use of iron tools and appliances being avoided. The effects of iron are to increase the hardness and brittleness of zinc and reduce its malleability, but when the refining by fusion has been properly conducted there is insufficient present to affect these properties.

For spelter intended for the manufacture of brass 0.05 per cent. of iron is often specified as the limit, but less than this amount is preferable for brass of high ductility and malleability.

Cadmum: Cadmium, being more volatile than zinc, is more difficult to condense, and is rarely present in spelter in injurious proportions.

Spelter may, however, contain as much as 2.0 per cent. of cadmium, but usually the quantity is under 0.2 per cent. Spelter free from cadmium can only be obtained by single smelting when the ore is free from cadmium, but by redistilling common spelter with proper control of the temperature, and separating the first distillate, a high-grade spelter, low in cadmium, is easily produced.

Cadmum has a pronounced hardening effect on spelter and tends to increase its brittleness, but its effect on zinc to be used for the production of alloys requires further investigation. As the result of practical experience many metallurgists consider that cadmium up to 0.5 per cent. has no injurious effect on zinc used in the manufacture of cartridge brass, nickel silver, and similar alloys.

The specification of military engineers for high-grade spelter for the production of cartridge brass permits a maximum of only 0.15 per cent. of cadmium.

Season cracking in brass, which was formerly attributed solely to cadmium, is now recognised to be the result of internal strains...
THE PHYSICAL AND CHEMICAL PROPERTIES OF ZINC

due to improper heat treatment or the entire lack of heat treatment. On the other hand, cadmium if present beyond 0.5 per cent. is considered to be injurious when the spelter is used for sheet rolling, for galvanising, and for making slush (ornamental) castings. Its presence in galvanising is very important, as brittleness due to cadmium causes the coating to peel off. This is of particular importance in galvanised wires for telephone and telegraph purposes, which are sharply bent in making splices.

Cadmium has a strong tendency to make castings crack. In brass cadmium tends to act like lead, and is also said to make the metal more sensitive to heat treatment. The amount present in brass is, however, seldom large, since it readily volatilises during melting.

Arsenic, Antimony, Copper, Sulphur and Carbon. These elements are seldom present in sufficient quantities in spelter to affect its properties for the uses for which the metal is usually employed. Arsenic, however, should be absent in zinc used for generating hydrogen for use in lead burning, or autogenous welding, otherwise it is often impossible to burn a strong seam. It should also be absent in zinc intended for the precipitation of gold in the cyanide process, as in treating the precipitate with acid arseniuretted hydrogen is given off, and this has resulted in several fatal accidents.

Tin and Aluminium should always be looked for in remelted spelter. Tin tends to make zinc very hard and brittle in rolling. Some brands of remelted spelter contain aluminium, usually to the extent of about 0.3 per cent.

Small quantities of copper are not infrequently present in remelted spelter.

147
CHAPTER IX

THE MARKETING OF ZINC

Grades of Commercial Zinc

The quality of commercial zinc varies considerably according to the method of production, but in many cases the sole practical difference between ordinary commercial spelter and the much more valuable fine-zinc is represented by the lead content. For some industrial uses zinc is required in a state of fairly high purity, consequently there is a good demand for high-grade metal.

The brands of zinc produced by remelting scrap metal, &c., usually contain impurities and are of inferior quality.

The slab zinc is marketed under various names, which are used by the different smelting companies to denote their products, the quality of which is known to the users of zinc.

A large number of brands of spelter are made on the Continent. Many of the works make two or three different brands, varying in quality and price mainly according to the lead contents, but in some cases dependent upon whether the metal is higher or lower in iron. The grading of commercial zinc according to the amount of impurity, especially lead, is most desirable, and, as shown below, has been generally adopted in America in recent years. In this country, however, a hard and fast classification does not appear to obtain, and what are described as good ordinary brands show a very large variation in the proportion of lead. Furthermore, different consignments of spelter of the same brand will often vary in this manner to an undesirable degree.

In good ordinary brands (G.O.B.) of British spelter the lead usually varies from 0.8 to 1.8 per cent. and the iron from 0.02 to
THE MARKETING OF ZINC

0.04 per cent. In Silesian unrefined spelter, as tapped in hand ladles, the lead is usually higher, reaching over 2 per cent. In some brands of American high-grade zinc lead is absent or does not exceed 0.02 and the iron 0.01 to 0.02 per cent. The brands of electrolytic zinc seldom show higher purity than is obtainable by modern fire refining. The purity in both cases is usually guaranteed 99.95 per cent of zinc.

The following analyses of British, Continental and American brands of spelter may be taken as typical:

<table>
<thead>
<tr>
<th>Brand</th>
<th>Zine Per Cent</th>
<th>Lead Per Cent</th>
<th>Iron Per Cent</th>
<th>Cadmium Per Cent</th>
<th>Tin Per Cent</th>
<th>Copper Per Cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Zinc Co. (British)¹</td>
<td>98.042</td>
<td>1.203</td>
<td>0.06</td>
<td>0.098</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td>V.M.G. (Belgium)²</td>
<td>98.05</td>
<td>0.66</td>
<td>0.26</td>
<td>0.003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vieille Montagne (Belgium)²</td>
<td>97.80</td>
<td>2.00</td>
<td>0.01</td>
<td>0.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freiberg (Saxony)³</td>
<td>98.81</td>
<td>1.01</td>
<td>0.01</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laziynutte (Upper Silesia)²</td>
<td>97.85</td>
<td>1.12</td>
<td>0.02</td>
<td>0.017</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lipine Electrolytic (Upper Silesia)²</td>
<td>99.965</td>
<td>0.06</td>
<td>0.01</td>
<td>0.0005</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Font-d'Art (France)³</td>
<td>99.718</td>
<td>0.15</td>
<td>0.20</td>
<td>0.123</td>
<td>trace</td>
<td></td>
</tr>
<tr>
<td>Scrap²</td>
<td>96.417</td>
<td>2.05</td>
<td>0.03</td>
<td>0.003</td>
<td>1.11</td>
<td>0.06</td>
</tr>
</tbody>
</table>

The virgin spelter produced by the Central Zinc Company, at Seaton Carew, Durham, is from Broken Hill ore.

The American Society for Testing Materials suggested in 1911 the following four grades for commercial spelter:

<table>
<thead>
<tr>
<th>Grade</th>
<th>Lead Per Cent</th>
<th>Iron Per Cent</th>
<th>Copper Per Cent</th>
<th>Total not over per cent.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A High grade</td>
<td>0.03</td>
<td>0.03</td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td>B Intermediate</td>
<td>0.20</td>
<td>0.04</td>
<td>0.05</td>
<td>0.50</td>
</tr>
<tr>
<td>C Brass special</td>
<td>0.75</td>
<td>0.04</td>
<td>0.75</td>
<td>1.20</td>
</tr>
<tr>
<td>D Prime Western</td>
<td>1.50</td>
<td>0.88</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

THE ZINC INDUSTRY

The figures represent the maximum percentage of impurities allowable. This classification corresponds substantially with the understanding among American zinc smelters.

The following table gives the analysis of typical commercial samples of the various grades of American spelter:

<table>
<thead>
<tr>
<th>Grade</th>
<th>Zinc Per cent</th>
<th>Lead Per cent</th>
<th>Iron Per cent</th>
<th>Cadmium Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>High grade</td>
<td>99.969</td>
<td>.010</td>
<td>.026</td>
<td>.040</td>
</tr>
<tr>
<td></td>
<td>99.015</td>
<td>.011</td>
<td>.014</td>
<td>.001</td>
</tr>
<tr>
<td>Intermediate</td>
<td>99.951</td>
<td>.045</td>
<td>.014</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>99.896</td>
<td>.005</td>
<td>.017</td>
<td>.001</td>
</tr>
<tr>
<td>Brass special</td>
<td>99.740</td>
<td>.023</td>
<td>.011</td>
<td>.120</td>
</tr>
<tr>
<td></td>
<td>99.641</td>
<td>.020</td>
<td>.009</td>
<td>.002</td>
</tr>
<tr>
<td></td>
<td>99.513</td>
<td>.011</td>
<td>.014</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>99.036</td>
<td>.010</td>
<td>.010</td>
<td>.001</td>
</tr>
<tr>
<td>Prime Western</td>
<td>99.645</td>
<td>.041</td>
<td>.014</td>
<td>.002</td>
</tr>
<tr>
<td></td>
<td>98.253</td>
<td>.014</td>
<td>.014</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>98.641</td>
<td>.070</td>
<td>.010</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>98.503</td>
<td>.048</td>
<td>.024</td>
<td>.002</td>
</tr>
<tr>
<td>Wallemsite (Eastern Pennsyl.1)</td>
<td>99.955</td>
<td>.030</td>
<td>.086</td>
<td>.001</td>
</tr>
</tbody>
</table>

The "Prime Western" brand corresponds with the good ordinary brands in European quotations and includes the bulk of American spelter.

The grade produced in largest amount in America is "Prime Western," a considerable part of which is used for galvanising iron and steel wire and sheet. "Brass special" is used chiefly in the manufacture of brass. The price of "high-grade" spelter is usually 2 to 4 cents per lb. more than that of "Prime Western." The "high-grade" and "intermediate spelters" are made by only a few smelters, but the "brass special" and "Prime Western" are made by many concerns.

Sampling Zinc.—Slabs of spelter as supplied by the smelter are not of exactly uniform composition, as the kettle into which the metal is received from the furnace holds a relatively small quantity, and the impurities passing over with the zinc vary in

1 G. C. Stone, Transactions of the American Institute of Metals, 1875, vol. 18
2 J. L. Jones, ibid.
amount in different parts of the furnace, according to the temperature of the retort. To ensure uniformity as far as possible, the zinc should be tapped into large ladles or remelted in large pots or furnaces before being cast into slabs for delivery.

Segregation of the impurities, however, invariably takes place, and slabs of commercial zinc are rarely uniform in composition. Under these conditions the sampling of the slabs is a matter of considerable importance, although it does not always receive the attention it deserves.

One slab out of every ten should be taken for sampling to secure a trustworthy average of the shipment or consignment, but this practice is not always carried out. American brass makers follow a time-honoured practice of sampling a carload (about 50,000 lb of spelter in 820 to 900 slabs) by drawing 10 slabs at random, and that practice has recently received the endorsement of the American Society of Testing Materials.

The sample for analysis is taken from the selected slabs either by breaking a small piece off one corner of each slab or by drilling right through each slab.

The latter method is the more satisfactory, provided proper precautions are taken to prevent contamination of the sample with iron from the drill. A twist drill, about \( \frac{1}{8} \) inch, is very suitable for the purpose. It must be kept sharp and be fed slowly enough to enable it to clear itself of all drillings. If this is not done, the drillings are liable to pick up iron from the drill in such a firmly adhering form that removal by means of the magnet or otherwise is out of the question. Sampling by sawing the slab completely through with a band saw, as is frequently done in sampling pigs of lead, has been adopted in a few cases with satisfactory results.

The Price of Zinc

When viewed over a considerable period of years, the market value of spelter has, not unnaturally, fluctuated considerably. When first produced it realised a high price, which rapidly fell as production increased and no new output for its consumption opened out.

In reviewing the price of zinc Mounden points out that in 1867 \(^1\)

\(^1\) The prices quoted, 1807 to 1830, are based upon figures as given by Liebig. "Zink und Cadmium," Leipzig, 1913 (per J. C. Mounden)
THE ZINC INDUSTRY

it was about £40 per ton, rose in 1808 to £84 per ton, and then fell steadily as production overtook demand, until in 1820 it stood at no more than £11.

The extension of sheet rolling caused the price to rise until in 1825 it reached £30; it fell again as production increased, and between 1830 and 1836 fluctuated between £10 and £19. It again fell to £10 in Breslau (the Silesian centre) in 1848. In 1850 it was quoted at about £10, and from that time onward to 1913 the yearly average fluctuated between £13 19s. 11d. (the lowest touched in 1885) and £27 16s. 5d. in 1906.

Moulden remarks that the general tendency of late years has been towards a distinctly higher average level. For a very long time low wages and easily won and treated ores kept the price low. As wages increased and difficulties of treatment arose the improvements in metallurgical efficiency and extraction kept pace up to a certain point and compensated the producer. Beyond this point there was bound to be a rise in average value, and this is clearly reflected in the fact that only twice since 1898 has the average price been below £20, and never since the close of 1902. Prior to the war industrial conditions had reached such a point that, broadly viewed, a £20 market was considered by smelters to be unremunerative and distinctly unprofitable in particular for those concerns which did not themselves possess mines.

The establishment of the Zinc Conventions (see p. 155) and the German control of Australian concentrates, not unnaturally, had some influence in regulating the price of spelter.

"The Metallgesellschaft, acting on behalf of the German Group, purchased for a number of years the whole supply of Australian zinc concentrates, and the price was regulated by the average of the mean daily quotations made on the London Metal Exchange. The Metallgesellschaft, through its Australian connection, the Australian Metal Company, and Hirsch & Company, through their Australian representative, arranged the contract with the Broken Hill Groups.

"The contract was made so that if the price of spelter rose above £22 or £23 a ton, any excess above that price was divided equally between the buyer and the seller. That contract having been signed, the European Spelter Convention was formed about the middle of January, 1909. Spelter at that time was £21 10s. a ton, and it is now common knowledge that it was forced up to
more than £27 a ton. The higher price brought a remarkable increase in production, so that the price, after touching more than £27 a ton in 1911 and 1912, fell during the first half of 1913 to £22 a ton, and during July and August of the same year to about £20 a ton. Thus the successful negotiations and contracts for the Australian was a mere question of £ s. d. or who would pay the highest price.

Owing to the conditions that prevailed consequent upon the outbreak of war, the selling price of spelter appreciated to more than five times its pre-war figure. During 1915 the price of the metal was subject to more violent fluctuations than have been recorded during the past fifty years.

### The Highest, Lowest, and Average Price Per Ton of Commercial Metallic Zinc in the London Market from the Year 1900 to 1917

<table>
<thead>
<tr>
<th>Year</th>
<th>Highest</th>
<th>Lowest</th>
<th>Average English Spelter</th>
<th>Average Foreign Spelter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900</td>
<td>£ 22 15 0</td>
<td>18 10 0</td>
<td>20 10 0</td>
<td>20 13 5</td>
</tr>
<tr>
<td>1901</td>
<td>18 18 9</td>
<td>16 7 6</td>
<td>17 11 5</td>
<td>17 7 9</td>
</tr>
<tr>
<td>1902</td>
<td>19 17 6</td>
<td>16 7 6</td>
<td>19 1 8</td>
<td>18 14 8</td>
</tr>
<tr>
<td>1903</td>
<td>23 18 9</td>
<td>19 15 0</td>
<td>21 12 0</td>
<td>21 4 11</td>
</tr>
<tr>
<td>1904</td>
<td>25 10 0</td>
<td>21 2 0</td>
<td>23 11 0</td>
<td>22 18 0</td>
</tr>
<tr>
<td>1905</td>
<td>29 2 6</td>
<td>23 5 0</td>
<td>26 0 0</td>
<td>25 15 2</td>
</tr>
<tr>
<td>1906</td>
<td>29 10 0</td>
<td>24 0 0</td>
<td>27 12 4</td>
<td>27 8 0</td>
</tr>
<tr>
<td>1907</td>
<td>28 2 6</td>
<td>19 10 0</td>
<td>24 11 1</td>
<td>24 9 6</td>
</tr>
<tr>
<td>1908</td>
<td>21 17 6</td>
<td>18 0 0</td>
<td>21 0 11</td>
<td>20 17 1</td>
</tr>
<tr>
<td>1909</td>
<td>23 6 3</td>
<td>21 1 3</td>
<td>22 16 6</td>
<td>22 13 0</td>
</tr>
<tr>
<td>1910</td>
<td>24 5 0</td>
<td>21 14 0</td>
<td>23 19 0</td>
<td>23 12 0</td>
</tr>
<tr>
<td>1911</td>
<td>27 17 6</td>
<td>22 17 6</td>
<td>25 3 9</td>
<td>25 16 7</td>
</tr>
<tr>
<td>1912</td>
<td>27 12 6</td>
<td>25 0 0</td>
<td>26 3 4</td>
<td>27 4 2</td>
</tr>
<tr>
<td>1913</td>
<td>34 0 0</td>
<td>21 6 3</td>
<td>Average</td>
<td>22 14 1</td>
</tr>
<tr>
<td>1914</td>
<td>120 0 0</td>
<td>28 0 0</td>
<td>23 15 6</td>
<td></td>
</tr>
<tr>
<td>1916</td>
<td>110 0 0</td>
<td>44 0 0</td>
<td>160 13 8</td>
<td></td>
</tr>
<tr>
<td>1917</td>
<td>57 0 0</td>
<td>44 0 0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It rose gradually from £28 per ton in January of that year to £120 in June; then a reaction occurred, and by August the price had fallen to £55 a ton. Thence up to November there was

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THE ZINC INDUSTRY

another increase until the price was again more than £100. In 1916 the highest price reached was £110, and the lowest £44, while in 1917 the price rose to £57 and went as low as £44. The year closed with zinc at about £52 per ton.

The yearly and monthly average prices of spelter for the ten years prior to the war are given in the table on p. 153.

In normal times the prices of metals reflect, in a large measure, the relation between production and consumption, but for some time past such cannot be said to be the case, as the metal industry is now controlled by the Government, almost all the available supply being devoted to the purposes of war, the ordinary trade requirements having, naturally, to be left unfilled.

The World's Zinc Markets

London is the principal European zinc market, the price of the metal being quoted in £ s. d., according to the prevailing prices for G.O.B. ("Good ordinary brands" or "Good ordinaries"), and a slightly higher quotation for "Specials," the purer quality of zinc. As previously stated, many of the smelters, both in this country and abroad, make two or three different brands of zinc, varying in quality mainly according to the lead contents, but in some cases dependent on the iron content. They are sold at various prices, the better grades of metal naturally commanding higher prices. British spelter is usually quoted under the heads of "Ordinary brands," "Special brands," and "English Swansea".

The several selling centres for zinc in the German Empire are Breslau, Cologne, and Frankfort-on-Main. The price is always quoted in marks per ton, the difference in price between each brand being usually 1 or 2 marks.

The American zinc market is entirely independent of that of the rest of the world, as, under normal conditions, America is not favourably situated to compete with the British and Continental markets. The conditions relating to the marketing of zinc in America have been summarised recently by C. H. Fulton as follows:


154
"The main market or basing point for spelter is St. Louis, Missouri, for the reason that the great zinc fields and a large number of the smelting plants for zinc are situated not far from St. Louis. However, the large consumption of spelter is at places between St. Louis and New York, and it is sold in New York on a St. Louis basis, the quotations being given in cents per lb. The New York price is the St. Louis price plus 15 cents per 100 lb., which is the freight rate on spelter from St. Louis to New York. The American market is in part independent of the European market, because spelter is protected by an import duty of 15 per cent. and zinc in ore by a duty of 10 per cent. ad valorem.

"In the marketing of zinc, it is customary for the producer to sell direct to the manufacturer. This policy, however, in view of the large number of producers, is not nearly so closely followed as in the selling of copper, and some of the producers, particularly the smaller ones, sell to anyone who cares to purchase. This condition of course gives rise to more speculation in zinc than in copper. The real spelter market is established by the private transactions of producer and consumer, and any information as to the state of the market can come only from them. The facilities for exchanging information in the spelter market are not as good as those in the copper market, and hence transactions between producer and manufacturer often show considerable difference in price." The four brands of spelter on the American market, with their names and permissible proportions of impurities, have been given on p. 149.

The Spelter Convention

Prior to the outbreak of war the spelter market was very largely controlled by the Spelter Convention, an association of zinc smelters formed in 1909 and elaborated in 1910. Separate syndicates were formed for each zinc-producing country, and included all the German, most of the Austrian, Belgian and French, and many of the British smelters. The Convention consisted of three groups:

Group A, known as the Verband, or German Syndicate, com-
prised the associated German and Belgian makers, whose output
was disposed of by a joint selling office.

Group B comprised certain Belgian and French producers
Group C comprised the British producers.

The two latter groups constituted the International Spelter
Syndicate, which on December 18th, 1913, was, with slight
changes, renewed on the old conditions until April 30th, 1916.
The German Syndicate was also prolonged until the same date.

The object of the Convention was to control output by fixing,
within certain limits, the individual production of its members,
and to ensure a uniform mode of selling, and, if the market
showed that the demand was not keeping pace with the output,
to restrict the latter.

On the Continent, the sale of the metal was in the hands of
the leading trading companies in metals and minerals, who,
jointly with the producers, fixed the selling prices and the
quantities to be produced by each works. Over-production
above the quantities fixed by the board of management was
subject to heavy penalties. The total of the amounts realised,
after deduction of selling and administration expenses, was
distributed amongst the various works in accordance with the
deliveries made by them, and in taking into consideration certain
geographical positions and superior qualities of spelter produced,
various premiums were admitted. The smelters with their own
mines ("Erzhuetten"), on the other hand, paid a certain amount
for each ton of ore produced and treated by them to make up
for the advantage they had against the "Lohnhuetten," or
customs works, who bought their ore in the market

Restriction of output came into force when the average price
of spelter in the London market had remained at £22 or under
for two months, and when the unsold stocks, which were taken
quarterly, amounted to 50,000 tons.

The British and French smelters were bound to a joint restric-
tion of output in certain circumstances, but they had more
liberty of action than the other members, being free from selling
restrictions. The German smelters were under the most stringent
rules as regards production, prices and agencies through which
sales could be made.

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THE MARKETING OF ZINC

American smelters were not included in the Convention, as the home consumption at that time equalled the production, and it was therefore unlikely that they could influence the European market.

Pursuant to the above provisions the International Syndicate on May 26th, 1913, reduced prices by 50s. per ton, and the London quotation went down to £23. On October 1st, 1913, the Convention ordered a reduction in output of 8 per cent.

"On the whole," according to J. Gilbert,1 "the Spelter Syndicate may be said to have served the interests of European producers to some considerable extent by regulating the uniformity of the supply, which has permitted a steady progress of the industry, with fairly uniform remuneration of capital and labour, and without unduly exposing it to the inveterate risk of speculation, which very frequently most radically interferes with the interests of both producers and consumers of certain commodities. Unfortunately, however, so far as British interests are concerned, one all-important feature has been overlooked, and that is the fact that, whilst British consumers of spelter absorb about 40 per cent. of the European production, the British production of spelter hardly exceeds 10 to 12 per cent. of the European output."

The Production and Consumption of Zinc

Production.--Owing to the complications introduced by primary and secondary and redistilled hard spelter, &c., it is very difficult to ascertain with accuracy the world's yearly production of zinc. The bulk of the metal will, however, have been produced direct from ore, possibly about 75 per cent., leaving 25 per cent. for remelted metal recovered from scrap metal, galvanisers, ashes, &c. The world's output of spelter from the early days of the industry to modern times has been given previously. The quantities of spelter produced by the chief countries for the ten years ending 1913 are shown in the following table.

<table>
<thead>
<tr>
<th>Countries</th>
<th>1904</th>
<th>1905</th>
<th>1906</th>
<th>1907</th>
<th>1908</th>
<th>1909</th>
<th>1910</th>
<th>1911</th>
<th>1912</th>
<th>1913</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>191,060</td>
<td>197,184</td>
<td>205,023</td>
<td>208,707</td>
<td>216,876</td>
<td>229,080</td>
<td>227,747</td>
<td>259,393</td>
<td>271,064</td>
<td>283,114</td>
</tr>
<tr>
<td>Belgium</td>
<td>138,982</td>
<td>145,592</td>
<td>152,461</td>
<td>154,492</td>
<td>165,019</td>
<td>167,100</td>
<td>172,378</td>
<td>195,092</td>
<td>200,168</td>
<td>197,704</td>
</tr>
<tr>
<td>Holland</td>
<td>13,099</td>
<td>13,767</td>
<td>14,650</td>
<td>14,990</td>
<td>17,257</td>
<td>19,548</td>
<td>20,975</td>
<td>22,733</td>
<td>23,932</td>
<td>24,323</td>
</tr>
<tr>
<td>France and Spain</td>
<td>49,682</td>
<td>50,399</td>
<td>51,756</td>
<td>55,733</td>
<td>55,819</td>
<td>56,118</td>
<td>59,141</td>
<td>64,221</td>
<td>72,164</td>
<td>71,021</td>
</tr>
<tr>
<td>Austria and Italy</td>
<td>9,648</td>
<td>9,357</td>
<td>10,780</td>
<td>11,359</td>
<td>12,761</td>
<td>12,638</td>
<td>13,305</td>
<td>16,876</td>
<td>19,604</td>
<td>21,707</td>
</tr>
<tr>
<td>Russia</td>
<td>10,606</td>
<td>7,642</td>
<td>9,610</td>
<td>9,738</td>
<td>8,839</td>
<td>7,945</td>
<td>8,631</td>
<td>9,036</td>
<td>8,763</td>
<td>7,610</td>
</tr>
<tr>
<td>Norway</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production in Europe</td>
<td>459,293</td>
<td>474,800</td>
<td>498,397</td>
<td>510,614</td>
<td>531,044</td>
<td>542,779</td>
<td>565,455</td>
<td>613,887</td>
<td>661,081</td>
<td>673,012</td>
</tr>
<tr>
<td>United States of America</td>
<td>165,850</td>
<td>183,245</td>
<td>202,062</td>
<td>220,538</td>
<td>189,041</td>
<td>240,446</td>
<td>250,627</td>
<td>267,472</td>
<td>314,512</td>
<td>340,284</td>
</tr>
<tr>
<td>Australia</td>
<td>290</td>
<td>630</td>
<td>1,026</td>
<td>900</td>
<td>1,087</td>
<td></td>
<td></td>
<td>1,727</td>
<td>2,296</td>
<td>3,724</td>
</tr>
<tr>
<td>Total</td>
<td>625,400</td>
<td>658,700</td>
<td>692,000</td>
<td>738,400</td>
<td>722,100</td>
<td>781,200</td>
<td>816,000</td>
<td>902,100</td>
<td>977,900</td>
<td>997,900</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Yearly average price</th>
<th>i s d</th>
<th>i s d</th>
<th>i s d</th>
<th>i s d</th>
<th>i s d</th>
<th>i s d</th>
<th>i s d</th>
<th>i s d</th>
<th>i s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average monthly price</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

1 To convert to English long tons, multiply by 0.9842
THE MARKETING OF ZINC

From the figures on p. 158 it will be seen that the absolute and relative contributions of Europe and the United States to the world's production of spelter for the years 1910-1913 are as follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>Europe</th>
<th>United States</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Metric tons</td>
<td>Per cent of world's output</td>
</tr>
<tr>
<td>1910</td>
<td>505,500</td>
<td>69.4</td>
</tr>
<tr>
<td>1911</td>
<td>632,900</td>
<td>70.2</td>
</tr>
<tr>
<td>1912</td>
<td>661,100</td>
<td>67.6</td>
</tr>
<tr>
<td>1913</td>
<td>673,000</td>
<td>67.5</td>
</tr>
</tbody>
</table>

Consumption. One of the difficulties in estimating the amount of zinc used in the Arts is that variable proportions of old material are used with new material, and in consequence the consumption sometimes exceeds the total production for the year. The estimates of consumption take no account of any stocks which may exist, and hence, theoretically, the total consumption should yield the same figures as the total production.

Taking into account stocks at German works, the actual consumption of spelter in Germany during 1911 was about 217,900 tons, in 1912 about 220,800 tons, and in 1913 about 221,800 tons. When the stocks of other countries are taken into account, the returns show that prior to the war the production for the years named was in excess of the consumption.

The following table shows the absolute and relative contributions of Europe and the United States to the world's consumption of spelter for the years 1910-1913.

<table>
<thead>
<tr>
<th>Year</th>
<th>Europe</th>
<th>United States</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Metric tons</td>
<td>Per cent of world's output</td>
</tr>
<tr>
<td>1910</td>
<td>399,400</td>
<td>73.4</td>
</tr>
<tr>
<td>1911</td>
<td>652,400</td>
<td>72.3</td>
</tr>
<tr>
<td>1912</td>
<td>667,700</td>
<td>68.2</td>
</tr>
<tr>
<td>1913</td>
<td>675,000</td>
<td>67.7</td>
</tr>
</tbody>
</table>
THE ZINC INDUSTRY

The world's consumption of spelter during the ten years immediately preceding the war is shown in the following table.

<table>
<thead>
<tr>
<th>Countries</th>
<th>1904</th>
<th>1905</th>
<th>1906</th>
<th>1907</th>
<th>1908</th>
<th>1909</th>
<th>1910</th>
<th>1911</th>
<th>1912</th>
<th>1913</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>157,100</td>
<td>179,000</td>
<td>200,000</td>
<td>217,000</td>
<td>230,000</td>
<td>240,000</td>
<td>250,000</td>
<td>260,000</td>
<td>270,000</td>
<td>280,000</td>
</tr>
<tr>
<td>Germany</td>
<td>151,600</td>
<td>162,700</td>
<td>179,300</td>
<td>174,800</td>
<td>168,000</td>
<td>158,600</td>
<td>140,700</td>
<td>138,500</td>
<td>135,500</td>
<td>133,500</td>
</tr>
<tr>
<td>Great Britain</td>
<td>190,100</td>
<td>236,000</td>
<td>280,000</td>
<td>283,000</td>
<td>280,000</td>
<td>280,000</td>
<td>280,000</td>
<td>280,000</td>
<td>280,000</td>
<td>280,000</td>
</tr>
<tr>
<td>France</td>
<td>67,200</td>
<td>59,700</td>
<td>69,400</td>
<td>77,000</td>
<td>82,100</td>
<td>86,500</td>
<td>90,600</td>
<td>95,100</td>
<td>100,000</td>
<td>105,000</td>
</tr>
<tr>
<td>Belgium</td>
<td>54,000</td>
<td>42,100</td>
<td>51,000</td>
<td>65,000</td>
<td>70,000</td>
<td>76,000</td>
<td>85,000</td>
<td>96,000</td>
<td>104,000</td>
<td>112,000</td>
</tr>
<tr>
<td>Austria-Hungary</td>
<td>25,000</td>
<td>26,000</td>
<td>26,000</td>
<td>28,000</td>
<td>30,000</td>
<td>32,000</td>
<td>34,000</td>
<td>36,000</td>
<td>38,000</td>
<td>40,000</td>
</tr>
<tr>
<td>Russia</td>
<td>23,500</td>
<td>23,000</td>
<td>24,000</td>
<td>24,000</td>
<td>24,000</td>
<td>24,000</td>
<td>24,000</td>
<td>24,000</td>
<td>24,000</td>
<td>24,000</td>
</tr>
<tr>
<td>Italy</td>
<td>5,100</td>
<td>5,600</td>
<td>6,200</td>
<td>7,000</td>
<td>8,200</td>
<td>10,000</td>
<td>12,000</td>
<td>14,000</td>
<td>16,000</td>
<td>18,000</td>
</tr>
<tr>
<td>Spain</td>
<td>4,000</td>
<td>4,700</td>
<td>5,000</td>
<td>5,000</td>
<td>6,000</td>
<td>8,000</td>
<td>8,000</td>
<td>8,000</td>
<td>8,000</td>
<td>8,000</td>
</tr>
<tr>
<td>Netherlands (estimated)</td>
<td>3,700</td>
<td>3,800</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
</tr>
<tr>
<td>Other countries</td>
<td>9,700</td>
<td>11,000</td>
<td>12,000</td>
<td>13,000</td>
<td>14,000</td>
<td>15,000</td>
<td>16,000</td>
<td>17,000</td>
<td>18,000</td>
<td>19,000</td>
</tr>
<tr>
<td>Total</td>
<td>693,300</td>
<td>763,800</td>
<td>875,200</td>
<td>943,500</td>
<td>978,900</td>
<td>1,012,700</td>
<td>1,016,000</td>
<td>1,015,000</td>
<td>1,015,000</td>
<td>1,015,000</td>
</tr>
</tbody>
</table>
CHAPTER X

THE INDUSTRIAL APPLICATIONS OF ZINC

The most important use of metallic zinc is in galvanising, which probably consumes more than 70 per cent. of the total output. The manufacture of brass probably utilises another 20 per cent., while the remaining 10 per cent. is used for conversion into sheets and for minor purposes, such as the production of alloys other than brass.

Galvanising—The process of zincing, or, as it is termed, galvanising, which was discovered by Crawford in 1837, consists in depositing a very thin coat of zinc on iron, whereby the latter is preserved from oxidation by the atmosphere. In the United Kingdom galvanising has become an important branch of metallurgical industry and is very extensively practised, the chief centres of production being the Birmingham, Wolverhampton and South Wales districts.

Galvanising may be effected by the method known as hot galvanising (immersion in molten zinc), by the electrolytic process, by Sherardising, or by Schoop's metal-spraying process.

The hot galvanising process was, however, responsible for the production of practically all the 850,000 tons of galvanised sheets and wire exported from the United Kingdom in 1913.

In this process the iron is first freed from scale by immersing ("pickling") in hydrochloric acid, then washing well and scouring with sand. After cleaning, the plates or other articles are immersed in the galvanising bath, which is contained in a wrought iron pot, and consists of molten zinc covered with a layer of ammonium chloride.

The strength of acid used for pickling varies with the nature of the work. In the United Kingdom a 20 per cent. solution of
THE ZINC INDUSTRY

hydrochloric acid is generally used for iron sheets, and acid of 12 per cent. strength for iron wire and tubes. The pickle is used cold, or nearly cold, and the operation is complete in a few minutes. At some works, particularly on the Continent, dilute sulphuric acid is used in place of hydrochloric acid for reasons of economy, but in this case a longer immersion is necessary. The temperature of the galvanising bath determines the thickness of the zinc coating; the hotter the bath the thinner the deposit. The solvent action of zinc on iron, according to Dietel, increases gradually up to about 490° C., above which temperature it rises very rapidly, being thirty times greater at 530° C. than below 490° C.

The iron sheets may be passed, after their passage through the bath, between rolls or wire brushes to remove superfluous zinc, and thus reduce the consumption of zinc. This treatment considerably improves the surface of the sheets. Zinc of good quality should be used for the galvanising bath, as the presence of lead exceeding 2 or 2.5 per cent. renders the zinc unsuitable for galvanising, the lead being easily dissolved by most soft waters, thus exposing the surface of the galvanised metal and hastening corrosion. Galvanised sheets often exhibit a beautiful moiré-métallique surface, due to the crystallisation of the zinc. When it is especially desired that the finished articles shall have a spangled appearance, from 2 to 3 per cent. of tin is sometimes added to the zinc bath. The addition of aluminium is said to increase the fluidity of the galvanising bath, owing to its deoxidising action, and also to its influence in effecting the separation and precipitation of the iron that accumulates in the bath. The aluminium should be added in the form of a zinc-aluminium alloy with a melting point below 480° C. Corrugated iron sheets form a considerable portion of the galvanising trade; these are often galvanised plain and then passed through the corrugating machine. The galvanising of iron wire, such as is employed for fencing, signal wires, &c., is performed with great rapidity, thecoiled wire being annealed at the same operation. For this purpose the coiled wire is drawn through a furnace of such length that the wire in its passage through it is heated to redness, whilst the heated wire, as it passes out from the furnace, is directed by guide pulleys through a reservoir of dilute sulphuric acid (pickle), which has

THE INDUSTRIAL APPLICATIONS OF ZINC

the effect of cleaning off any scale. On leaving the pickle it passes through a quantity of sand, whereby the wire acquires a clean metallic surface before it enters the bath of molten zinc. In this manner, whilst one end of the wire is still passing through the annealing furnace, the other extremity is being wound on to a drum in its galvanised state.

Owing to the great ease with which zinc is attacked by acids, galvanised iron is not adapted as a constructive material where it would be exposed to acid vapours.

In addition to sheets and wire, the process of galvanising is applied to chains, links, and many other articles requiring to be protected from corrosion.

The hot galvanising process yields two by-products: (1) hard zinc and (2) flux skimmings. The former is an alloy of zinc and iron, containing from 2 to 5 per cent. of iron, resulting from the gradual contamination of the zinc bath with iron. Being heavier than zinc, this alloy sinks to the bottom of the bath in pasty masses, and is removed from time to time by means of a perforated iron ladle, and cast into plates, which, when broken, exhibit a close-grained fracture with black spots characteristic of zinc containing iron. Part of this alloy passes into commerce for use where a zinc-iron alloy is required, and the remainder is liquated to separate as much zinc as possible. For this purpose the alloy is usually remelted at a high temperature, when it separates into two layers, the top layer consisting of tolerably pure zinc, which is carefully bailed off. The bottom layer is much less fusible, and forms a hard crystalline or granular material of the colour of zinc, but less lustrous. This ferriferous zinc is very friable, and frequently exhibits surface colorations of great beauty; it contains about 7.5 to 9 per cent. of iron, and is sold to the zinc smelters, who recover the zinc by a special redistillation.

The scum that accumulates on the surface of the galvanising bath and known as "flux skimmings" is removed from time to time. It consists of chloride and oxide of zinc together with some ammonium chloride and dirt. It is sold to the smelters, who treat it, usually by distillation, for the recovery of the zinc.

The disposal of the waste pickling liquors, which contain about 15 per cent. of hydrochloric acid and 10 per cent. of iron, chiefly as ferrous chloride, has caused considerable trouble in many localities where galvanising is carried on, and special
processes have been devised to deal with them. Hitherto the usual system has been to neutralise the acid with lime and subsequently to roast the precipitate of ferrous hydroxide so obtained in order to convert it into red oxide of iron, which is sold.

The great increase in the price of zinc since the outbreak of war seriously affected the galvansing industry and led to the adoption of other methods and of substitutes, such as electro-galvansing, which consume much less zinc, and galvansing with lead, either by the hot process or by electro-deposition. Although it is not easy to disturb the settled demand for a world-wide commodity such as galvanised sheets, there are obvious possibilities in substitutes, once the buyer is familiarised with them and finds them cheaper. Experience shows that substitutes for zinc will probably hold some of the ground they have temporarily acquired.

The electro-galvansing process has gained considerable favour in recent years, and its use is rapidly extending for certain classes of work, as it possesses several important advantages over hot galvansing. These may be summarised as follows: (1) greater economy in the use of zinc, as a much thinner deposit than that afforded by hot galvansing is sufficient to prevent rusting; (2) more complete control of the thickness of the coating on various surfaces; and (3) suitability for articles, such as steel springs, which have been subjected to special heat treatment and must not be heated to the temperature of molten zinc. Another advantage claimed for electrolytic galvansing is that it reveals defects, such as fine cracks, &c., in the iron, which would be concealed by hot galvansing. On the other hand, the electro-galvansed surface is dull or "dead" and not so pleasing in appearance as that produced by the older method.

Although a large number of solutions have been tried for electro-zincing, the general opinion amongst practical operators is that solutions of the sulphate, either alone or with other salts, give for general purposes the most trustworthy results, with the minimum of trouble in working. In practice, the zinc is usually employed either in the form of a neutral solution of the sulphate or dissolved in excess of caustic soda.

"Sherardising."—In the process of coating iron and steel with zinc, introduced by Sherard Cowper Cowles, and known as

"Sherardising," the articles, after being thoroughly cleaned by pickling, &c., are heated in metal drums, or boxes, in contact with zinc dust at a temperature of from 260° C to 425° C. Vaporisation of the zinc dust takes place, the metal vapour then condensing on the surface of the iron articles. A zinc dust having a high metallic content will give the best coating. The condensed zinc slowly combines with the iron, giving a coherent protective coating that is highly resistant to corrosion.

The iron content of the Sherardised coating is a function of the temperature. The process is therefore carried out at the lowest temperature that is economically possible to secure a low iron content in the coating, since a high iron content is detrimental to the weathering properties of the coating.

The Sherardised surface is light grey in colour, with a dull or matte finish, but it is capable of receiving a high polish and made to resemble nickel plate. The process is economical and yields a superior product, and will doubtless receive more attention in the future than has been hitherto accorded to it. It is specially adapted for coating articles having a pattern or design on the surface which would become filled up and obliterated if the ordinary galvanising process were employed. Iron screws which have been galvanised by Sherardising are ready for use without further treatment. Narrow tubes can be galvanised inside by Sherardising, and this process has been used for coating with zinc the iron 5 plating pieces recently introduced in the coinage system of Germany.

The process of galvanising, patented by Schoop, of Zurich, consists in projecting a spray of pulverised zinc on to the goods, previously cleaned and warmed, until a zinc deposit about 0.1 mm. thick is produced. The adherence of the deposit is said to be perfect. In the latest development of the spray process the zinc in the form of strip or wires is fed at a uniform rate into an oxy-hydrogen or other flame (or even an electric arc) sufficient to melt it readily. As fast as the metal melts a stream of compressed gas directed on it carries it away in a state of fine subdivision on to the surface to be coated. In practice, a specially constructed "metal spray pistol" is used for producing the spray. Very promising results are said to have been obtained by this process in Belgium and France, where it is in use on a large scale.
Rolled or Sheet Zinc

Zinc lends itself well to rolling into sheets when the operation is carried out at a temperature between 100° C. and 150° C., within which range the metal is most malleable and ductile. In spelter intended for rolling, a small percentage of lead is desirable, as it improves the rolling qualities of the zinc, but the amount should not exceed 1 per cent. The rolled zinc of commerce is therefore a nearly saturated solution of lead in zinc, since it usually contains 1 per cent. of lead. Iron increases the hardness and impairs the malleability of zinc and should not exceed 0.15 per cent. In practice, it is usual partially to refine the spelter by liquation, so as to reduce the lead and iron to the minimum practicable by such methods, and when the refining has been properly conducted these amounts have little or no effect upon the malleability and ductility of the zinc. The metal to be used for rolling into sheets is cast in open moulds into flat ingots or plates which, whilst still hot, at the proper temperature, are rapidly passed through the rolls until the correct gauge is attained. For convenience, the ingot moulds are sometimes arranged in a circle on a rotating table.

Most of the zinc rolling is done on the Continent in Silesia and Belgium. The output of sheet zinc in Belgium in 1913 was 51,500 metric tons. A small quantity is rolled in the United Kingdom, chiefly at Birmingham, where zinc was first rolled early in the last century. There are also zinc rolling mills in the United States.

Prior to the war it was usual to import Continental zinc for rolling in this country, as it contained more lead than most of the British brands, which after refining are relatively free from lead, and are mainly employed for the production of alloys. It is customary when rolling Continental zinc to remove the excess of lead by liquation, as previously stated. In addition to the small amount of zinc rolled in this country, more than 20,000 long tons of foreign sheet zinc are annually imported into the United Kingdom. It would thus appear that there is ample scope for the extension of the British zinc rolling industry. A very large proportion of the zinc sheeting annually produced is employed for roofing purposes, mainly on the Continent. The metal is used either in the original sheets, or in the form of ornamental stamped
tiles, which are nailed to the roof in an inclined position in the same way as slates. As a roofing material, sheet zinc is durable, light and efficient. Although up to the present it has found little application in the United Kingdom for roofing, its uses for this purpose have become so extensive in Continental countries that the spelter market is very materially influenced by the prosperity or otherwise of the general building trade.\footnote{J. C. Moulton, \textit{loc. cit.}, p. 522.}

Thin sheet zinc finds application for a variety of purposes. In this form it lends itself readily to stamping in dies, and stamped ornaments in zinc were first produced in 1852. Within recent years it has found very considerable use for ceilings, the metal being stamped with varied ornamental designs in relief. It finds employment in the manufacture of many articles in ordinary domestic use, such as bath-tubs, pails, toys, \&c. Metal of thinner gauge is used for the lining of air-tight wooden cases, hermetically sealed by soldering, for export to tropical countries. When perforated, sheet zinc is used for screens, sieves and other purposes. Rolled zinc plates of specially high quality find important use in the photographic reproduction process known as photo-zincography and in photo-etching.

Hot zinc sheets with a fine smooth polished surface are employed for producing the satinsised surface finish on the better-class papers.

Thick rolled zinc plates, sawn to suitable sizes and drilled for bolting, are used to a considerable extent in marine boiler work to prevent corrosion of the boiler plates. For this purpose the zinc is bolted into position in different parts of the boiler, and owing to its being highly electro-positive it is first attacked by the corrosive influences and can be renewed when necessary. It is essential, however, that thorough metallic contact between the surfaces should be made to obtain full advantage of the protective influence of the zinc.

\textit{Zinc Castings}

The use of zinc in the foundry is somewhat limited, the demand for the cast metal being very small. It contracts but slightly on solidification, and is thus well adapted for castings. The castings made at a high temperature are brittle and largely

167
crystalline; but when cast near the solidifying point they are more malleable. Overheating of the metal, with its attendant losses, should be carefully avoided. Ammonium chloride (sal ammoniac) is recommended as the best flux, its action being to convert the floating dross from a pasty mass to a "dry dust."

Aluminium is recommended as the best deoxidiser, to be added after skimming, in the proportion of 0.001 per cent., and in the form of thin sheet clippings, the fluidity of the molten zinc is thus increased.1

Owing to the facility with which lead segregates, especially if the metal is poured at a high temperature, no brand of zinc containing more than 0.5 per cent of lead should be used in the foundry.

Dies or blocks upon which hats are shaped are made of cast zinc. Cast zinc dies are used in the dental laboratory for swaging artificial metal-dentures. It is also employed for monuments, statues and tombstones, under the name of white bronze.

Spelter is also largely used for the production of "slush" castings for ornamental purposes.

In these, the metal in the mould is poured back into the ladle as soon as a thin layer has solidified on the face of the mould. These hollow castings must be sound, not merely for strength, but because they are all ornamental in character, and are usually required to be subsequently plated. The moulds are usually made of bronze, and many of the shapes are such as to cause excessive strains in the solidified zinc. The castings are polished and plated or otherwise finished. Makers of intricate slush zinc castings find it necessary to use metal of high grade, otherwise the castings are very liable to crack. Indeed so much is this liability to crack an indication of the quality of the metal that a number of the makers of high-grade zinc in America use the slush mould as a means of testing their product.

Cast zinc rods had extensive application in battery cells for electrical work. Rods are also prepared for this purpose by rolling, or by extruding the metal. Zinc of high grade should be used in their manufacture, as the life of such rods is much longer than of rods made from ordinary brands of spelter.

The employment of zinc for the manufacture of seamless pipes

1 The Foundry, 1915, Vol. VIII, p 244
THE INDUSTRIAL APPLICATIONS OF ZINC

for water supply has been advocated in recent years. The pipes are made from pure "hard" zinc and have a diameter up to 80 millimetres. They can be tin-lined if required. Two pipes can be joined in the usual manner by widening the end of one and inserting the end of the other, or by covering the adjacent ends with a sleeve, and soldering. Tin solder is used, preferably with a stearine flux. The manufacture of the pipes is simple, and their bending easy. The pipes are as useful for water supply as lead pipes, and have the advantage of being much safer from a hygienic point of view, as no injury has been found to arise from the traces of zinc which are dissolved by water. Zinc is cheaper than lead for this purpose, and on account of its lightness the pipes do not require such strong wall supports. A pressure of 500 atmospheres is required to burst the pipes. These pipes cannot, however, be used for a hot water supply on account of the great expansion of zinc. In some recent tests by Runck, tap water of medium hardness was sealed up in large zinc pipes with air excluded. After a year the amount of dissolved zinc was 2 to 3 milligrammes per litre. Physiological tests over a long period with water containing 7 to 8 milligrammes of zinc per litre gave no indications of injurious results.

Other Uses of Zinc

Metallic zinc plays an important part in several metallurgical operations, notably in the precipitation of gold and silver in the cyanide process, the desilverisation of argentiferous lead by the Parkes process, and the reduction of silver chloride in gold refining.

Large quantities of zinc are used annually in South Africa and elsewhere for precipitating gold from cyanide solutions by means of zinc shavings. The precipitation is usually effected in wooden or steel troughs (known as zinc boxes) containing shavings of zinc coated with precipitated lead, formed by dipping the shavings into a strong solution of lead acetate. The zinc shavings are very thin and light, and are carried on iron gratings.


THE ZINC INDUSTRY

through which the auriferous solution passes. The gold is precipitated on the zinc as a black mud, and is recovered by dissolving out the excess of zinc with acid. After drying, the gold mud is melted with fluxes and the resulting metal refined. From 5 oz. to 16 oz. of zinc shavings are generally needed for each ounce of gold recovered. The consumption of zinc in South Africa, chiefly for this purpose, amounted to 4,867 tons in 1914.

The employment of zinc in the desilverisation of lead is based on the fact that when molten zinc is stirred with a bath of argentiferous lead, which is afterwards allowed to cool, a crust forms on the surface consisting of zinc alloyed with silver and any gold and copper that may be present.

In the Parkes process, the solid zinc in slabs is thrown on the surface of the molten lead, and when it is melted the mixture is well stirred and then allowed to cool. The total amount of zinc added varies according to the content of silver, but is usually from 1/2 to 2 per cent. of the weight of the argentiferous lead, and it is added in two or three lots, as several treatments with zinc are necessary to remove all the silver. The zinc crusts that form on the surface are removed by means of perforated ladles, the crusts being kept separate.

Fresh additions of zinc are made until the lead contains only about one-sixth of an ounce (0.0005 per cent.) of silver per ton. The zinc crusts, which are largely contaminated with lead, are submitted to liquation, whereby the lead separates and flows away, leaving the enriched scum behind.

The rich scums are distilled so that a large proportion of the zinc is recovered and is available for further use. The residue consists chiefly of lead, and contains from 5 to 10 per cent. of silver, which is recovered by cupellation. It is essential that fairly high grade zinc be used for the Parkes process, as certain impurities, particularly iron, cause a much larger consumption of zinc. The process is carried out in large cast iron pots holding as much as 50 tons.

Zinc plates are used to a limited extent for the reduction of silver chloride resulting from the refining of gold. For this purpose the silver chloride is melted and cast into slabs, which are encased in flannel bags and boiled in water to remove base metals. The slabs are then arranged alternately with zinc plates in a tank of acidulated water, whereby the silver is reduced by
electrolytic action. In modern practice, however, iron plates have been substituted for those of zinc.

Attention has already been directed to the use of zinc balls for the precipitation of impurities in solutions that are to be submitted to electrolysis. Recently the use of zinc balls for the precipitation of gold in cyanide solutions in place of zinc shavings has been suggested and introduced at several mines.

Metallic zinc has also been used for coinage. A new coin consisting of pure zinc, and representing in value the ¼-th part of a piastre, was legalised in 1905 for circulation in Indo-China. In that year 60,000,000 pieces, valued at £21,600, were struck at the Paris Mint.

Zinc Dust (Blue Powder)

There is a limited market for zinc dust, which, as previously pointed out, is a by-product from the distillation process. When zinc vapour is cooled too rapidly after distillation, or if it becomes too largely diluted with other gases, it condenses, not as fluid metal, but in the form of a fine bluish-coloured powder, consisting of an infinite number of minute globules coated with oxide, which prevent it from coalescing by ordinary means. Some of this substance, which is known as "Zinc Dust," "Blue Powder," or "Poussière," is always formed during the process of distillation, and is usually found in the "prolongs" beyond the condensers.

The amount produced varies from 3 to 10 per cent. of the total zinc present when retort smelting is used, but with electro-thermic processes the quantity is usually much larger.

The commercial value of zinc dust depends upon its content of metallic zinc, and the best grades contain from 86 to 92 per cent. of zinc in the metallic state.

The commercial standard is that it shall pass a 100-mesh sieve and not contain more than 10 per cent. of zinc oxide.

Zinc dust is considerably more active chemically than spelter, being oxidised readily, and having the power to absorb hydrogen. On this account it finds many uses in chemical industries, being used to discharge locally the colour of dyed cotton goods and in the preparation of the indigo vat. It is used as a precipitant for

1 Thirty-sixth Mint Report, 1905, p. 44.
2 J. C. Moulden, loc. cit., p. 324.
THE ZINC INDUSTRY

the removal of copper, antimony, arsenic, &c., from electrolytic solutions containing these and other metals.

It has also been used for the recovery of gold and silver from cyanide solutions of these metals, for which purpose it has been stated to be more efficient than zinc shavings. Latterly it has found increasing favour for this purpose, as the small amount of lead it usually contains acts beneficially in promoting more rapid and complete precipitation of the gold and silver.

Reference has already been made to its use in the Sherardising process.

Care has to be exercised in the storage of zinc dust, owing to the readiness with which it will fire if exposed to moist air, or wetted, when in bulk. Serious fires and even explosions have been caused in this manner.
CHAPTER XI

INDUSTRIAL ZINC ALLOYS

ZINC enters into the composition of a number of important alloys, to which, when present in certain proportions, it communicates hardness without impairing the malleability of the alloy. In larger proportions it often renders the alloy brittle.

Owing to the comparatively low melting point and volatility of zinc, the preparation of its alloys requires considerable care to prevent unnecessary loss of the metal.

Modern research has shown that the mechanical properties of metals and alloys are materially influenced by the presence of small quantities of impurities, and has emphasized the necessity of employing pure metals in the preparation of alloys. This has led, in the case of zinc alloys, to an increasing demand for zinc containing less lead and other impurities than are usually present in commercial spelter.

The economy and other advantages resulting from the use of high-grade zinc for alloying purposes are so great that brass and other alloy makers who have once employed it will never resort to ordinary spelter if they can help it. To meet this demand various works in the United Kingdom are producing a considerable amount of high-grade metal by distillation, and also by electrolytic processes.

There are but few alloys in which zinc is the main constituent, the chief being the so-called anti-friction metals, but in smaller proportion zinc is a valuable constituent in several very useful alloys.

The alloys of industrial importance in which zinc is a constituent are (1) those consisting of zinc and copper, constituting
THE ZINC INDUSTRY

the numerous varieties of brass; (2) those consisting of copper, zinc, nickel, forming the so-called "German or Nickel Silvers"; and (3) zinc with tin and other metals known as "anti-friction metals."

Brass.—Brass was first made by the Romans shortly before the Christian era, and was used both for coins and ornaments. The ancient name of the alloy was latten, which is still retained in the French word laiton. In the Middle Ages the Germans were famous for the production of brass, which was imported into this country, principally from Cologne, chiefly in the form of rectangular pieces known as Cullen plates, this was employed for the so-called "brasses" of churches, particularly in the Eastern Counties. More than 4,000 such brasses are known to exist in various churches, &c., in the United Kingdom, which is far richer in this respect than any other country. The first works for the production of brass in England are stated to have been erected by a German, at Esher in Surrey, about the middle of the seventeenth century, copper being imported from Sweden for its manufacture. Its manufacture was started in Bristol in 1702, and brass works were erected in Birmingham about 1740 by the Turner family. Birmingham is now the principal seat of the brass industry of this country, and so rapid has been the development within recent years, that in Birmingham alone prior to the war more than 35,000 persons (male and female) were employed in the brass trade, the value of the metal consumed amounting to four millions sterling.

Considerable impetus was given to the brass industry in the early part of the eighteenth century by the introduction of rolling mills, with the subsequent application of powerful stamping machinery, in 1769, which enabled articles to be produced in sheet metal more rapidly, with better finish and with less metal than by the process of casting hitherto exclusively employed.

Among the more important factors that have contributed to the enormous development of the zinc industry in more modern times must be mentioned the introduction of gas fittings, in the early part of the nineteenth century; the use of brass tubes in locomotives and marine engines; the introduction of yellow metal sheathing; the extended uses of brass for engineer's work, and for water fittings, &c.; and more recently the very extensive employment of the metal for electrical fittings.

174
Until the middle of last century, brass was exclusively made by the old process of "cementation," in which metallic copper was heated in crucibles in contact with calamine (zinc ore) and carbon, whereby zinc was liberated and combined with the copper to form the alloy known as "calamine brass." This ancient process was superseded by the direct preparation of brass which is now exclusively employed. This is effected by melting together a mixture of copper and zinc, either in crucibles, or when very heavy castings are required in a reverberatory furnace.

When prepared in crucibles the zinc is added to the copper immediately after the latter is completely melted, the ingots of copper having been heated to redness prior to their introduction into the pots. In making castings, and in the remelting of brass, there is always a considerable loss of zinc through volatilisation, for which allowance must be made when arranging the mixture.

The clay or graphite crucibles usually hold about 90 lb. of metal, but much larger pots are sometimes employed. The crucibles are heated in small wind furnaces burning coke as fuel, or in furnaces heated by gas or oil.

Zinc and copper alloy in all proportions, the resulting products being of uniform composition throughout, as the metals do not segregate. The colour and properties of the alloys vary with the relative proportions of the metals. When the alloys are of a decidedly yellow colour they are known industrially by the general term "brass," although many special names have been introduced by different makers to represent one and the same alloy, thus giving rise to considerable confusion.

The term white brass is given to alloys in which zinc predominates, giving a white alloy. As a result of the work carried out by modern methods of research, our knowledge of the constitution of alloys of the zinc-copper series has advanced considerably of late years. The constitution of alloys rich in zinc is very complex, but these alloys are of little industrial value, on the other hand, the constitution of the alloys rich in copper which constitute the brasses proper is comparatively simple. With a few exceptions the zinc-copper alloys of industrial importance may be said to contain from 50 to 70 per cent. of copper, and within this range there are three constituents or phases, which are respectively designated by the Greek letters α, β, and γ.
THE ZINC INDUSTRY

Research has shown that in certain mixtures of metals there is obtained one or more classes of crystal formation, depending on the mutual solubility of the two metals. Thus iron and nickel dissolve in one another in all proportions and give only one type of crystals, no matter what the proportions. On the other hand, zinc and copper are not mutually soluble in all proportions. Starting with pure copper and adding zinc, the limit of solubility is reached with 36 per cent. of the latter metal. Up to this point only α-crystals are observed under the microscope, beyond it β-crystals appear with the α-crystals, and later γ-crystals appear. The Alpha-constituent consists of a solid solution of zinc in copper, the maximum content of zinc being as stated, about 36 per cent. at 400° C. The Gamma-phase was regarded by Shepherd as a solid solution, but as the result of more recent research there is evidence to show that the Gamma-phase contains a definite compound, Cu₂Zn₃, containing about 40 per cent of copper. The Beta-constituent contains about 52 per cent. of copper and has the properties of a solid solution. According to Carpenter, however, the so-called Beta-constituent splits up into an intimate mixture of Alpha and Gamma on cooling from a critical temperature of 470° C. On heating above this temperature the reverse change takes place. This critical temperature is found in all alloys containing from 60 per cent. of zinc down to 28 per cent., and probably less.

The Alpha-phase is relatively soft and ductile, and the Beta-phase is harder and less ductile, while the Gamma-phase is still harder and very brittle, and can be readily powdered in a mortar. As the Gamma constituent is very brittle, the fact that the stable phase above 470° C. is Beta, and below this temperature Alpha plus Gamma, has an important bearing on the cause of the brittleness and decay of many brasses in engineering work (Carpenter).

The brasses containing more than 64 per cent. of copper consist of a single homogeneous solid solution, while those containing from 55 to 64 per cent. of copper are composed of two constituents, each of which is a solid solution. Rapid cooling from a suitably high temperature is capable of profoundly modifying the structure and constitution, and consequently the properties, of the zinc-copper alloys.

176
INDUSTRIAL ZINC ALLOYS

The constitution of the chief commercial brasses has been classified by Hudson¹ as follows:

<table>
<thead>
<tr>
<th>Copper per cent</th>
<th>Nature of Constituent</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-71</td>
<td>Consists entirely of Alpha phase at all temperatures</td>
</tr>
<tr>
<td>71-64</td>
<td>Alpha-phase below 400⁰ C., Alpha plus Beta above</td>
</tr>
<tr>
<td>64-63</td>
<td>Alpha plus Beta at all temperatures</td>
</tr>
<tr>
<td>63-53.5</td>
<td>Alpha plus Beta at low temperatures, Beta only at some higher temperature</td>
</tr>
<tr>
<td>53.1-51</td>
<td>Consists entirely of Beta at all temperatures</td>
</tr>
<tr>
<td>51-40</td>
<td>Beta plus Gamma at low temperatures, Beta only at higher temperature</td>
</tr>
</tbody>
</table>

It will be noted that the proportion of the Beta-constituent increases as the temperature rises, and this fact has important bearings on the heat treatment of brasses. As shown by Charpy, the effect of adding zinc to copper is to increase the tenacity and to diminish the ductility.

With more than 40 per cent. of zinc, however, the tenacity very rapidly decreases, whereas the ductility is diminished after the addition of 30 per cent. of zinc.

Consequently, for ductile brasses the limit of zinc is usually about 30 per cent., and in cases where a combination of ductility and strength is required, as with brass for cold-drawn tubes, or for cartridge cases, an alloy of about 70 per cent. of copper and 30 per cent. of zinc is preferred.

The industrial brasses may be conveniently considered under three heads, viz: (1) Cast brass, (2) low brass (i.e., low copper-content) for hot rolling, and (3) high brass (i.e., high copper-content) for cold rolling.

(1) Cast brass is very variable in composition, but with the exception of a few alloys rich in copper used in the manufacture of cheap jewellery, &c., the usual composition of cast brass is about 66 per cent. of copper and 34 per cent. of zinc, which is known as English standard brass. It casts well, and is capable of being rolled and hammered and even drawn into wire if so required.

(2) Low brasses suitable for hot rolling contain from 55 to 63 per cent. of copper. The commonest of these yellow brasses is that known as Muntz metal, patented by G. F. Muntz in 1832.


177
THE ZINC INDUSTRY

and consisting of 60 per cent. of copper and 40 per cent. of zinc. Although Muntz metal was originally introduced for sheathing wooden ships, it is now chiefly used, either under the name of Muntz metal or "yellow brass," for the cheaper varieties of brass tube, wire and sheet.

Muntz metal is hardened by quenching, and the explanation of this is readily seen from its structure. With increasing temperature the Alpha-constituent is dissolved by the harder Beta-constituent until, at 720° C., the alloy containing 60 per cent. of copper consists entirely of the Beta-constituent. If, now, the alloy is quenched from this temperature the separation of the Alpha-constituent is hindered, and the alloy will be found to be stronger but less ductile than before.1

(3) High brasses, suitable for cold rolling, usually contain more than 60 per cent. of copper. Whereas these alloys are readily workable in the cold, they are quite brittle when hot, and, therefore, cannot be subjected to hot working. The best alloy of this class is the brass used for tubes and wire drawing, which contains 70 per cent. of copper and 30 per cent. of zinc. This alloy possesses the maximum elongation of the copper-zinc series combined with a considerable degree of strength. On this account it is used for the production of cartridge cases, alike for rifle, machine-gun and the lighter types of artillery, and is frequently referred to as "Cartridge" brass.

As it is subject to the severest of treatment, cartridge brass requires that both the copper and zinc shall be as pure as possible, 99-8 per cent. of zinc being a minimum, with 0·1 per cent. of lead and 0·1 per cent. of iron as maxima.

The annealing of brass is carried out in reverberatory furnaces, the temperature employed varying with the composition of the brass. In the case of cartridge brass, the maximum effect of annealing is reached at 600° C., whilst there is a very marked softening of the alloy at 420° C.

Industrial brass is capable of withstanding very drastic treatment, and in addition to rolling, drawing, stamping and spinning, it is capable of being extruded or forced through dies at temperatures somewhat below the melting point of the alloy. Great advances have been made within the last few years in the extrusion of brass, and complicated sections which it would be impossible to produce by rolling are now regularly manufactured by

INDUSTRIAL ZINC ALLOYS

this process (Law). The alloys used for this purpose usually contain about 40 per cent. of zinc.

Brasses containing Iron.—The addition of iron to brass, first suggested by Kier in 1779, imparts special hardness, toughness, tenacity and wearing properties, whilst the alloy can be rolled either hot or cold. In more modern times brasses containing iron as an essential constituent have been introduced under special names, such as "Sterro-metal," or "Gedge’s alloy," "Aich’s metal" and "Delta metal," which may be taken as representative of the class.

These alloys, which are now largely used, consist essentially of yellow brass, containing from 55 to 60 per cent. of copper and 38 to 41 per cent. of zinc, with the addition of iron, which varies from 1.5 to 4.5 per cent. In addition to iron, small quantities of other metals are frequently added.

Sterro-metal contains 60 per cent. of copper, 38 per cent. of zinc, and 1.5 to 2 per cent. of iron, and Aich’s metal is practically the same, although various analyses show that the percentage of iron present varies within somewhat wide limits, and tin is sometimes present. Sterro-metal can be made very hard and dense by suitable mechanical treatment, which has as great an influence in modifying its properties as its chemical composition. In rolling or hammering this alloy when hot, special care is requisite in regulating the temperature to which it is raised, as it becomes brittle when overheated, and cracks under the hammer or between the rolls.

Delta metal, introduced by Alexander Dick in 1883, varies in composition, an average composition consisting of approximately copper 55 per cent., zinc 42 per cent., with 1 to 2 per cent. of iron. In some cases small amounts of manganese, aluminium, tin or lead are added to the alloy to impart special properties to it.

Delta metal is stronger, harder and tougher than brass. It is easily cast, forged or stamped, and is capable of being rolled hot and drawn cold. In addition, it has a much greater power of resisting corrosion than ordinary brass, which enables it to be used for many purposes where such brass is inadmissible, more especially for shipbuilding, marine engineering and sanitary work. The maximum stress of Delta metal varies from 27.8 to 35.4 tons per square inch, according to the treatment to which it has been subjected. The constitution of the iron brasses does not appear
THE ZINC INDUSTRY

to have been sufficiently investigated; when present in small amounts the iron appears to enter into the alloy as a solid solution and does not form definite chemical compounds (Law). When more than about 2 per cent. of iron is present, the iron and zinc would seem to combine. Formerly the iron was added to these alloys in the form of a copper-iron alloy, but this was not found to be entirely satisfactory, the metals in all probability not being properly alloyed. Dick, when he patented Delta metal, suggested the introduction of the iron in the form of an alloy of iron and zinc, which can be obtained of reliable composition, and is also relatively cheap as a by-product from the galvanising process. Since that time iron-zinc alloys have been largely used. The preparation of iron-zinc alloys for this purpose is dealt with subsequently.

Brasses containing Lead.—A small addition of lead is beneficial in brasses intended for turning, the best alloy, and that which is most commonly used, containing about 60 per cent. of copper, 38 per cent. of zinc, and 2 per cent. of lead; it is sometimes termed “clock brass.” The lead is usually added after the zinc, and while the crucible is still in the fire, the temperature being kept as low as possible. Lead does not alloy with brass, but separates out in the form of globules and films between the crystals of the brass, a condition which necessarily weakens the metal, so that the addition of lead is only permissible where strength is of secondary importance. The fracture of brass containing lead is distinctly grey in colour, owing to the fact that the line of fracture passes through the lead.

The beneficial effect of lead in brasses intended for turning was known long before the nature of its influence was understood. Ordinary brass is difficult to turn owing to the character of the turnings, which are long and tenacious, and tend to foul the tools; a slow speed has also to be employed. On the other hand, the presence of lead in a free state in the brass renders the alloy less tenacious, and the turnings break off through the lines of weakness caused by the lead, so that chips are produced instead of spiral turnings. The lead also appears to act as a lubricant, with the result that a much higher speed can be employed and a better finish given to the work. Brass containing not more than 2 per cent. of lead can be rolled, but the alloy is rolled cold, on account of its liability to crack if rolled hot.

Brass containing Tin.—A small percentage of tin renders brass,
and more especially low brasses of the Muntz metal type, less liable to corrosion by sea-water when in contact with gun-metal. On this account brasses containing tin are employed in naval construction, the alloys being known as "naval" brasses. They contain approximately 62 per cent. of copper, 37 per cent. of zinc and 1 per cent. of tin. The mechanical properties of brass are not seriously affected by the addition of 1 per cent. of tin, but beyond this amount there is a rapid increase in brittleness and hardness, whilst with more than 2 per cent. the alloys lose their useful properties.

Many of the more important of the copper-zinc alloys are those containing about 60 per cent. or less of copper in which part of the zinc is replaced by small quantities of one or more other metals, such as those mentioned above. The number of such special brasses is now increased by the so-called vanadium bronzes, in which cupro-vanadium is used as one of the ingredients. The actual effect of vanadium in alloys does not appear to be very great.

*Alloys of Zinc and Iron.*—With iron zinc forms a series of alloys which are generally white, hard and brittle. When the iron does not exceed about 5 per cent. the alloys are less crystalline and darker in colour than pure zinc, such alloys are produced in the process of galvanising, and are known as "hard zinc." The alloys become greyer, harder and more brittle as the iron content is increased. The alloy obtained by saturating zinc near to its temperature of volatilisation with iron is not attracted by a magnet; it does not rust, nor give sparks by friction or blows. It is dense in structure, but is only semi-metallic in fracture, and contains about 22 per cent. of iron.

The zinc-iron alloys have a somewhat important application in the preparation of the special yellow brasses, such as Delta metal, which contain from 1.5 to 4.5 per cent. of iron, and to which reference has been previously made.

The necessary zinc-iron alloy is prepared commercially either (1) by direct union of the constituent metals, or (2) by the treatment of hard zinc from galvanising. The alloys actually used in practice generally contain from 7 to nearly 30 per cent. of metallic iron.

The production of the zinc-iron alloys by direct fusion of the metals is difficult owing to the high melting point of iron and the volatile character of zinc. When prepared by this method,
clean iron wire, or sheet, is added to a bath of molten zinc heated to near its boiling point. The union of the metals is facilitated by the addition of a little charcoal and some solid ammonium chloride. This method of preparation is usually accompanied by a considerable loss of zinc.

Alloys rich in iron are usually obtained commercially by liquating the hard zinc from galvanising works to remove part of the zinc, and then strongly heating the residue, which is rich in iron, in a closed crucible.

The excess of zinc is thus volatilised, leaving a zinc-iron alloy in which the content of iron increases with an increase in the temperature employed.

_Nickel Silver_ or _German Silver._—The white alloys manufactured under these names consist essentially of nickel, copper and zinc. An alloy composed of these three metals was known in early times in China, and was exported to Europe in the eighteenth century under the name of "pack-fong," or white copper. Pack-fong seems to have been recognised as a triple alloy of nickel-copper-zinc in 1776, when Engeström published what appears to have been the first analysis. The manufacture of a white alloy composed of these metals was first started on a commercial scale at Berlin, about the year 1824, and was subsequently exported to the United Kingdom as a cheap substitute for silver, and it is probably owing to this fact that the alloy became known as "German silver."

Although alloys of nickel-copper-zinc are now usually known in the trade under the general term of nickel silver, they probably exist under a greater number of special names than any other alloy, since different manufacturers employ fanciful names to denote alloys containing different proportions of the constituent metals which they consider best suited to produce an alloy of good white colour and possessing satisfactory working qualities. Thus Nevada silver, Virginia silver, Potosi silver, Silveroid, Arguzoid, &c., may be given as examples.

The term nickel silver is somewhat misleading, as the alloy does not contain silver. If a nomenclature which indicates the true nature of the alloy be adopted, it would be described as a zinc-cupro nickel, but it is probably more convenient to call it a nickel brass, and this term is now usually adopted by research workers on these alloys, although this name has to a certain extent unfortunately become associated with the alloys of the copper-
INDUSTRIAL ZINC ALLOYS

nickel series containing no zinc and used for coinage purposes.

The nickel silver alloys are now prepared largely as a basis metal for electro-plating upon, and as a substitute for silver for the manufacture of table forks, spoons, &c., the chief centres of production being Sheffield and Birmingham.

In the form of wire they are used for electrical resistances. The percentage of zinc in the industrial alloys varies from 20 to 35 per cent., and it is added as a substitute for the more expensive metal nickel.

The various grades of nickel silver in general use in the United Kingdom are known in trade circles as firsts, seconds, thirds and fifths, which contain approximately the following percentages of nickel: firsts, 20 per cent.; seconds, 16 per cent.; thirds, 12 per cent.; fifths, 7 per cent.; the content of copper appears to vary between 50 and 59 per cent.

The alloy known as seconds is used by many firms as the basis metal for electro-plate wares of best "A 1" quality, although an alloy of higher nickel content is preferred by others. The seconds alloy is also largely used for the manufacture of best quality nickel silver spoons, forks, &c., that are sold as such and not plated.

The character of the silver deposit in relation to the composition of the basis metal has been studied by McWilliam and Barclay,1 who conclude that when the proportion of nickel exceeds 14 per cent. the silver is more liable to strip off irregularly in actual use. It seems advisable, therefore, to avoid too high a percentage of nickel in the basis metal for high-grade electro-plate which has to endure rough usage. Although the alloys poor in nickel are not so white and not so strong as the richer alloys, the importance of the colour is not so great where there is a heavy deposit of silver.

Owing to the high temperature required for the fusion of the nickel, and the low melting point and ready oxidisability of zinc, the preparation of nickel silvers is attended with a loss of zinc, and special care is accordingly required in their production. To overcome this difficulty the alloys are made by melting together an alloy of copper and nickel (usually containing 50 per cent. of each metal) and brass. The copper-nickel alloy has a lower melting point than pure nickel, whilst the brass has a higher

1 *Journal of the Institute of Metals, 1911, vol v, p 214.*
THE ZINC INDUSTRY

clean iron wire, or sheet, is added to a bath of molten zinc heated to near its boiling point. The union of the metals is facilitated by the addition of a little charcoal and some solid ammonium chloride. This method of preparation is usually accompanied by a considerable loss of zinc.

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INDUSTRIAL ZINC ALLOYS

750° C. is sufficient to render the metal soft enough for all purposes.

For ornamental castings, nickel silver containing 1 or 2 per cent. of tin is frequently used; the presence of tin, however, even in small quantity, makes the alloy decidedly yellow in colour; it also renders it brittle and unfit for rolling.

It has been frequently asserted that the brass and nickel silver made in Germany and America, and imported into the United Kingdom prior to the war, is superior in working qualities to that produced in this country. Whilst there is undoubtedly some truth in this assertion, it is well to bear in mind that this superiority of product has only been attained by the use of pure metals, and the application of scientific knowledge to the melting, casting and heat treatment of the alloys, and also to scrupulous cleanliness in all the processes through which the metal passes during manufacture. All these conditions for the production of high-grade metal are equally available to British manufacturers, and it is gratifying to know that within recent years many firms have availed themselves of the rapid advancement of scientific knowledge in the preparation and treatment of metals and alloys, and are now producing metal equal in quality to any supplied from foreign sources. On the other hand, it is unfortunately true that there is still a considerable number of manufacturers who appear to have inherited a certain conservatism, and a tendency to cling to "rule of thumb" methods which may produce alloys suitable for certain classes of work, but they frequently fail to produce the high quality metal required to withstand the severe mechanical treatment to which brass and other non-ferrous alloys are now subjected in modern manufacturing processes, as in the production of cartridge cases.

Anti-friction Metals.—Zinc enters into the composition of a number of so-called anti-friction alloys, or white metals, used for bearings. Bearing linings of white metal are indispensable for certain purposes, as they are soft and enable the axle to adapt itself to the condition of the bearing and run with much less friction than in the case of harder alloys. This tendency of white metal to reduce friction has given rise to the term "anti-friction" metal, which is now generally used for such alloys. One great advantage of white metal alloys for this purpose is their low melting point, which permits of a worn-out bearing being readily melted out and replaced by a new one. The white metal is
generally melted in an ordinary ladle, and when the journal or mandril is wiped dry and chalked, the molten metal is poured in.

Since the introduction of white-metal bearings an immense number of so-called anti-friction metals have been placed upon the market. The composition of these varies very considerably, and they may contain copper, tin, zinc, antimony and lead; but seldom more than three of these metals are used in any one alloy.

Whilst zinc in small proportions enters into the composition of many anti-friction metals, the alloys in which the percentage of zinc preponderates form a comparatively small class.

The composition of a number of white metals in which zinc is the chief constituent is given in the table on p. 190.

From these figures it will be seen that the zinc content may reach 90 per cent. The alloys of zinc, tin and antimony possess a high compressive strength, and they are employed for bearings of machinery, such as rock-breakers, where strength is of more importance than perfect anti-frictional qualities.

Zinc Alloys for Die-casting.—Within recent years white metal alloys containing zinc have found extensive application in the production of die-casting or casting under pressure in steel moulds. In this process the molten metal is forced into the die or mould under a pressure of 100 to 400 lb. per square inch, the pressure being transmitted by a mechanically or hand-operated plunger, actuated by compressed air or by centrifugal force. The alloys used for the production of die-castings are generally white metals of low melting points. The shrinkage of the alloys is an important consideration, and involves special provision in making the moulds. The shrinkage of zinc-base alloys, that is, those in which zinc is the main constituent, is said to be about twice as great as that of tin-base and lead-base alloys and about one-third that of aluminium-base alloys. In a zinc-base alloy the shrinkage is given as 0.004 inch per inch of dimension, thus indicating the care required in making the dies, which are made of special alloy machinery steel. The cost of the dies is very considerable, but upwards of 100,000 duplicate castings, each accurate, may be made from a properly constructed die, thus making the die-cost per casting small.

In ordinary practice, die castings are made to dimensions of plus or minus 0.001 inch to each inch of dimension.

The temperature of the dies and of the metal varies with the
different alloys used, so as to assist in controlling shrinkage. The zinc-base alloys may contain zinc 50-80, tin 5-30, copper 2-20, aluminium 2-6, and antimony 1-5 per cent. A considerable range of alloys is thus available in this series. The following alloys may be given as representative of zinc-base white metal for die-casting.\(^1\) Nos. 1 and 2 are stated to be suitable for ordinary work in place of brass, No. 3 is harder and No. 4 harder still.

### Zinc-Base Die-Casting Alloys

<table>
<thead>
<tr>
<th></th>
<th>No. 1</th>
<th>No. 2</th>
<th>No. 3</th>
<th>No. 4</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Per cent</td>
<td>Per cent</td>
<td>Per cent</td>
<td>Per cent</td>
</tr>
<tr>
<td>Zinc</td>
<td>73.75</td>
<td>72.7</td>
<td>73.8</td>
<td>70.2</td>
</tr>
<tr>
<td>Tin</td>
<td>14.75</td>
<td>14.0</td>
<td>14.0</td>
<td>14.0</td>
</tr>
<tr>
<td>Copper</td>
<td>5.45</td>
<td>5.0</td>
<td>10.0</td>
<td>29.4</td>
</tr>
<tr>
<td>Aluminium</td>
<td>6.25</td>
<td>10.0</td>
<td>14.3</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Antimony</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Gas furnaces may be used for melting the metal, the pot being covered to prevent oxidation, and the metal forced through a tube and nozzle into the moulds.

The advantages of die-casting are low cost of production and interchangeability, together with greater degree of accuracy in the case of small castings than is possible by machinery. The introduction of die-castings has done much to facilitate the work of the foundry, as the process is adopted for making intricate parts which would be expensive to cast in sand, to stamp in dies, or to machine. The accuracy of die-castings having holes, screw threads, teeth, &c., is as great as with ordinary machined parts. Owing to technical difficulties the limit in weight of average die-castings is given as 5 lb., although in special cases the weight may be as high as 11 lb. Some of the uses of die-castings are as bearing magneto parts, electric lighting and starting systems, speedometer housings, &c., in automobile work, and as parts in automatic machines, cash registers, &c.

### Alloys of Aluminium and Zinc

The importance of alloys of aluminium and zinc has long been recognised, but it is only within recent years that the price of aluminium has enabled its alloys to be used on a large scale. Zinc forms solid solutions with aluminium, and the alloys of these metals, either alone or more.

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\(^1\) *Engineering*, 1911, vol. LXXIII, pp. 144-145.
THE ZINC INDUSTRY

often with small additions of other metals such as copper or magnesium, are practically the only aluminium alloys of industrial importance.

The alloys are largely used in connection with munitions of war, as in certain parts of shells, in aeroplane construction, in the motor industry and for many other purposes where strength and lightness are desired.

Only the aluminium-zinc alloys containing less than 40 per cent. of zinc are single homogeneous solid solutions, and they are therefore the only ones of practical value. Those containing up to 15 per cent. of zinc are soft enough to be rolled or drawn, whereas beyond this amount the alloys are hard and more suitable for castings, as they are easily worked. In practice the alloys usually contain from 10 to 20 per cent. of zinc, with the addition of a small quantity of copper. The properties of the aluminium-zinc alloys have been investigated by Rosenhain and Archiblett,¹ whose mechanical tests indicate that alloys containing from 15 to 25 per cent. of zinc (with or without addition of copper) would be more serviceable than alloys containing less than 15 per cent. of zinc, which are much more widely used in present practice. If dynamic as well as tensile tests be taken into consideration, the alloy containing 20 per cent. of zinc appears to be the most useful of the binary alloys. A characteristic feature of the alloys is the very large effect produced upon them by hot work.

When the alloys are heated, the tensile strength falls rapidly, but the hot alloys exhibit a considerable amount of ductility, so that it is possible to roll into bars alloys which are brittle in the cast state. The alloys containing respectively 25 and 20 per cent. of zinc attain their maximum tensile strength when in the form of rolled bar 1/4 in. diam., the figures for the two alloys being: ultimate stress, 27.5 and 22.64 tons per square inch, yield point, 25 and 17.3 tons per square inch, elongation on 2 in., 10.5 and 20.5 per cent. respectively. The alloys, with and without addition of copper, differ from most non-ferrous alloys in that in the rolled condition they exhibit a definite and well-marked yield point. All the alloys containing from 10 to 30 per cent. of zinc are very easily machined. Corrosion tests in sea-water showed that the loss of weight increases with increasing zinc content. The rapid corrosion (especially in moist air) frequently observed with commercial aluminium-zinc alloys is attributed

¹ Fenth Report to the Alloys Research Committee, Inst. Mech Eng, 1912

188
INDUSTRIAL ZINC ALLOYS

to the presence of impurities derived from the spelter employed in their production.

The alloys are now very generally melted by means of coal-gas as a fuel. Melting is performed either in graphite crucibles or very commonly in cast iron pots, which are preferably protected by a wash of inert material.

Miscellaneous Zinc Alloys. The Biddery ware manufactured at Bidar in India usually contains about 90 per cent. of zinc together with copper, lead, and tin in different proportions. Two analyses of Biddery metal are given in the table on p. 160.

Zinc alloys readily with silver, the alloys rich in silver presenting some resemblances to the corresponding silver-copper alloys, although somewhat whiter in colour. They are malleable and ductile and take a high polish.

Silver-zinc alloys have long been used by native silver-smiths in India for the production of silver wares. For this purpose the silver is usually alloyed with about 10 per cent. of zinc.

Zinc in small proportions also enters into the composition of a number of important industrial alloys.

The addition of a small quantity of zinc to certain alloys increases their wearing power, and for this reason it is added to the bronze used for coinage, which contains 1 per cent. of zinc, 4 per cent. of tin and 95 per cent. of copper. This alloy was first used in England in 1861.

A standard Admiralty bronze consists of 88 per cent. of copper, 10 per cent. of tin and 2 per cent. of zinc, whilst in some alloys of this class the percentage of zinc reaches 10 or even 15 per cent. Statuary bronze usually contains from 2 to 10 per cent. of zinc. The alloys used for this purpose lie midway between the bronzes and the brasses and usually contain a considerable percentage of lead.

The addition of zinc renders the alloy more fluid and greatly facilitates the operation of casting. Too much zinc, however, has to be avoided or the metal will have a brassy colour, and will not assume a pleasing "patina" on exposure to the atmosphere.

The class of alloys known under the name of Britannia metal, consisting of tin and antimony together with small quantities of other metals, not infrequently contains zinc.

The percentage of zinc is, however, usually under 5 per cent., as it increases the hardness and brittleness of the alloy, and is therefore not a desirable constituent if present in large amounts.
THE ZINC INDUSTRY

The composition of typical industrial alloys in which zinc is an important constituent is shown in the accompanying table.

Typical Zinc Alloys.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Zinc</th>
<th>Copper</th>
<th>Tin</th>
<th>Lead</th>
<th>Nickel</th>
<th>Antimony</th>
<th>Iron</th>
<th>Magnesium</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antifriction Metals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Anti-friction metal</td>
<td>95.0</td>
<td>5.0</td>
<td></td>
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<tr>
<td>Brakes, etc.</td>
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<td></td>
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<tr>
<td>Bearing metal</td>
<td>62.0</td>
<td>4.0</td>
<td>19.0</td>
<td>19.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bearing metal hard</td>
<td>87.0</td>
<td>3.0</td>
<td>10.0</td>
<td>10.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Bearing metal medium hard</td>
<td>80.0</td>
<td>7.0</td>
<td>18.0</td>
<td>18.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bearing metal very hard</td>
<td>75.0</td>
<td>6.0</td>
<td>17.0</td>
<td>17.0</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Bearing metal lumen bearing metal</td>
<td>74.0</td>
<td>5.0</td>
<td>17.0</td>
<td>17.0</td>
<td></td>
<td></td>
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<tr>
<td>Special</td>
<td>58.0</td>
<td>11.0</td>
<td>20.0</td>
<td>10.0</td>
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<tr>
<td>Vanadium's alloy</td>
<td>75.0</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Brass</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum brass</td>
<td>90.0</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Best yellow brass</td>
<td>92.0</td>
<td>2.0</td>
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<td>Brass</td>
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<td>Budding ware</td>
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<tr>
<td>For work under water</td>
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<td>15.0</td>
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1. Compiled from tables in Law's 'Alloys,' and other sources.
CHAPTER XII

COMMERCIAL COMPOUNDS OF ZINC. ZINC PIGMENTS

Of the various compounds of zinc of commercial value zinc oxide is by far the most important. It is largely used as a pigment under the name of zinc white, and is valued for its permanency, as it is not blackened by sulphuretted hydrogen like white lead, for which it is a substitute. Although it lacks the body and opacity of white lead, it has good covering power, and is non-poisonous.

The zinc oxide of commerce is prepared either (1) direct from zinc ore or (2) by the combustion of crude spelter. One of the best known direct methods is the Wetherill process, which is largely used in the United States, especially in New Jersey and Pennsylvania. The ore treated is obtained from the mines of Franklin Furnace, New Jersey, where it is crushed and concentrated, first by magnetic separators and then by jigs, giving four products.¹

The first, franklinite, consists mainly of oxides of zinc, iron and manganese, with practically no injurious impurities.

This ore is worked by itself, making the best qualities of oxide. The manganeseous residue remaining in the furnace after removal of the zinc is treated in blast furnaces for the manufacture of spiegeleisen. The second product contains about the same amount of zinc as franklinite, but less iron and manganese, and does not make quite so good an oxide. It is used, like franklinite, for the manufacture of oxide, and the residues are thrown away.

The third product is willemite, anhydrous zinc silicate, which is used for the production of high-grade zinc. The fourth

¹ Plant of the New Jersey Zinc Company. Oil, Paint, and Drug Report, Nov. 2nd, 1914
THE ZINC INDUSTRY

product consists of limestone tailings. The ore is shipped to Palmerton, where a very extensive plant produces enormous quantities of zinc oxide annually. The plant comprises 54 blocks of furnaces with a total grate surface of about one-half acre. Each furnace, known as a "Wetherill grate," consists of a brick chamber with an arched roof and a flat grate, under which is a closed ashpit. The ore is mixed with the quantity of powdered anthracite necessary for its reduction, and then spread over a layer of burning anthracite on the perforated grate of the furnace, through which a low blast from a fan is forced, producing an underdraught. The zinc is volatilised and burned to oxide by the excess of air above the charge. The zinc oxide so produced and the products of combustion are drawn from the furnace by large exhaust fans which draw them over to the bag-rooms. These are provided, at the top, with distributing pipes, from which hang muslin bags about 45 feet long and 6 feet in circumference. The combustion gases pass out through the bags and the oxide is collected in them. The bags are connected with hoppers at the bottom, from which the finished oxide is drawn to be taken to the packing room. The six bag-rooms contain nearly 71 miles of bags, with a total surface of 51 4 acres of muslin. The oxide is first sifted through wire screens, and then fed into a packer which forces the oxide into barrels or bags. The barrels are made at the works and contain 300 lb. of oxide each. For smaller quantities paper bags, containing 50 lb. each, are used.

The Wetherill process is also carried out at Liège and other places, but the ore used is generally zinc blende, which is first converted to oxide by roasting.

Leclair's process of making zinc oxide by distilling and burning metallic zinc, started between 1840 and 1850, is still in use in Europe and also at the Florence works of the New Jersey Zinc Company of Pennsylvania.

In the Silesian method, the spelter is heated to its boiling point in retorts, and the vaporised metal is conveyed into chambers through which air is kept in circulation, when the metal burns, and the oxide, with more or less metallic zinc, is deposited in a series of condensing chambers. As the crude spelter always contains some lead, which in this process would be converted to oxide and impart a yellowish tint to the zinc white, impairing its commercial value, a small quantity
COMMERCIAL COMPOUNDS OF ZINC: ZINC PIGMENTS

of gas containing carbon dioxide is introduced into the retort. By this means the lead is converted into carbonate, which is considerably heavier than the zinc white, and therefore settles first in the condensers.

In Belgium, zinc white is also made by burning spelter in the manner described, but the final product is purified by levigation. The spelter used in Belgium contains up to 2 per cent. of lead, but the purified product contains under 0.2 per cent. of lead, with very small amounts of iron, and zinc oxide from 99.69 to 99.99 per cent.

Commercial zinc oxide nearly always contains lead compounds (carbonate or basic sulphate), the presence of which affects its market value. It has been claimed that zinc white made direct from the ore is a more durable pigment than that obtained by burning spelter.

Zinc oxide is prepared for pharmaceutical purposes by precipitating a solution of zinc sulphate with sodium carbonate and igniting the basic carbonate thus thrown down. Zinc oxide is a pure white, amorphous powder, which when heated becomes yellow, but again becomes white on cooling. When ignited at a high temperature it shrinks and becomes hard and gritty. It is infusible at all ordinary temperatures, but distinctly volatile at a white heat. The oxide does not fuse in the oxy-hydrogen flame, but, like lime, in these circumstances becomes intensely incandescent; for some time after being so heated it appears phosphorescent in the dark.

The oxide prepared by burning the metal has a specific gravity of 5.6. It is insoluble in water, and does not combine directly with water to form the hydroxide. It dissolves in acids, producing the different zinc salts.

Commercial zinc oxide is not infrequently adulterated with barium sulphate (barytes), which is cheap and blends well with the oxide.

An impure zinc oxide, known as zinc grey, is obtained as a by-product in the manufacture of zinc white. It is used as a silver-grey paint, and, when made into a paste with wood oil, as a cement for steam joints.

Lithopone.—The important zinc pigment known as lithopone, or Orr’s zinc white, was first produced by T. B. Orr in 1874 (English patent of Feb. 10). Theoretically it is a mixture in molecular proportions of zinc sulphide and barium sulphate, but
THE ZINC INDUSTRY

the products on the market contain other substances as well.¹ The advantages claimed for it are that it is not affected by sulphides and has high covering power, and its disadvantages, due to particular methods of manufacture, are that on exposure to sunlight it often turns grey and becomes chalky. It is prepared by mixing solutions containing equivalent quantities of barium sulphide and zinc sulphate. As in the case of other white pigments, purity of raw materials is essential, iron compounds being very objectionable.

Barium sulphide is obtained by roasting ground barytes (barium sulphate) with coal or other carbonaceous material in a reducing atmosphere, either in a flat bedded reverberatory furnace or in a rotary kiln of the Bruckner type. Lixiviition of the product of the roasting gives a solution of sufficient purity for the purpose.

For the zinc sulphate solution any zinc-bearing material may be used. Spelter and dross, when treated with sulphuric acid, leave little or no zinc in the insoluble residue, but zinc ashes usually leave so much mud in the solution tanks that the unit of zinc in this material is not so valuable. Iron and manganese when present are usually removed by boiling with bleaching powder. The two solutions in proportionate quantities are then mixed to produce the mixed precipitate, which is filter-pressed and dried. In some cases about 0·5 to 1·0 per cent. of a mixture of freshly prepared magnesia and common salt is added to the precipitate before filtration. The dried precipitate is mixed with 3 per cent. of ammonium chloride, and the whole heated to dull redness to give it body, which it lacks if not sufficiently heated. Excessive heating converts some of the zinc sulphide into oxide. Some oxide is always found in lithopone, but it should not exceed 2 per cent.; it ranges, however, in commercial samples from 0·5 per cent. to as much as 12 per cent. After burning, the red-hot pigment is at once quenched and ground fine, after which it is thoroughly washed, dried, dis-integrated, usually in pebble mills, and then packed.

Ordinary lithopone contains about 29·5 per cent. of zinc sulphide. A higher grade, containing from 45 per cent. to 48 per cent. of sulphide, is produced by replacing part of the barium sulphide by sodium sulphide, and washing out the resulting


194
sodium sulphate. Lower grades are also made by replacing part of the zinc sulphate by sodium sulphate. When used for outside painting, lithopone is frequently mixed with other pigments, so as to prevent the darkening which takes place when it is exposed to sunlight. Unlike ordinary zinc white, lithopone is free from lead.

Lithopone is chiefly made in the United States, and the quantity made has increased considerably within recent years. The amount produced in the United States in 1912 was 24,220 short tons; in 1913 the output was 29,685 short tons.

Zinc-lead pigment, or leady zinc oxide, consists of a mixture of zinc oxide and sulphate, lead oxide and sulphate, with some sulphurous acid and water. Commercial samples contain lead up to about 25 per cent. The output of this pigment has been rapidly increasing. It is usually produced by the treatment of zinc-lead concentrates, or residues containing these metals.

Zinc oxide also finds limited application in the glass industry for the production of opal glass, and also in the preparation of crystalline glazes for pottery and stoneware, as such glazes are less liable to "craze" than lead glazes.

Zinc chloride, \( \text{ZnCl}_2 \), is formed by the direct combination of zinc with chlorine, or by the action of hydrochloric acid upon the metal. The latter method is adopted for the production of zinc chloride on a large scale. For this purpose scrap zinc is placed in hydrochloric acid contained in a stone, cast iron or wooden vessel. The solution so obtained is neutralised with sodium carbonate, warmed to 40° or 50° C., and bleaching powder added to precipitate iron and manganese. When the precipitate has settled, the clear solution of zinc chloride is siphoned off and boiled down in enamelled iron pots. The evaporation is continued until the temperature of the liquor is 230° or 240° C., a little potassium chlorate is added to oxidise any organic matter, and some pure hydrochloric acid carefully poured into the hot solution to dissolve any basic salt. The mass is then allowed to solidify, and while still warm is packed in iron drums of from 30 to 50 kilos. capacity, which are at once closed air-tight.

When the aqueous solution of zinc chloride is evaporated, partial decomposition takes place, hydrochloric acid being evolved and basic compounds precipitated, consisting of combinations of the chloride and oxide. Hence, during the concentration of
the liquid in the preparation of zinc chloride, hydrochloric acid is added to re-dissolve this compound.

The anhydrous chloride is a greyish-white, soft, waxy-looking substance, which is readily fusible, melting at 202° C. to a clear, mobile, highly refractive liquid; at a higher temperature it volatilises and distils without decomposition, with the production of peculiarly irritating fumes. It deliquesces rapidly on exposure to moisture, and is very soluble in water or alcohol, its solution being powerfully caustic.

From a strong aqueous solution, deliquescent crystals are deposited on evaporation, having the composition ZnCl₂.H₂O.

A concentrated solution attacks and dissolves vegetable fibre, consequently it cannot be filtered through paper; it should be filtered through asbestos or glass wool. When a solution of zinc chloride is electrolysed, chlorine is evolved and crystalline zinc deposited.

Zinc chloride is extensively used as a preservative of timber, and it acts as a powerful dehydrant. It is much used for railway sleepers, either alone or in combination with creosote. American railroad companies buy sleepers specified to contain ½ lb. of zinc chloride per cubic foot, equal to about 0.5 per cent of zinc. The textile industry absorbs considerable amounts, and it is used in "mercerising" or giving the appearance of silk to cotton goods.

In dilute aqueous solution it is employed as an antiseptic, acting as a powerful disinfectant and germicide.

Zinc chloride for medical purposes is usually cast in the form of small rods or tablets. A paste made by moistening zinc oxide with zinc chloride rapidly sets to a hard mass; this mixture, under the name of oxychloride of zinc, is employed in dentistry as a filling or stopping for teeth. Many of the oxychloride cements used for this purpose contain small amounts of other ingredients, such as powdered glass or silica, to confer greater hardness on the mass when set. Other zinc compounds used as cements by dentists are oxy-phosphate and oxy-sulphate. The former consists of zinc oxide mixed with one of the forms of phosphoric acid, and the latter is a mixture of zinc oxide and calcined zinc sulphate made into a paste with a solution of gum arabic. Compared with metal fillings these cements usually lack hardness, but they are non-irritating and set fairly rapidly. They are all more or less readily acted upon by the fluids of the mouth.
**COMMERCIAL COMPOUNDS OF ZINC. ZINC PIGMENTS**

Zinc oxychlorides are also used as pigments.

**Zinc Sulphate, or White Vitriol,** known also as zinc vitriol, is prepared on the large scale either by the action of sulphuric acid on zinc or by the treatment of zinc sulphide ore (blende). In the former case commercial zinc scrap or zinc waste is dissolved in sulphuric acid, and the solution evaporated to the crystallising point. When produced from ores containing blende, these are carefully roasted to produce zinc sulphate, which is extracted with water, and the salt crystallised from its aqueous solution by evaporation. It was obtained, on a manufacturing scale, by this method as far back as the sixteenth century. The water from zinc mines is frequently charged with zinc sulphate which is extracted by crystallisation.

The salt crystallises with seven molecules of water in colourless rhombic prisms, which on heating fuse readily in their water of crystallisation. Commercial zinc vitriol is made to assume the shape of a sugar-loaf by stirring the fused salt in wooden troughs with wooden shovels until crystallisation takes place, and subsequently pressing the mass into moulds.

In common with all the soluble salts of zinc, zinc sulphate has an astringent taste, and is poisonous. It dissolves in less than its own weight of water at the ordinary temperature. When exposed to the air, the crystals slowly effloresce; if heated to 100° C. they lose six molecules of water, leaving the monohydrated salt, ZnSO₄·H₂O. At a temperature of about 300° C. this is converted into the anhydrous compound, and at a white heat it gives off sulphur dioxide and oxygen, leaving the oxide.

Zinc sulphate is used as a mordant in calico printing, and is employed as a clarifying agent and preservative in the manufacture of glue. In medicine it is employed as an astringent, and a very weak solution forms a common eye lotion. It, however, finds its greatest application in the manufacture of lithopone, to which reference has already been made.
CHAPTER XIII

THE FUTURE OF THE ZINC INDUSTRY IN GREAT BRITAIN

The question of the future supply of zinc in sufficient quantity for the maintenance and development of the metal industries of this country, without the importation of foreign metal, has been brought into special prominence by the exceptional circumstances arising out of the world-war. The conditions which gave rise to the very serious position in which this country was placed at the outbreak of war in regard to her zinc supplies have already been referred to. It has been shown that during the past few decades the zinc market was becoming increasingly a German monopoly. The war has, however, fortunately brought about the beginning of a new epoch in the development of this important branch of non-ferrous metallurgy, and if certain comprehensive schemes, which have recently been formulated, for the treatment of Imperial zinc ores in the United Kingdom come to fruition, the increase in zinc production may be considerable.

The first essential in the development of any industry is a regular and ample supply of raw material, and where this is lacking progress is invariably retarded. Undoubtedly one of the obstacles to the expansion of the British zinc industry in the past lies in the fact that for many years the smelters have relied for raw materials chiefly upon the rich ores which have been shipped in comparatively small lots from foreign sources.

Before the war there was little difficulty in obtaining all the ore required to sustain the comparatively small output of metal hitherto produced in this country, the ore itself being moderate in price, whilst freights were low. Now the cost has greatly increased, and the expenses of ocean transport have advanced enormously and are likely to remain high for some time to come.
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THE ZINC INDUSTRY

enhanced prices, or may be cut off altogether in times of urgent need, as experience has unfortunately proved.

It may be well to repeat that the extensive deposits of zinc ore at Broken Hill, New South Wales, afford an ample supply of ore, sufficient to meet all the zinc requirements of the United Kingdom for some years to come, and now that the difficulties which at first attended the treatment of the ore have been successfully overcome, there is every reason why this ore should be smelted in preference to ores from foreign sources. The importance of treating Broken Hill zinc concentrates within the Empire, and more particularly in this country, becomes more apparent on reviewing the situation as created by the war. The effect of the outbreak of war on the zinc industry was felt more quickly in Australia than in Great Britain. The mines, deprived of the greater part of their market, had to curtail production very considerably, and it is to their credit that, in order to minimise hardships among their labouring population, they continued to produce considerably more ore than they could for the time being dispose of. Certain considerations bearing on the question of the future markets for Broken Hill concentrates have been enumerated as follows.\(^1\)

(1) Australian legislation has been passed canceling the contracts for the sale of Australian ores to alien firms and prohibiting them for the future, so that no zinc concentrates will be henceforth shipped to Germany. The Australian mine-owners will therefore have to find fresh markets for that considerable proportion of their ore which previously went to Germany or to the German smelters in Belgium.

(2) Germany, in spite of the length of time that her own ore deposits have been worked, has still large reserves. She has also considerable zinc-mining interests in China, and before the war shipped zinc concentrates from that country. She will not fail to develop her trade in this direction as far as she is able to do so after the war, and will continue to be an important producer of spelter.

(3) The United States zinc smelters will be formidable competitors after the war so long as high prices are maintained. They have used their large profits wisely in making their plants efficient and up to date, and in accumulating large financial reserves. Their present rate of production is sufficient for more than 70 per

FUTURE OF THE ZINC INDUSTRY IN GREAT BRITAIN

cent. of the world's peace requirements before the war. They will have considerable tonnages of the metal available for export. They have very large ore supplies, not only of "straight" zinc ores, but of the complex ores in which zinc blende is associated with galena and other metallic sulphides, and which now constitute an increasingly important source of spelter. It is very unlikely, therefore—quite apart from the 10 per cent ad valorem tariff to which zinc ores imported into the United States are liable—that Australian zinc concentrates will find a market in America.

(4) The Canadian Government is encouraging zinc extraction by granting bounties on zinc produced in Canada from Canadian ores. Australian concentrates are therefore not likely to enter Canada to any great extent.

(5) The future of the Belgian industry is quite uncertain, but it is much to be hoped that it will be re-established and the smelting works rebuilt after the war, and in this case, as it will depend largely on imported ores, there may be a renewal of the contracts with the Broken Hill mine-owners.

(6) By virtue of the magnitude of its population, its transport facilities, markets and the raw materials necessary for zinc smelting—apart from the ore itself—Great Britain is the most suitable country for the treatment of Broken Hill concentrates exported from Australia. The future development of the British zinc industry is largely dependent on the facilities that will be afforded for their treatment, by the adaptation and enlarging of existing works, and the erection of new works for the extraction of the zinc and other metals, &c., by distillation, or by electrolytic or other processes.

The Australian Government has dealt with the situation created there, and a scheme has been drawn up affecting the future of the zinc mining and smelting industry, and one in which Australia and Great Britain are immediately concerned. It does not appear probable that America will be able to compete in the supply of spelter at a reasonable price on the English market after the war.

A new company, known as the Zinc Producers' Association Proprietary, Limited, has recently been formed to handle all zinc concentrates produced within the Commonwealth. This is the largest and most powerful metal combination in the Southern Hemisphere, and one of the most important in the
THE ZINC INDUSTRY

world. The Commonwealth's annual output of zinc ores and concentrates amounts to 450,000 tons, and the gross value of metal is not less than £5,000,000. All the zinc-producing companies of Australia are members. The Association will act for all Australian producers of zinc ores who belong to it during the next fifty years, on a co-operative basis, the companies undertaking to have all their smelting done through it. One of the fundamental principles is "equality of treatment" of all members, irrespective of the tonnage of output. The Commonwealth Government is represented on the board, thus safeguarding the interests of the general community.

In spite of the Commonwealth Prime Minister's efforts in England, the spelter question has not yet been definitely settled, so far as Great Britain is concerned. A contract has been entered into for a large supply of zinc concentrates per annum for Great Britain during the continuation of the war, with the option of increasing the quantity. The British Government has entered into a definite agreement for a term of ten years to take a minimum of 100,000 tons of Australian concentrates at satisfactory prices.

As to the remainder, arrangements have been suggested whereby Australia will treat locally 40 per cent. of the whole of the zinc concentrates produced in the Commonwealth.

The British Government has further contracted to take up to 45,000 tons per annum of spelter and electrolytic zinc produced in Australia for a period of ten years. The post-war requirements of France, Belgium and the other Allies are being considered.

In order to deal with some of the zinc concentrates reserved to Australia under the scheme, a company, called the Australian Electrolytic Zinc Company, has been formed, and will, it is hoped, be successful.

Contracts for power have been arranged with the Tasmanian Government; technical experts have been engaged in America, and the company promises to be one of the foremost industrial concerns in the Commonwealth. Towards securing capital for Australian zinc industries the Imperial Government undertakes to advance a substantial sum at the same rate of interest as is paid by the Imperial Government, if required, to finance Australian zinc works until war restrictions are removed. The

1 Chamber of Commerce Journal, March, 1917.
Mount Lyell Company is embarking upon a new venture, and promises to be a large producer of electrolytic zinc. The enlargement of the Port Pirie zinc distillery is receiving attention. Zinc specialists have been engaged to undertake the modernisation of the zinc distilling plants in Australia, and also to install and work the electrolytic zinc processes. All the above provisions will, however, only permit of the treatment of a portion of the zinc concentrates which can be produced in Australia for which concentrating plant is already in existence. What is to become of the balance of the concentrates available for smelting is uncertain, but Japan has already made offers for purchasing considerable quantities.

With regard to the development of the British zinc industry there has been much discussion, it has been proposed to erect large smelting works in this country under Government subsidy, in addition to the extension of existing works, with a view to largely increase the output and render this country less dependent on foreign supplies. A special committee has been appointed by the Secretary of State for the Colonies and the President of the Board of Trade to elaborate a scheme. What is involved in this proposition is best seen by reference to the figures representing the output and consumption of zinc in the United Kingdom under normal conditions. From the few available statistics it would appear that the maximum production of spelter in this country in any year before the war was approximately 58,000 English tons, whereas the consumption was approximately 200,000 tons, the difference between production and consumption being 142,000 tons.

The actual production for 1913 was 58,298 tons, of which, as previously stated, probably not more than 31,290 tons was "primary" spelter, produced direct from ores, the balance of 27,008 tons being "secondary," or remelted metal from the treatment of by-products, &c. Thus secondary zinc forms an exceptionally abnormal proportion of the total British output.

Practically the whole of the primary spelter was produced from imported ores, the metal produced from British ores being comparatively insignificant and probably amounting to not more than 2,500 tons.

The consumption of virgin zinc in 1913 was 203,302 tons, of which no less than 145,004 tons was imported.

The actual consumption of spelter in 1913, after allowing for
THE ZINC INDUSTRY

imports of zinc wire and sheet, and that present in imported brass, was 224,000 tons, but even this does not include the zinc contained in zinc dust, zinc oxide, lithopone and salts of zinc (chloride and sulphate), figures for the import of which are difficult to obtain, but the quantities are by no means inconsiderable.

The imports of drawn and rolled zinc in 1913 were 18,768 tons. With regard to these imports it is of interest to note that in 1913 Germany imported 311,269 tons of zinc ore, 57,041 tons of spelter and 725 tons of drawn or rolled zinc, and exported in the same year 14,731 tons, 109,606 tons, and 21,095 tons of these materials respectively. It should be noted also that the British statistics refer only to the United Kingdom, and take no account of the imports of crude or manufactured zinc into Canada, Australia, South Africa and India, which were large.

From the above figures it will be evident that in order to render this country independent of foreign supplies of zinc it will be necessary to smelt sufficient ore to produce annually at least 140,000 tons more spelter than has been produced in the past.

Apart from the provisions that have been made recently for an adequate supply of zinc ore for British smelters, there is very little information available as to what steps are being taken to increase the output of metal in this country. According to the latest report of the Inspector of Alkali Works, extensive additions were made to registered zinc works in 1916, but no new works were added. In 1916 the Sulphide Corporation acquired the smelting works of the Central Zinc Company at Seaton Carew, and in 1917 they purchased the sulphuric acid works constructed by that company for £52,000. These works utilise the sulphurous gases coming from the zinc-roasting furnaces. The smelting works are to be doubled, and when this is accomplished they are expected to be able to treat 30,000 tons of Broken Hill concentrates yearly, equal to an annual output of zinc of about 12,000 tons. This tonnage amounts to one-half the Sulphide Corporation's output of zinc concentrates.

Considerable additions are also being made to the Swansea Vale Spelter Works, the largest works in the Swansea district. Good progress has been made with the extensions, which, when completed, will give an output of 15,000 to 20,000 tons of spelter per annum. Extensions are in progress, or completed, in other works, and according to a recent estimate when all the new plant is erected the total capacity of the British smelting
works will be about 78,000 tons of primary spelter, made up as follows: 1

<table>
<thead>
<tr>
<th>Works</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swansea Vale</td>
<td>20,000 English tons</td>
</tr>
<tr>
<td>English Crown Spelter</td>
<td>18,000</td>
</tr>
<tr>
<td>Vivians</td>
<td>10,000</td>
</tr>
<tr>
<td>Seaton Carew</td>
<td>10,000</td>
</tr>
<tr>
<td>Dulwyn...</td>
<td>8,000</td>
</tr>
<tr>
<td>Williams Foster</td>
<td>6,000</td>
</tr>
<tr>
<td>Sundry lesser plants</td>
<td>6,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>78,000 English tons</strong></td>
</tr>
</tbody>
</table>

This estimate is based on the theoretical capacity of the respective plant extensions when finished, the actual production would naturally be lower. According to this estimate the total production of zinc from ores will be approximately 50,000 tons more than the pre-war output of virgin metal, or, including secondary zinc, an increase of nearly twice the pre-war annual output.

To encourage the smelting of Broken Hill concentrates by British smelters the Government, in connection with the British-Australian scheme, has guaranteed the minimum price of £23 for ordinary spelter and £28 for high-grade spelter.

An agreement has also been reached between the spelter producers in this country and the Ministry of Munitions on the subject of new works. The producing companies are to be allowed to deduct from their excess profits the difference between the cost of new production during the war and before the war, they are also to receive from the Ministry of Munitions a "reward" for extending their works, in that they will be allowed to deduct from their excess profits, before taxation, 50 per cent. of the pre-war cost of construction.

Before the war it was agreed by producers generally that it did not pay to produce permanently under £22 per ton. With existing methods and conditions of production, the cost for some time to come must be considerably more.

In these circumstances it is considered by many that the margin of profit is not sufficient to stimulate private enterprise. In this connection it may be permitted to quote the opinion of Mr. J. C. Moullin, who has had wide experience in zinc smelting. Compared with the production of other metals in common use, he considers "that there is no branch of the metallurgical industry

THE ZINC INDUSTRY

in which, considering the difficulties and risks involved, the invested capital has been so ill-requited as that of zinc. What profits there have been were made largely by the ore and metal-dealing firms, and those who, in addition to smelting, turned out rolled and stamped zinc together with lead and silver from complex ores—and possibly also zinc oxide.” That zinc smelting can, however, be profitably undertaken, under favourable conditions, and by the utilisation of all the valuable by-products, with good management and if equipped with labour-saving appliances, is evident from the fact that the Continental zinc-smelting companies have in recent pre-war days paid dividends of 20 to 25 per cent. and over. Under the conditions that obtain in this country it seems obvious that the Government must undertake the cost of erecting new works if they want to see the position much further advanced, and it is the uncertainty of what they are going to do which makes an estimate of the outlook for home production so much a matter of hypothesis, and which prevents private capitalists from embarking. The problem is obviously a very different one for the Government in contrast to private enterprise. They have not merely to consider the question from the point of view of the price of spelter after the war. Beyond economic factors there is the consideration of the public safety in view of possible restrictions on the necessary supplies of sulphuric acid and spelter.

Assuming that the above estimate of increased production is substantially correct, it will be evident that something like another 100,000 tons of metal will be required to bring up the spelter production to correspond with the pre-war consumption, and it is to supply this extra output that the construction of smelting works by the Government has been suggested. The erection of smelting works at Avonmouth, capable of producing 24,000 tons of zinc per annum from Australian ore, has been proposed, and in this connection the Bristol City Council recently sanctioned the preparation of schemes for extending the accommodation of the Royal Edward Dock to meet the traffic incidental to the proposed shipment of zinc concentrates from Australia. Negotiations for the treatment of further quantities of these concentrates at Widnes, and possibly elsewhere, are also in progress. But after allowing for the carrying out of the present programme for the expansion of the productive capacity of existing works, even including the 24,000 tons per annum for the proposed new works at
Avonmouth, it would appear that the possible output will be only about one-half the pre-war consumption. It is most unfortunate in the future interests of the zinc industry in this country, and in the interests of the metal industries dependent on metallic zinc as raw material of first importance, that the Government has not, up to the present, taken any steps to begin the erection of new zinc-smelting plant. Moreover, it cannot be too strongly urged that the provision for increased zinc output so far suggested is inadequate to meet the situation, and the erection of large works would be one of the greatest factors in supplementing the zinc deficiency, and would help to keep the production in our own hands and remove our dependency on metal from foreign sources.

In addition to the home output, there is the proposed spelter production from Australia, which, as stated above, is to be imported to the extent of 45,000 tons per annum, and which would be of great assistance in making the total output approximately equal to the demand.

Climatic and labour conditions are, however, against any large extension of zinc distilling in Australia, and up to the present only the erection of small plant has been started there, and for a long time to come no appreciable tonnage of metal can be expected.

The Government has bought supplies of Broken Hill zinc concentrates, and many tons have been shipped to this country, but they are of no value to the country until they are turned into metal. The erection of works to effect this with all possible speed becomes imperative. It may be well to emphasise the fact that the complete treatment of these concentrates involves not only the production of zinc, they are also a potential source of sulphuric acid, and of lead and silver, and for economic reasons they should be worked to produce all these. The general method of treating the concentrates is shown in the accompanying flow sheet. (p. 208.)

To erect new zinc-smelting plant without proper provision for the utilisation of so valuable a product as the sulphur would undoubtedly be a serious mistake, and would greatly hinder the future development of the British zinc industry which is so urgently necessary, because it would not only waste a product of considerable value to the chemical industries, but would also deprive the zinc industry of a source of profit and increase the
Flow Sheet Showing the General Method of Treating Australian Zinc Concentrates.

Zinc Concentrates.

Roasting to expel Sulphur.

Roasted Concentrates mixed with Coal

Distillation

Sulphur Fumes

Sulphuric Acid Works

Market.

Furnace Residues (containing Lead and Silver.)

Concentrated in jigs.

Argentiferous Lead Concentrate.

Lead Smelter.

Lead
Silver
To Market.

Zinc Powder

Sifted through 70-mesh Screen.

Market

Spelter

Market

Packed in Drums or Barrels

Market
difficulty of meeting foreign competition. It is just the fact that this ore is a potential source of sulphuric acid which renders it necessary for the bulk of the concentrates to be shipped from Australia, where the market for acid is limited, to a country like Great Britain, with nine times the population of Australia and highly developed industries which can absorb the acid.

Probably one of the most difficult problems in connection with the utilisation of the sulphur is to decide on the most suitable location of the plant for roasting the ore. The Swansea district is one of the most favourably situated places in the world for the production of zinc and is the chief seat of the British industry, but it does not follow that the roasting of the ore for acid should necessarily be effected at the same place as the smelting of the roasted material for the metals. As already pointed out, it is not uncommon to find the roasting and the manufacture of sulphuric acid carried on in one district and the roasted ore smelted in another district where economic considerations render this course desirable. In treating the Australian concentrates in this country, therefore, it may be found, after a due consideration of all the circumstances, to be more suitable to roast the ore for acid at some centre connected with the chemical or galvanising industries, and to treat the roasted ore for zinc and its allied metals at Swansea or some other zinc-smelting centre, or even to extract the zinc in the same locality as that in which the sulphuric acid is made.

In adopting this latter course a considerable quantity of by-products from galvanisers' works would be available in the immediate proximity of the projected smelting works, and the saving in freight alone on this material would probably be considerable. A most important element in favour of a scheme for the production of sulphuric acid from the roasting of concentrates is the keen interest shown by the leading manufacturers of sulphuric acid, who have been longing for an opportunity to adopt the Belgian blende roasting system in preference to the roasting of pyrites, which have been advancing in price considerably of late.

There is always an increasing demand for sulphuric acid in this country, especially for non-arsenical acid, as produced from zinc ores.

The whole question of the treatment of the Broken Hill zinc concentrates is, in view of the commercial and military
THE ZINC INDUSTRY

value of zinc, of great importance, and the Government authorities have rightly decided that the handling of what is undoubtedly a great Imperial asset requires careful consideration. At the same time, there seems to be no reason why that consideration should be indefinitely deferred, and why, under proper safeguards to retain the control of this asset of the Empire, the treatment of the ore for its zinc and other valuable constituents should not be proceeded with without further delay, so that the country may be relieved of the necessity of importing spelter. The shortage of domestic zinc is bound to continue unless works are built capable of dealing with the zinc concentrates from Broken Hill. The war may yet last a long time, and it will scarcely be possible to hold up all trade and development questions until peace arrives.

The establishment in this country of a zinc-smelting industry on a scale commensurate with its needs is most urgently required. There is no reason, if there is a proper application of organising ability, technical knowledge, perseverance and resourcefulness, why success should not be achieved.

We have in the country metallurgists with knowledge and experience of the very best Continental zinc-smelting plants and methods; we have the raw materials in ample quantity in the Empire; we have the demand for the metal, but we have not yet availed ourselves of these.

As Professor H. C. H. Carpenter 1 has well said, "the establishment in this country of a zinc industry on a scale commensurate with its needs would be an industrial victory of the first magnitude and it would remove a peril in which this country was placed by the outbreak of war, a peril which has been all too imperfectly realised, and should never be allowed to recur."

The urgent need is to make provision for the reconstruction that must follow on the declaration of peace, and in that reconstruction the development of the zinc industry holds an important place. There can be no doubt that further to neglect to respond to the urgent demands for a largely augmented output of zinc in this country will very seriously interfere with the progress of the non-ferrous metal industries, which have hitherto played so important a part in the industrial development, not only of this country, but of the British Empire, and are destined to be of much greater importance in the near future.

FUTURE OF THE ZINC INDUSTRY IN GREAT BRITAIN

The question as to what is going to be the future of the zinc industry in this country is one which has been exercising the mind of those who have the welfare of this industry at heart ever since the lamentable and dangerous situation at the outbreak of war was revealed. One cannot refrain from comparing the long delay in dealing with the question of the future development of the British zinc industry with the very expeditious manner in which the Royal Ontario Nickel Commission, appointed by the Ontario Government in September, 1915, dealt with the question of the nickel industry. Although many countries were visited, the Commissioners have, after a lapse of only eighteen months, presented their valuable and exhaustive report, which deals very fully with the nickel question, especially in relation to industry and trade, and will form a standard work of reference on nickel for many years to come. As the result of the recommendations of the Commissioners, extensive works are now being erected in Ontario for the treatment of the large quantities of ore found in the district, which have hitherto been mainly treated in the United States.