PRIMARY ZINC SMELTER OPERATING DATA SURVEY

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ABSTRACT

A worldwide survey of zinc primary smelters was conducted to update similar data collected in 2000 and 2005. The survey provides high level data from responding operations regarding plant capacity, feed, roasting, smelting, acid plants, leaching, solution purification, electrolysis, casting, by-products and labor. The data was complied into a database and examined for correlations between operating variables. A comparison with 2000 and 2005 smelter survey data was also conducted to provide insight in the evolution of primary zinc operations over the past ten years.

INTRODUCTION

Over the past twenty five years, four papers have been written summarizing the information provided by zinc smelters and refineries around the world [1,2,3,4]. These surveys have documented operational data and allowed for researchers and industrial practitioners to understand and evaluate trends and changes that have occurred within the zinc industry. This symposium has asked the authors to continue this tradition and conduct such a survey again.

Plants from around the world were conducted and surveys were submitted by numerous operations. While several of the operations have participated in many of the previous surveys, several plants are participating for the first time. This creates difficulties in making direct comparisons between surveys. With that said, trends were evaluated between the surveys conducted and several observations are made.

SURVEY RESULTS

The zinc operations, country, reported capacity and 2009 zinc production for the plants who responded to the surveys are listed in Table 1. Of significant importance is the presence of two Chinese plants that participated in this survey. A total of eighteen plants provided operational data for this publication. These operations are located on four continents.

Table 1 - List of Smelters/Refineries who Provided Survey Responses

Smelter/Refinery	Country	Capacity (tons Zn/yr)	2009 Production (tons Zn/yr)
KCM	Bulgaria	N.R.	70275
Xstrata Kidd	Canada	315360	115619
Teck Metals Trail	Canada	295000	240000
Chihong	China	120000	127987
Baiyin	China	100000	100000
Boliden Kokkola	Finland	306000	N.R.
Nystar Auby	France	160000	160913
Kamioka Mining & Smelting	Japan	72000	59000
Hiroshima	Japan	84000	N.R.
Harima	Japan	90000	69537
Hachinohe	Japan	112000	96527
Annaka	Japan	146400	102250
Akita Zinc	Japan	200000	155884
Peñoles	Mexico	310000	238034
IMMSA	Mexico	105000	98685
Boliden Odda	Norway	160000	140000
Zincor	South Africa	110000	90940
Nystar Budel	The Netherlands	N.R.	220704

N.R. – not reported

According to the USGS 2010 Zinc Commodity Summary [5] which references the International Lead and Zinc Study Group’s October 2009 forecast, refined zinc metal production in 2009 was expected to 11.1 million metric tons. Based on this estimate, this survey includes operating data from plants that produce 20-25% of the world’s refined zinc.

A summary of the zinc capacity and 2009 production of zinc, cadmium, copper, lead/silver residue and gypsum is given in Table 2. Figure 1 illustrates the distribution of plant capacity from this survey and compares it to previous survey results from 1985, 1995 and 2000. The data clearly indicates the continuing trend toward larger plants as the percentage of plants below 50000 tons per annum has decreased and the percentage of plants above 150000 has increased.

Table 2 - Zinc and By-Product Production

	# of Plants	Minimum	Median	Maximum	Total
Zinc Capacity (tons/yr)	16	72000	133200	315360	2685760
Zinc Production (tons/yr)	17	59000	115619	240000	2222602
Cadmium Production (tons/yr)	16	94	371	1383	7678
Copper (tons/yr)	8	117	1403	6991	16445
Lead/Silver Residue (tons/yr)	8	7493	29442	155000	383127
Gypsum (tons/yr)	4	605	45566	103051	194787

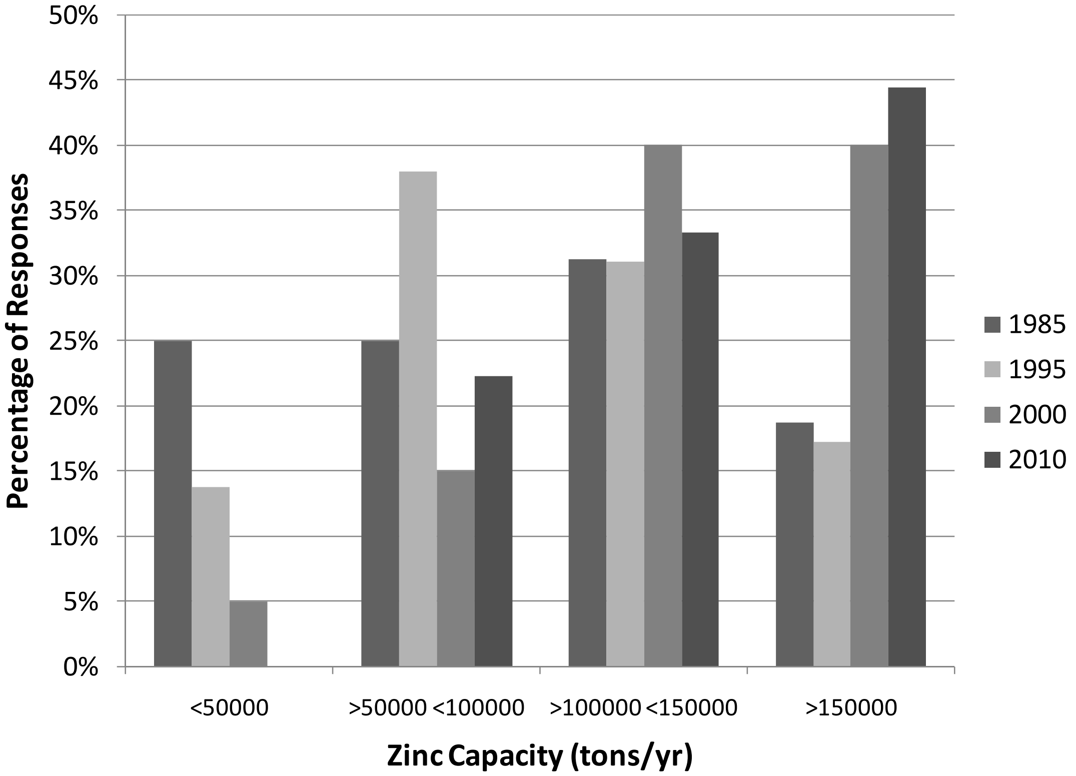

Figure 1 - Distribution of Capacity of Plants Responding to Survey

Plant Feed

The plant feeds were examined. Statistical information regarding the zinc sulphide concentrates and secondary (2ndary) zinc oxides are presented in Table 3. The main metallic impurities in the zinc sulphide concentrate are lead and iron as shown by Figure 2. It does not appear that zinc sulphide feed has changed much over the past 25 years as shown by the data in Table 4.

Table 3 - Summary of Plant Feed

	No. of Plants	Minimum	Median	Maximum
Zn Sulfide Concentrates (t/yr)	17	86929	221000	571003
%Zn	17	39.90	52.00	57.27
%S	17	23.45	30.40	32.99
%Fe	16	1.78	7.00	9.02
%Pb	17	0.35	1.80	15.80
%Cd	17	0.08	0.20	0.60
%Cu	17	0.16	0.51	1.10
g/ton Ag	13	0.01	130.00	507.50
Secondary Zinc Oxides (t/yr)	6	1000	46611	77500
% Zn	6	30.50	63.40	71.06
% Fe	6	0.80	2.35	11.85
% Pb	6	0.10	6.45	8.20
% Cd	6	0.00	0.03	0.40
%CaO	4	0.57	1.48	3.26
%SiO2	5	0.80	1.37	20.25
g/ton Ag	4	2.59	41.00	146.00

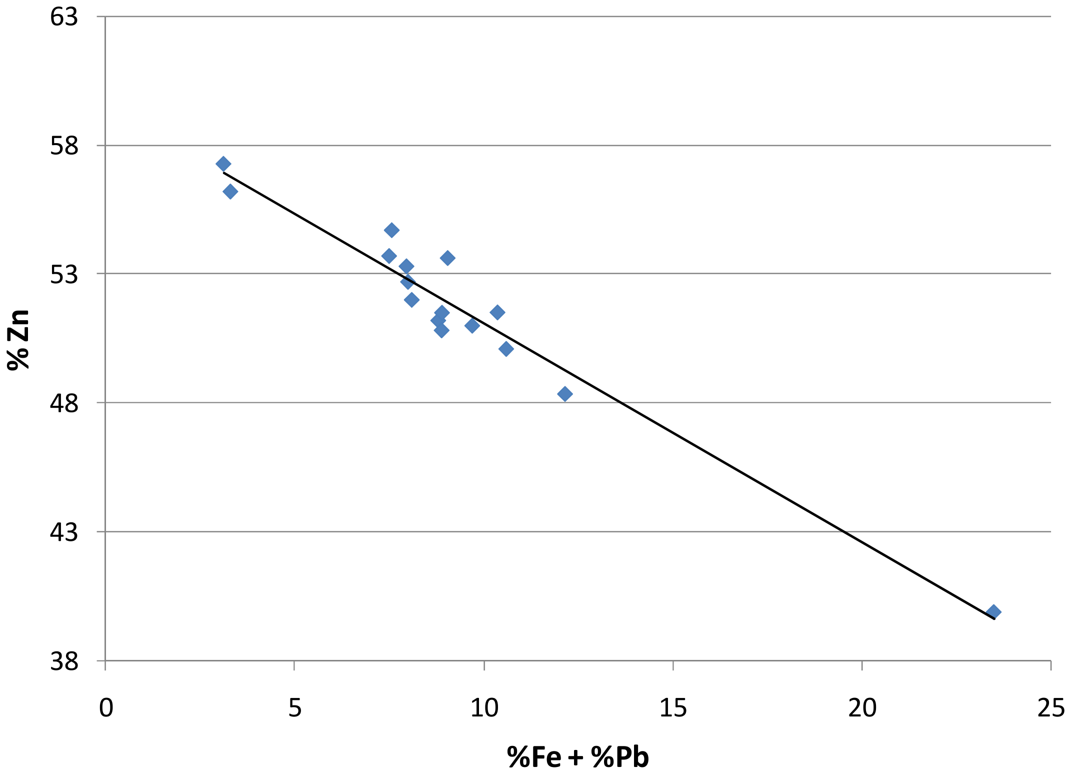

Figure 2 – Relationship between % Zn in Sulphide Concentrates and the Sum of Lead and Iron Impurities

Table 4 - Average Feed Quality of Reporting Plants

Year	Average %Zn	Average %Fe	Average %Pb
1985	52.7	7.4	1.8
1995	51.2	7.9	2.4
2000	51.7	7.5	3.3
2005	53.3	6.7	1.8
2010	51.9	6.5	2.7

While the plant feed has not changed much, the efficiencies of zinc operations has improved. This can be seen by the data presented in Figures 3 and 4. For the industry as a whole, the percent recovery of zinc has improved for each survey conducted over the past twenty five years. This is a testament to the dedication and hard work of operators and engineers who control and improved their operations on a continual basis.

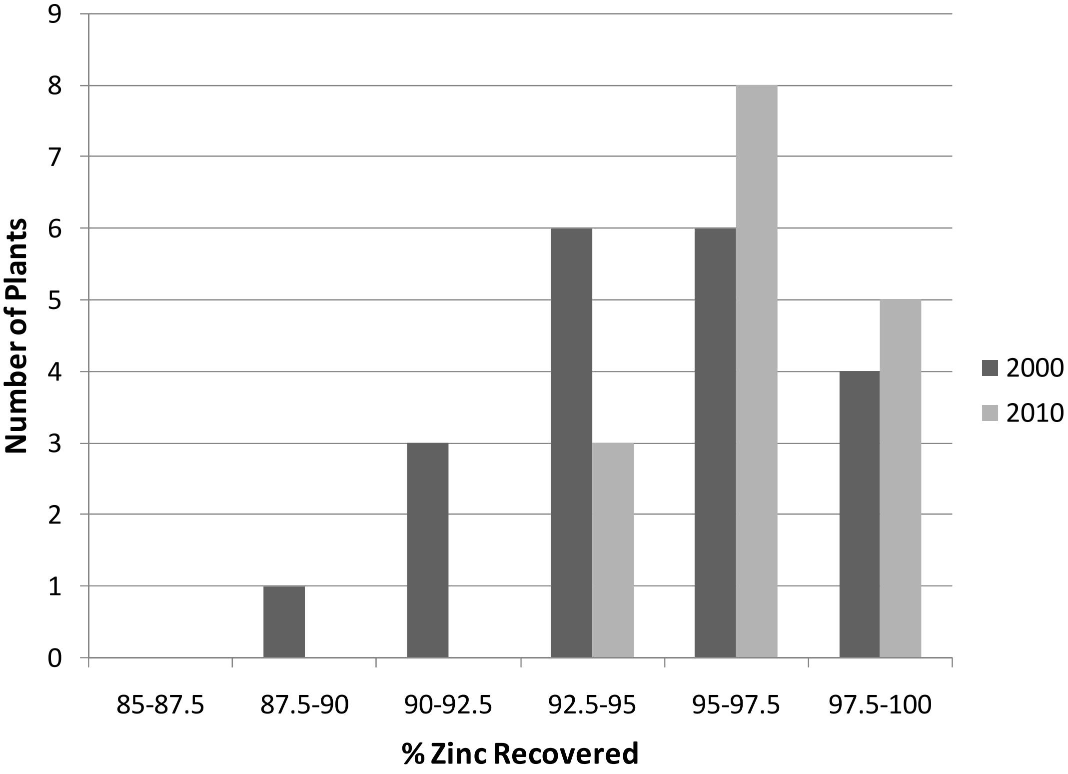

Figure 3 – Distribution of Overall Zinc Recovery from Feed Materials

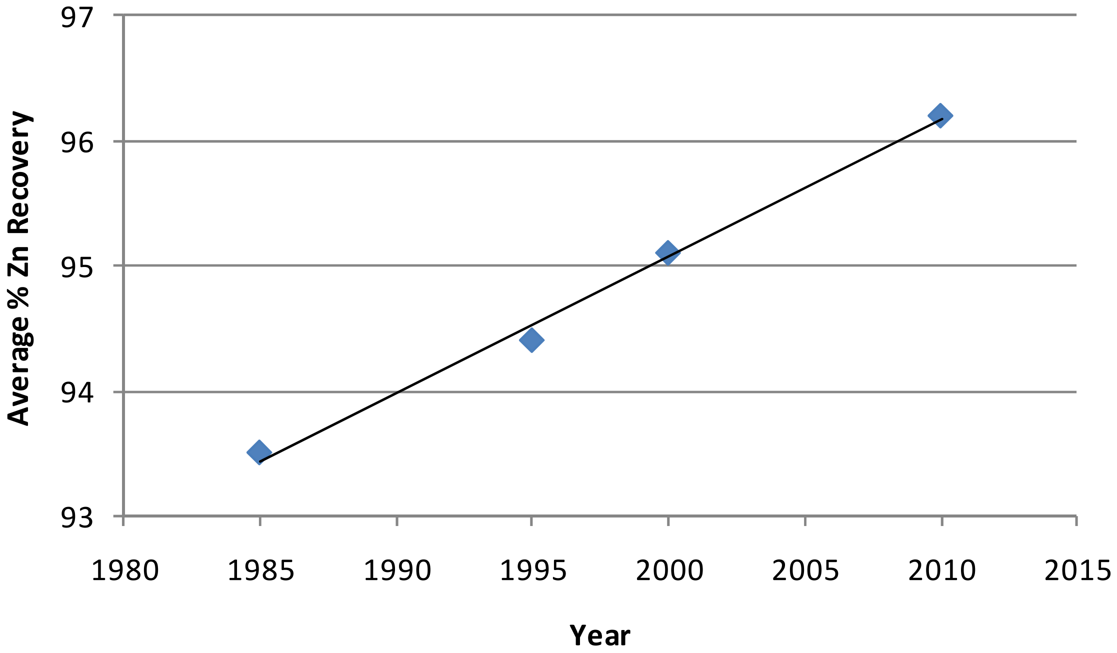

Figure 4 – Average Zinc Recovery from Feed Material

Roasting

Roasting was performed at most of the plants that participated in this survey. Statistical information regarding the roasters is presented in Table 5. Several plants have multiple roasters which accounts for the number of units being greater than the number of plants. Analysis of the roasting data revealed correlations between hearth area, feed rate and air volume. These correlations are presented in Figure 5.

Table 5 - Roasting Operating Data

Parameter	No of Units	Minimum	Median	Maximum
Hearth Area (m^2)	25	18	68	113
Air Vol (Nm^3/h)	25	7000	36000	51561
%O_2	11	2	23	25
Feed Rate (t/h)	26	4.7	21	31
Operating Temp ^oC	26	890	930	980
Calcine: S as Sulfide	26	0.07	0.26	2.5
Calcine: Total S	21	1.8	2.5	3.1

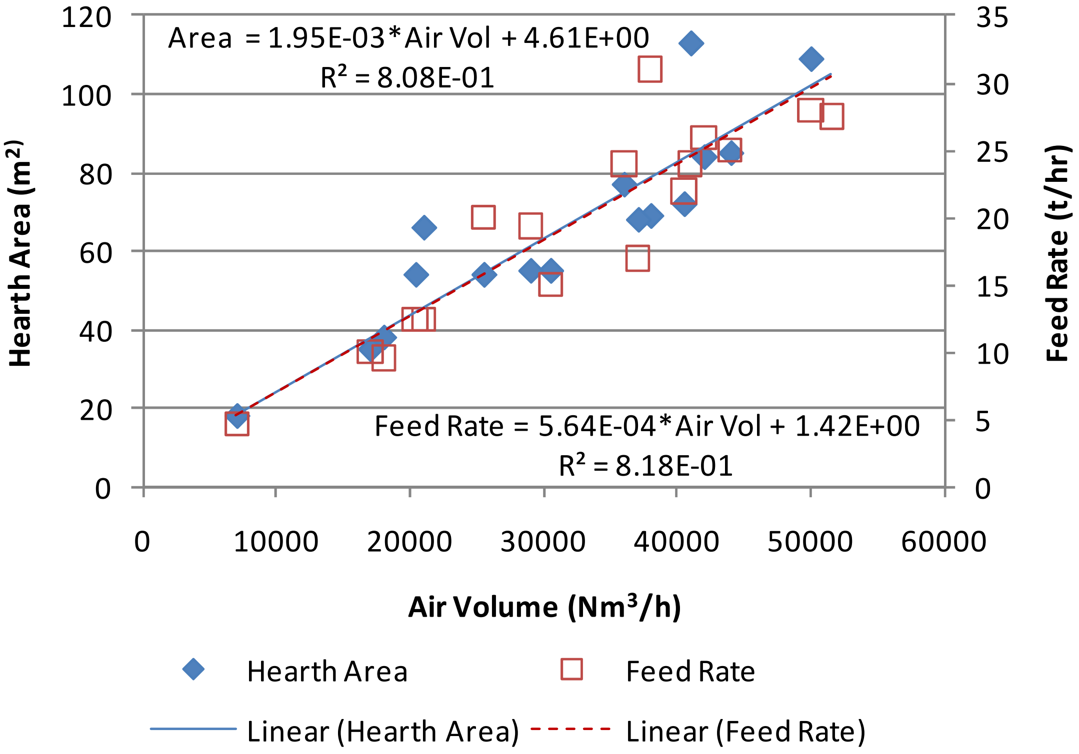

Figure 5 – Correlation between Roaster Hearth Area, Air Volume and Feed Rate

Sintering and Smelting

Only two of the facilities reported using sintering plants. These were in Japan with a total capacity of 42,000 metric ton per year. Both plants used up draft technology. No smelting activities were reported in this survey.

Acid Plant

The plants reported 2.8 million tons per year of sulphuric acid production capacity. A summary of the sulphur removal acid plant technology used by the plants in this survey are given in Table 6. The percentages of plants that use double or single adsorption did not change between the 2000 and 2010 survey with ~55% of the plants using double adsorption and the rest using single adsorption. It does appear that more plants are using tail gas scrubbers as 62% in 2010 use this technology versus 45% in 2000. Acid plants with single adsorption units appear more likely to use tail gas scrubbing than those with double adsorption.

Table 6 - Types of Sulphur Removal Equipment Used in the Acid Plants

	Tail Gas Scrubbing	
Adsorption Type (No. of Units)	Yes	No
Single (9)	35%	10%
Double (11)	30%	25%

Leaching

The electrolytic plants use multiple stages of leaching as shown in Figure 6. Every plant that provided details regarding their leaching circuit indicated a neutral leach. All plants also had some form of acid leach whether it is a weak acid leach or hot acid leach. The various types of leaches used are shown in Figure 7. Most of the stages listed as other were related to iron removal.

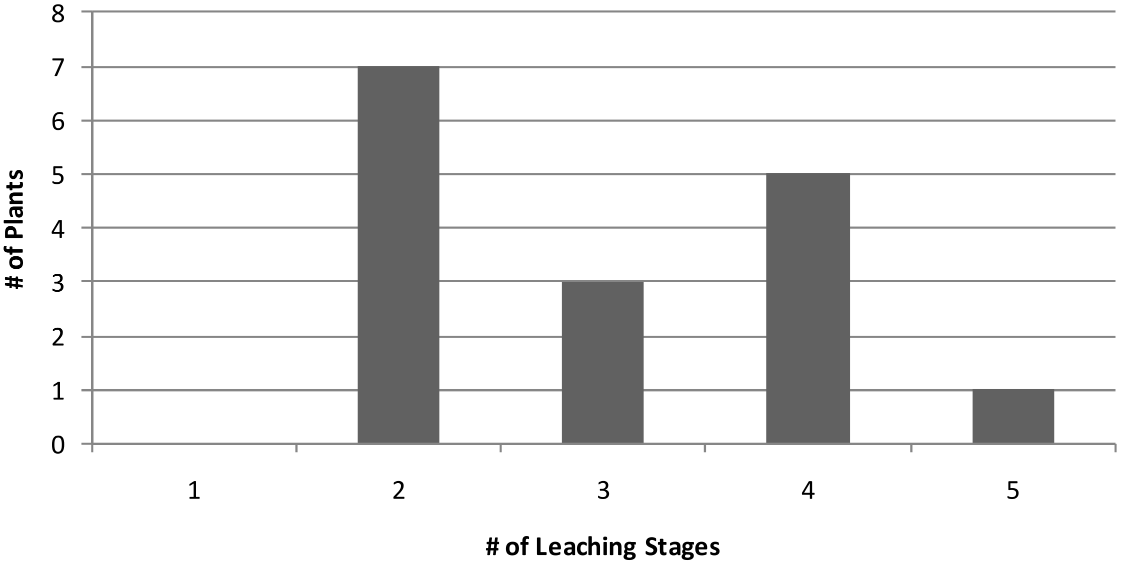

Figure 6 – Number of Leaching Stages per Plant

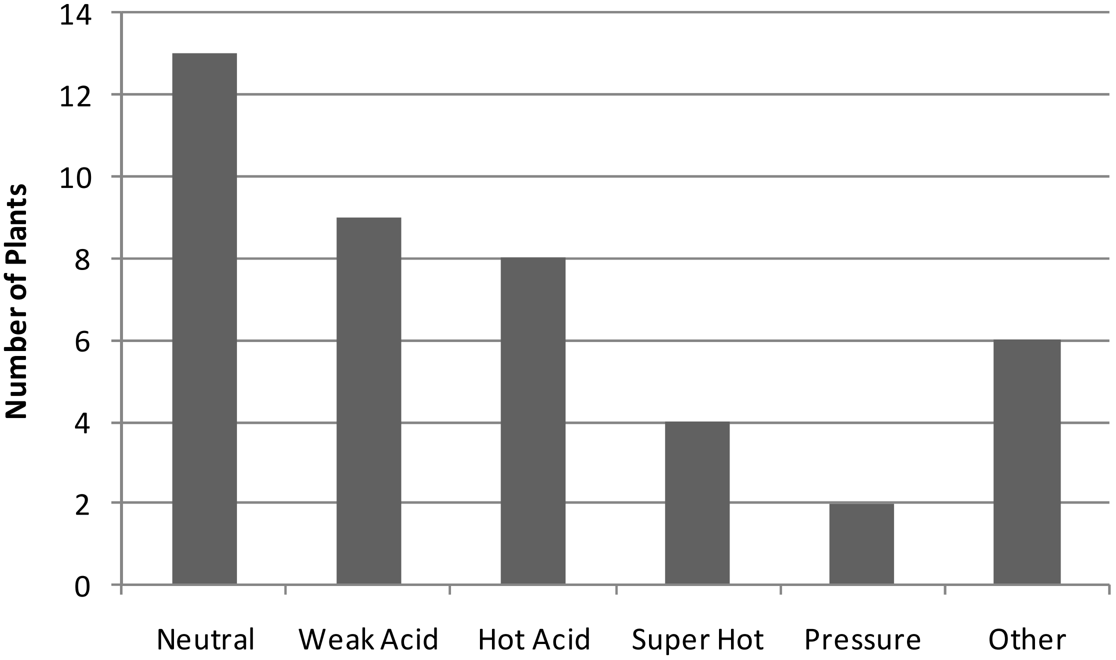

Figure 7 – Leaching Stages Used

Table 7 lists the various configurations of leaching stages reported. Iron removal stages were removed from this data set. It can be seen that the most common leaching sequences are two stages of leaching with a neutral leach followed by an acid leach. Once a third or fourth stage of leaching is added, there is no agreement across the industry surveyed. This may indicate site or feed dependences.

Table 7 – Leaching Stage Sequence

Leaching Method	Number of Plants
NL + WAL	3
NL + HAL	4
NL + WAL + HAL	1
NL + WAL + PL(SO_2)	1
NL + HAL + SHL	1
NL + WAL + HAL + SHL	1
NL + WAL + HAL + PL	1
NL + WAL + WAL + PL	1

(Note)

NL = Neutral Leach	WAL = Weak Acid Leach
HAL = Hot Acid Leach	PL = Pressure Leach
SHL = Super Hot Leach	PL(SO_2) = SO_2 Pressure Leach

The leach process data was analyzed and a summary is presented in Table 8. Neutral leach pH was fairly constant (4.15 to 5.0) across the plants surveyed. Most zinc is extracted in the neutral leach stage. The weak acid and hot acid leach stages data were more variable. Several oxidants are used with the most common being MnO_2 (6), air (6), $KMnO_4$ (5) and oxygen (4) with the number in parentheses being the number of plants reporting the oxidants use. The reported oxidant addition rates were normalized relative to plant zinc production and reported in Table 8. Oxygen values are not reported as the authors are not exactly clear on the units for oxygen provided by some of the plants.

Table 8 – Leaching Process Data

	No of Unit	Min	Median	Max
Neutral Leach				
pH	12	4.15	4.5	5
% Zn Extraction	8	64	85	89.3
Weak Acid Leach				
pH	3	2.8	3.5	3.5
H_2SO_4 g/L	5	2	12	30
Hot Acid Leach				
H_2SO_4 g/L	8	25	59	125
$KMnO_4$ (kg/t Zn)	5	0.01	1	142
MnO_2 (kg/t Zn)	6	0.01	8	30
Air (Nm^3/t Zn)	6	60	113	382

The leach solution and residue data was analyzed by stage. The summaries of the leach solution and leach residue information are provided in Tables 9 and 10, respectively. The solution analysis reveals increasing iron concentration with increasing stage number. The leach residue generally decreases in %Zn and %Fe with increasing stage number. The relationship between %Zn and %Fe by leach stage for various plants is shown graphically in Figure 8. The circled points appeared to be anomalous with the other plant residues for the stages listed.

The relative frequency of the iron removal processes reported are presented in Figure 9 and compared to data from the 2000 data. It is apparent the formation of jarosite has been and continues to be the most common method of iron removal. It is not clear if the goethite process is being replaced by other processes or this trend is an artifact of different plants being surveyed. This trend should be reviewed in future surveys.

Table 9 – Leach Solution Analysis by Stage

Stage	Element	Count	Minimum	Median	Maximum
1	Zn (g/L)	15	134	155	173
	Mn (g/L)	12	2	6	11
	Mg (g/L)	10	3	9	16
	Fe (mg/L)	14	1	6	30
	Cu (mg/L)	14	175	685	1500
	Cd (mg/L)	14	270	600	1400
	Co (mg/L)	14	2	17	38
	Ni (mg/L)	12	1	5	35
	Cl (mg/L)	10	50	217	500
2	Zn (g/L)	6	89	126	168
	Mn (g/L)	3	5	10	16
	Mg (g/L)	3	5	10	16
	Fe (mg/L)	7	8	17000	20000
	Cu (mg/L)	5	2	1859	4700
	Cd (mg/L)	3	175	190	550
	Co (mg/L)	2	5	13	21
	Ni (mg/L)	2	1	9	18
	Cl (mg/L)	3	145	250	400
3	Zn (g/L)	6	71	103	140
	Mn (g/L)	4	5	8	16
	Mg (g/L)	4	5	11	13
	Fe (mg/L)	6	4	12950	30000
	Cu (mg/L)	4	600	1900	3500
	Cd (mg/L)	3	120	400	400
	Co (mg/L)	2	5	10	14
	Ni (mg/L)	2	1	10	20
	Cl (mg/L)	4	140	225	400

Table 10 – Leach Residue Analysis

Stage	Element	Count	Min	Median	Max
1	% Zn	9	3	19	22
	% Fe	6	15	26	28
	% Pb	8	0	4	7
	% Cd	8	0	0	1
	% Cu	7	0	2	9
	% S	5	4	5	21
	g/ton Ag	9	104	200	430
2	% Zn	8	3	11	19
	% Fe	6	10	23	26
	% Pb	7	1	9	14
	% Cd	7	0.0	0.2	0.6
	% Cu	7	0.3	0.9	1.3
	% S	6	5	8	11
	% Ge	3	0.04	0.04	0.05
	% As	4	0.07	0.20	0.30
	g /ton Ag	7	275	520	800
3	% Zn	6	2	5	23
	% Fe	6	13	18	23
	% Pb	5	2	5	10
	% Cd	4	0.04	0.11	0.90
	% Cu	5	0.14	0.50	0.70
	% S	4	8	24	40
	g /ton Ag	4	350	650	974

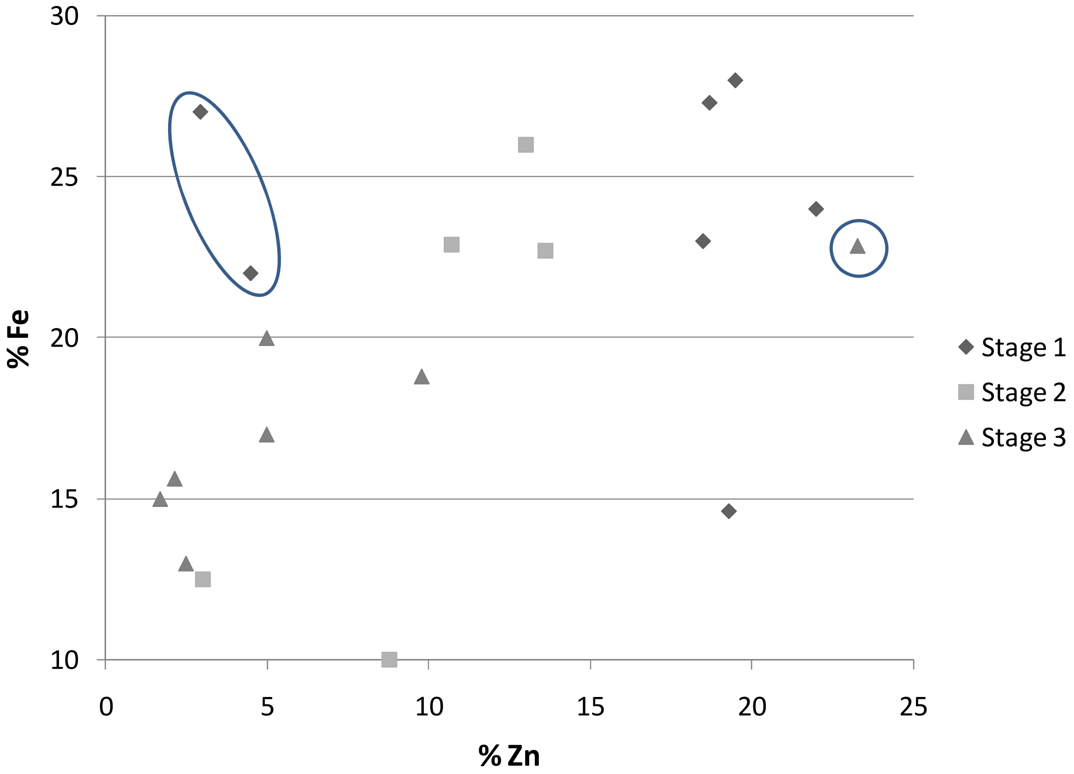

Figure 8 – Comparison of Zinc and Iron Content in Leach Residue

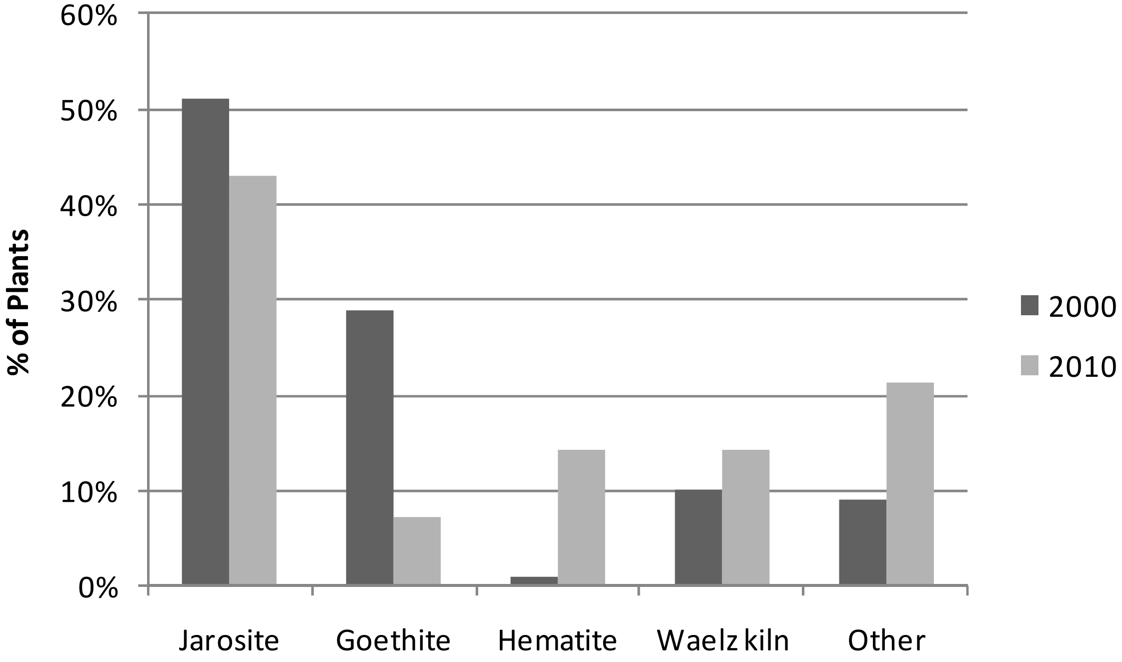

Figure 9 – Iron Disposal Processes Used

Purification

Purification of zinc electrolytes is primarily accomplished by cementation of more noble impurities by the addition of zinc dust. Purification processes are generally designated as removing Cu, Co, Ni, and/or Cd, (but also co-precipitate other elements such as Fe, Pb, Sb, and Ge) from the leach solution. The overall purification process is usually accomplished in three stages, but some plants use up to four stages. The usage of common reagents for purification of zinc leach solutions are reported in Table 11. Though first patented in 1994[6], this appears to be the first reported industrial use of the use of potassium ethyl-xanthate, PEX, to aid in the removal impurities from zinc electrolytes.

Table 11 – Additives for Solution Purification

Additive (kg/day)	Stage	No. Of Units	Minimum	Median	Maximum
Zinc dust	1	11	493	2942	14000
	2	11	355	7119	32000
	3	8	355	2674	9000
As_2O_3	1	1	23	23	23
	2	4	159	243	1337
Sb Metal	1	1	80	80	80
Sb Oxide	2	2	20	22	25
	3	1	2	2	2
Sb tartrate	2	2	0.4	8	15
Beta-Naphthol	2	1	1280	1280	1280
	3	2	204	216	228
Copper sulfate	2	2	30	54	77
	3	3	30	150	170
PEX	2	1	450	450	450

The concentrations of the major impurity elements in the leach solution and the corresponding filter cakes after the various stages of solution purification are listed in Table 12 and Table 13, respectively.

Table 12 – Purified Solution Analyses

Element (Concentration)	Stage	No. Of Units	Minimum	Median	Maximum
Zn (g/L)	1	10	145	152	176
	2	16	140	155	178
	3	16	140	155	178
Fe (mg/L)	1	11	1	10	24
	2	10	1	7.5	20
	3	10	0.1	5.75	26
Cu (mg/L)	1	9	0.01	2	371
	2	14	0.01	0.080	300
	3	14	0.01	0.080	300
Co (mg/L)	1	10	0.02	14	43
	2	11	0.01	0.160	20
	3	8	0.010	0.100	0.400
Ni (mg/L)	1	7	0.00	4	20
	2	10	0.00	0.10	500
	3	10	0.01	0.10	500
Cd (mg/L)	1	10	0.28	17.5	750
	2	14	0.10	0.25	1000
	3	14	0.10	0.25	1000

Table 13 – Purification Cake Analyses

Element (%)	Stage	No. Of Units	Minimum	Median	Maximum
Zn	1	12	3.50	9.68	39.40
	2	8	1.19	16.75	45.00
	3	6	6.52	18.40	65.00
Fe	1	6	0.10	0.225	1.89
	2	4	0.06	0.137	2.50
	3	3	0.008	0.087	0.100
Cu	1	12	5.00	56.65	78.00
	2	7	4.00	31.20	63.20
	3	5	0.01	1.60	60.43
Co	1	6	0.004	0.20	0.90
	2	7	0.40	2.00	3.50
	3	5	0.01	0.03	0.88
Ni	1	5	0.02	0.10	1.50
	2	6	0.10	1.41	4.00
	3	3	0.004	0.004	0.01
Cd	1	11	0.001	2.00	28.00
	2	9	0.19	3.95	26.90
	3	5	2.62	38.40	86.20

Figure 10 shows the relationship between temperature in the cobalt precipitation stage and cobalt concentration in the discharged solution. As previously reported [1], the residual cobalt concentration in the purified electrolyte generally decreases with decreasing purification stage temperature. However, the use of PEX appears to achieve suitable Co removal even at a relatively low temperature of 43°C. Also of note is that the reported cobalt concentrations in the purified leach solution in this survey, most of which are all below 1 mg/L, are generally lower than those reported in the 2005 survey [1], which ranged between 2 and 30 mg/L.

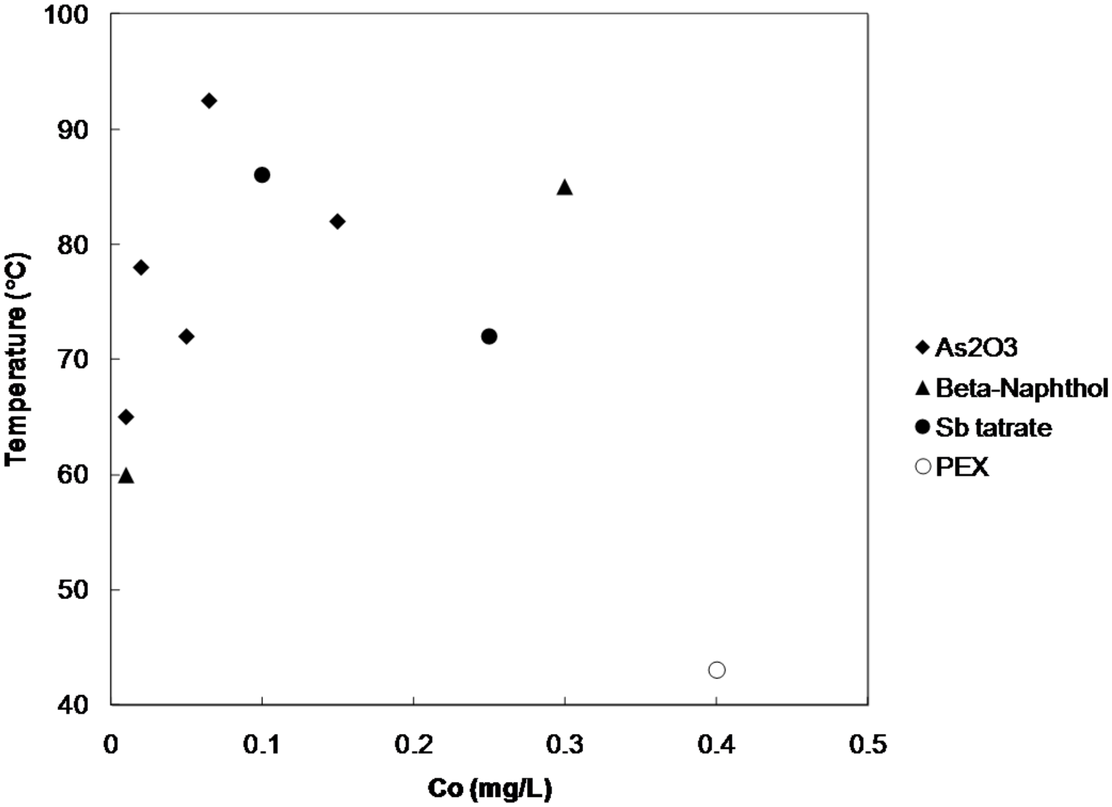

Figure 10 - Relationship between Co in Purified Solution and Temperature of Co Removal Stage

Electrolysis

Common performance indicators of zinc electrolysis processes are reported in Table 14. Some operations have more than one cellroom resulting in more units than reporting facilities. Table 15, which presents values of some of these performance indicators from past surveys, shows a trend of increasing current efficiency. Over the past 25 years, there has been a trend toward larger cathodes.

Table 14 – Electrolytic Cell Performance Indicators

	No. Of Units	Minimum	Median	Maximum
Cell Voltage (V)	18	3.2	3.5	3.6
Deposition Time (hr)	19	24	40	72
Current Density (A/m^2)	19	380	491	690
Current Efficiency (%)	19	85	91	93
Power Used (kWhr/ton (Zn))	16	2990	3200	3309
Electrolyte Temperature (°C)	13	35	39	45

Table 15 – Comparison of Average Electrolysis Conditions with Past Surveys

Year	Cathode Area (m^2)	Current Density (A/m^2)	Current Efficiency (%)	Power Used (kWhr/ton (Zn))
1985	1.75	527		3181
1995	2.20	484	89.2	3191
2000	2.09	510	90.3	3202
2010	2.29	499	90.6	3187

The configuration of the electrowinning cells, the composition of the zinc electrolyte, and addition rates for additives are reported in Table 16, Table 17 and Table 18 respectively.

Table 16 – Cell Configurations

	No. Of Units	Minimum	Median	Maximum
Cathode Area (m^2)	18	1.16	2.2	3.8
Anodes/Cell	16	28	45	101
Anode Life (month)	16	24	36	72
Cathode Life (month)	18	10	18	31.6
Cathode Spacing (mm)	19	46.6	75	90

Table 17 – Electrolyte Compositions

	No. Of Units	Minimum	Median	Maximum
Zn (g/L)	18	50	54.5	75
H_2SO_4 (g/L)	18	140	170	215
Mg (g/L)	17	1.6	4	15.7
Mn (g/L)	17	2	5.5	15
Cl (mg/L)	13	45	225	600
F (mg/L)	14	1.4	22.5	31

Table 18 – Electrolyte Additives

	No. Of Units	Minimum	Median	Maximum
Glue (kg/day)	7	2.9	25.2	80
Gelatin (kg/day)	8	5	21.75	66
Licorice (kg/day)	7	0.2	7	63
$SrCO_3$ (kg/day)	16	5.6	351	800
K-Sb-Tartrate (g/day)	6	15	51.25	91

Space-time yield is a commonly used measure of electrolytic cell performance. In the case of Figure 8, space-time yield is calculated as the sum of annual production of special high grade and high grade zinc divided by the total volume of electrolytic cells in a given plant (number of cells × length × depth × width). The results would suggest Japanese plants, which tend to be highly automated, and Chinese plants, which are relatively new, have higher space-time yields at comparable average current densities compared to European and North American plants.

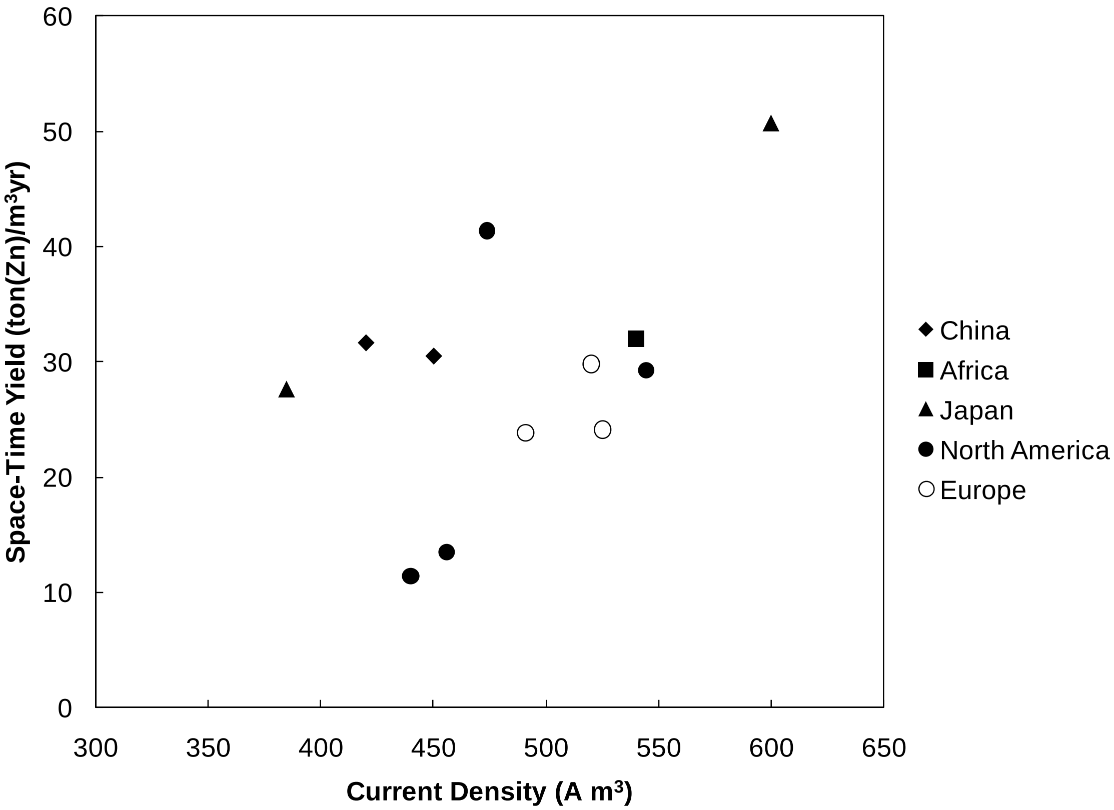

Figure 11 – Space-Time Yield versus Average Current Density by Region

Casting and Products

All reported furnaces for melting were induction type. The relative distribution of types of cast zinc products is presented in Figure 12. Special high-grade zinc is by far the most common zinc product, accounting for 63% of all zinc produced, while 25% of zinc is produced as alloys. As indicated in Figure 13, slab zinc is the most common form of zinc metal produced for sale, accounting for roughly two-thirds of all cast zinc metal products.

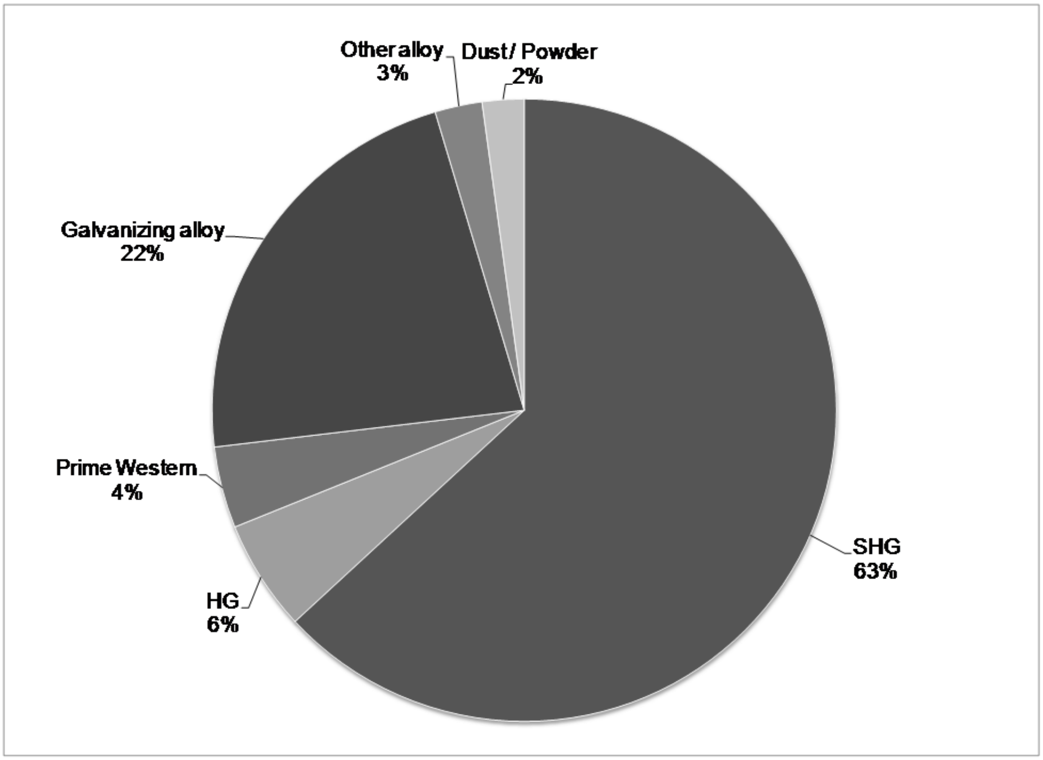

Figure 12 – Types of Zinc Metal Produced

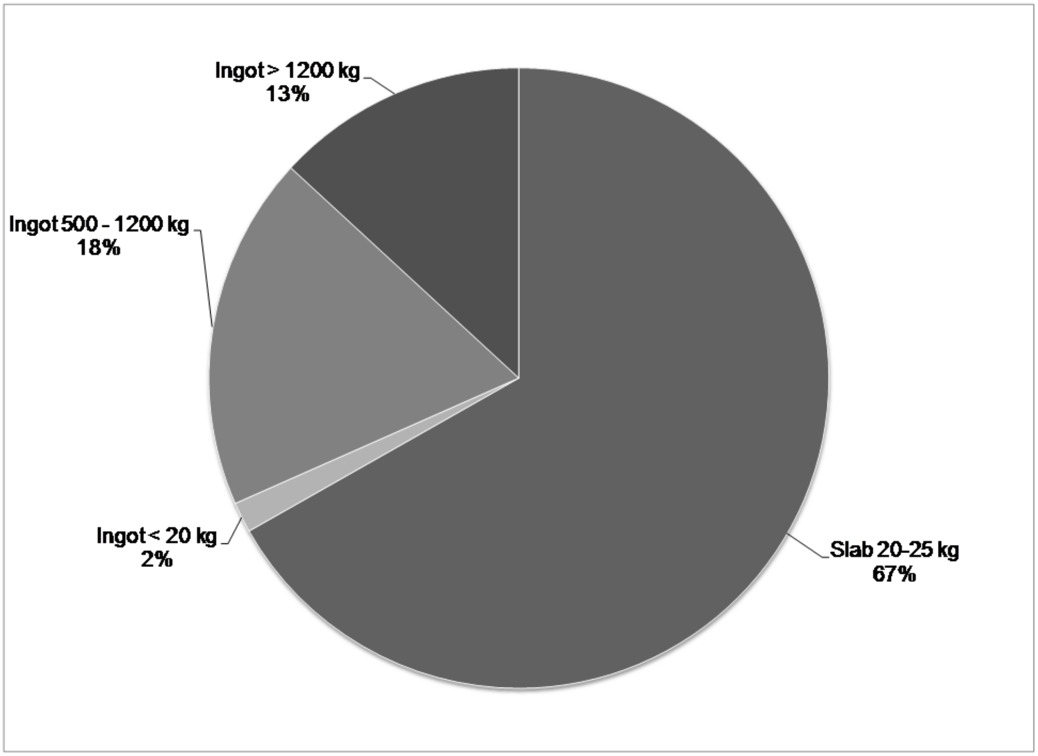

Figure 13 – Distribution of Shapes and Sizes of Cast Zinc Metal Products

Labor

Details of the number and types or workers in zinc plants are presented in Table 19. The relationship between plant capacity and productivity for zinc plants is presented in Figure 14. The results suggest that Japanese plants tend to be most productive in the world.

Table 19 – Breakdown of Zinc Plant Worker Numbers

	No. Of Units	Minimum	Median	Maximum
Total	18	57	285.75	1750
Maintenance	12	13	62.5	300
Contract	7	2	11	88

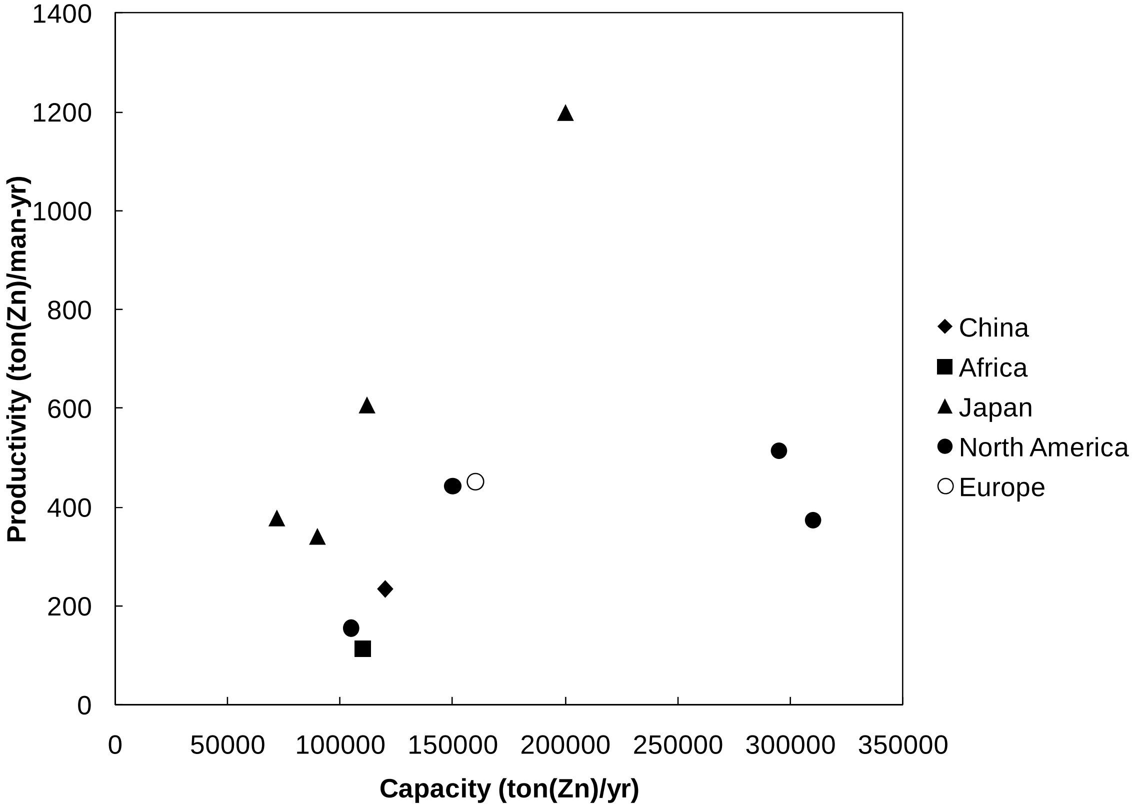

Figure 14 – Productivity versus Plant Capacity by Region

CONCLUSIONS

A survey of operating data for primary zinc smelters was conducted as part of Lead-Zinc 2010. Where possible the results were compared with those of previous surveys in 1985, 1995, 2000, and 2005. A continues trend toward improved efficiency in zinc extraction and current efficiencies can be seen. The survey includes data for the first time from modern plants built in China. The survey also contains the first reported use of potassium ethyl xanthate in solution purification. In terms of zinc production per man-yr, the Japanese plants are the most productive.

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