Article

Recovery of Zinc from the Concentrate of Domestic Waste Processing by Vacuum Distillation

Sergey Trebukhov, Valeriy Volodin, Alina Nitsenko *, Nurila Burabaeva and Galiya Ruzakhunova

Institute of Metallurgy and Ore Beneficiation JSC, Satbayev University, Almaty 050010, Kazakhstan; s.trebukhov@satbayev.university (S.T.); volodinv_n@mail.ru (V.V.); nuri_eng@mail.ru (N.B.); galiya_suleymen@mail.ru (G.R.)

* Correspondence: alina.nitsenko@gmail.com

Abstract: The heterogeneity and local distribution of elements are established as a result of the study of nonferrous metals distribution and the composition of domestic wastes processing concentrate containing 20–40% copper, 40–50% brass, 20–28% zinc and up to 1% aluminium. Metals are mainly concentrated in granules of three types: zinc-based, copper-based and copper–zinc alloy, i.e., brass. The phase composition of these granule types and their structure are determined. Zinc granules are covered with a refractory oxide shell. A distillation processing method for such raw materials based on full state diagrams, including the phase transition of melting pairs of double systems of copper and tin with zinc and lead, is offered. The possibility of a rather complete zinc distillation (over 90%) with the accumulation of other metals in the copper-based alloy, containing more than 96 wt. % of the basic element, has been demonstrated by electric crucible melting in a highly reducing atmosphere. Copper-based alloys, after adjustment for the content of some metals (tin), can be realized as pressure-treated tin bronzes. Copper with the content of impurities corresponding to the standard for blister copper can be electrolytically processed (after dissolution in sulphuric acid) in copper production. Equipment for the implementation of the electro-thermal processing process that provides metal recycling of the metal concentrate is proposed.

Keywords: recycling; copper; zinc; lead; tin; concentrate; distillation; state diagram; electrical melting; tin bronze; blister copper

1. Introduction

The use of domestic solid waste has now become a worldwide problem [1–4]. The Republic of Kazakhstan is also among the countries where this problem is very urgent [5]. Domestic waste disposal practiced for many decades is universally recognized as a non-perspective direction, both ecologically and economically [6]. In recent years, developed industrialized countries use a very efficient method of waste recycling, enabling the extraction of valuable components by recycling them into production [7]. This solution to the problem provides not only an economic effect due to the involvement of secondary raw materials in recycling but mainly solves the environmental problem [8].

One of the main methods of waste processing after pre-sorting is waste incineration, when about 20% of the total volume remains at the furnace bottom as slag, and 10% of the slag consists of metals, including about 8% ferrous metals, and the remaining 2–3% are non-ferrous metals [8–11]. Existing technologies allow for the separation of slag into ferrous and non-ferrous metal concentrates [12], with the non-ferrous metal concentrate being sent for recycling as secondary raw materials. However, up until now there has been no rational scheme for the extraction of metals forming the concentrate, for example, zinc (the content of zinc in the concentrate is up to 22%). The prevailing methods of zinc extraction are hydrometallurgical schemes proceeding from the established practice. There are methods to extract zinc by distillation at relatively moderate temperatures; however, pyrometallurgical processes of low-tonnage (1000–1200 t/year) amounts are not known.
The understanding of the behaviour of the main extractable constituents in distillation processes follows from the full state diagrams we constructed, including the liquid–vapour phase transition in the dual systems Cu–Zn, Cu–Pb, Sn–Zn and Sn–Pb (Figure 1).

![State diagrams for the systems: (a) Cu–Zn; (b) Cu–Pb; (c) Sn–Zn; (d) Sn–Pb.](image)

Figure 1. State diagrams for the systems: (a) Cu–Zn; (b) Cu–Pb; (c) Sn–Zn; (d) Sn–Pb.

The liquid boiling temperature, when the sum of the partial pressures of each of the double system metals is considered equal to the atmospheric pressure (101.33 kPa), was taken when the borders of the coexistence fields of the liquid and vapour (L + V) were calculated. The metal concentration in the vapour was found as a partial pressure fraction of the element in the total pressure over the melt. In connection with the fact that the distillation processes of metals, as a rule, are performed in a vacuum, the diagrams show borders of coexistence fields of liquid and vapour at 100 and 1 Pa (they are shaded).

The saturated vapour pressure of elemental copper was taken from [13], zinc in the copper–zinc system from [14] and lead in the copper–lead system from [15], when phase transitions are constructed. Thermodynamics of the tin–zinc [16] and tin–lead systems
were studied by us [17]. The field boundaries (L + V) are marked on the state diagrams from the reference book [18–20].

The area of liquid solutions in the Cu–Zn system at atmospheric pressure between the liquidus line and the boiling curve is not high in temperature, especially in the field of concentrations corresponding to the composition of brasses. The boiling temperatures in the fore-vacuum overlap with the fields of solid phases ε, γ, β, Cu3Zn, (Cu) and their solutions. The melt’s boiling curve intersects with the low copper concentration field (L) and the two-phase field (ε + L) only at 100 Pa pressure. Conversion of zinc to the vapour phase from its alloys with copper will be a sublimation process predominantly from the crystalline phases that greatly reduces the technological intensity of the separation process. The process of zinc evaporation from liquid solutions with copper in the equilibrium conditions in the fore-vacuum is possible only at very low concentrations of zinc—0.51 and 1 × 10⁻³% at 100 and 1 Pa, accordingly. The process of zinc evaporation from the melt requires a considerable pressure rise above the liquid bath. The melting point of even zinc-rich brass (up to 30%) is close to zinc’s boiling point at atmospheric pressure (907 °C). Consequently, evaporation extraction of zinc is possible only at atmospheric pressure when a similar metallic concentrate is melted. The vapour phase will be more than 99.9% zinc.

The boiling curve for solutions at atmospheric pressure is placed above the temperature 1745 °C in the diagram of the Cu–Pb system, and it is not shown in Figure 1. The line of the melt’s boiling point at 100 Pa is in the field of liquid solutions, at a concentration of ~20–60 at. % Pb in the region of separation L₁ + L₂, less than ~10 at. % in the two-phase field (Cu) + L. The melt’s boiling curve is placed in the (Cu) + L field at a pressure equal to 1 Pa, and the composition of the liquid phase corresponds to the composition of the melt at the crossing point of the liquidus curve ~94 at. % Pb. That is, evaporation of lead will proceed from the lead-rich alloy. Only the quantitative ratio of phases (Cu) and L will change as the lead evaporates at 1 Pa. Technological difficulty in the distillation separation of lead from copper in a vacuum is not expected based on the position of the boundaries of the vapour–liquid equilibrium fields. The vapour phase will be represented almost entirely by lead.

Technological difficulties are not supposed in the Sn–Zn system at the distillation separation. The field of coexistence of phases (L + V) is very wide according to the temperature. The only limitation may be the process pressure to be maintained over 30 Pa, as a lower pressure superposition of (L + V) field to two-phase field (L + (Zn)) occurs, which will accompany the process of zinc evaporation from the melt in the presence of the crystal phase. The evaporation of zinc in the presence of tin at atmospheric pressure has no limitations. The vapour phase will include almost entirely zinc, and the separation process can be realized in one operation.

There is also no difficulty in separating the metals in a vacuum in the Sn–Pb system. Distillation separation of Pb and Sn at atmospheric pressure is technically difficult because of the high boiling point of both metals.

In this connection, we performed research and technological testing of secondary zinc-containing metal-concentrate processing for zinc extraction into a separate product by means of a distillation method in the present study.

2. Research Methods

2.1. Microstructural and Elemental Composition Analyses

The study of material composition of samples was carried out by X-ray fluorescence analysis using an Axios “PANalytical” wave-dispersive combined spectrometer. Determination of contents of Cu, Pb, Sn and Zn was performed by sequential nitric and hydrochloric acid decomposition of samples and evaporation with aliquot analysis on atomic emission spectrometer Optima 8300 DV “Perkin Elmer” at wavelength 324.752; 220.353; 283.998 and 213.857, respectively, and parallel titrometric method.
Precious metal content (Au and Ag) was determined using AA240 “Varian Optical Spectroscopy Instruments” atomic absorption spectrometer. Au content was determined directly from the solution, and the solution was diluted 5/100 when Ag was determined.

A JEM-2100 electron-dispersive scanning electron microscope (JEOL) at 25 kV accelerating voltage was used for microstructural and elemental composition analyses of basic material and obtained samples.

2.2. Metal Concentrate Melting

The technological experiments were performed in an electric crucible shaft furnace with an external condenser (Figure 2).

![Figure 2. Scheme of the crucible electric furnace for zinc distillation with an external condenser: (1) heaters, (2) shaft, (3) crucible, (4) steam line, (5) condenser, (6) water-cooled tube, (7) fabric filter, (8) gas duct, (9) tank for condensate, (10) lid, (11) charging hatch and (12) gas supply pipe.](image)

The electric furnace intended to smelt the metal concentrate was a shaft (2) heated with graphite heaters (1) where the crucible (3) was located. The furnace shaft was connected with a heated steam line (4) with a water-cooled cylindrical and conical cyclone-type steam condenser (5). A water-cooled tube (6) with a fabric filter (7) is mounted inside the condenser along its axis and connected to the gas duct (8). The conical part of the condenser (5) is open to the side of the tank (9) for condensate collection. The distillation furnace shaft is covered with a lined lid (10) with a charging hatch (11) and a gas supply pipe (12). The inside part of the shaft is lined with chromium–magnesite bricks. The gas supply pipe inside the shaft is made of ceramic alundum. The temperature was measured with a thermocouple whose sheath was lowered into the melt (not shown in Figure 2).

The experiment’s procedure was as follows. Sand, lime and soda ash were loaded into the crucible at the rate of slag with wt. %: 40–45—SiO₂; 20–30—CaO; 25–35—Na₂O. When the slag was fused at 1250–1350 °C, we started loading the metal concentrate in the amount of 3–5 kg with addition of 1–2% coke breeze. Zinc loading and distillation process were conducted at supply of natural gas to maintain overpressure in electric furnace 0.1 kPa in order to avoid oxidation of melt components, steam phase and graphite heaters. When this temperature was reached, it was considered as the beginning of the experiment. Zinc steam was led through the heated steam line (at 950 °C) into the water-cooled condenser where the condensation process in the form of powder, druse or melted formations took place. Crystalline zinc, which crumbles or is removed at the end of the process from the condenser walls, as well as dust (containing zinc) from the bag filter fall into the condensate tank. The
zinc distillation process duration was 4–6 h. The melting products were copper alloy and zinc condensate. The electric furnace was cooled after completion of zinc evaporation, the melting products were extracted (in an inert atmosphere), weighed and analyzed.

3. Object of Research

A collective concentrate of non-ferrous metals was used as a subject of study. The particle size yield of the fractions was wt. %: grain size from 8.0 to 5.0 mm—24.24; from 5.0 to 3.0 mm—33.33; from 3.0 to 0.8 mm—36.36; from 0.8 to 0.3 mm—6.07. The appearance of the concentrate fractions of different sizes is shown in Figure 3.

![Figure 3. Metal concentrate fractions with size (in mm): (a) from 1.8 to 0.8; (b) from 3.0 to 1.8; (c) from 8.0 to 5.0.](image)

The sample of the collective concentrate was divided into three parts by colour to obtain information about the composition. The mass fraction yield of ash grey material (zinc fraction) was 15.4%, pale yellow material (brass fraction) was 59.3% and brownish red material (copper fraction) was 25.3%.

The results of elemental composition determination of the averaged samples of each colour and also the average calculated content of the elements in the source material are given in Table 1. Figure 4 and Table 2 show the results of microstructure and elemental composition analyses of concentrate fractions of various colours.

Table 1. Elemental composition of the concentrate with coarseness from 8.0 to 5.0 mm, divided into fractions by colour and estimated average element content in the original concentrate.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Zinc Fraction</th>
<th>Brass Fraction</th>
<th>Copper Fraction</th>
<th>Estimated in Concentrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn</td>
<td>93.75</td>
<td>33.66</td>
<td>0.94</td>
<td>34.63</td>
</tr>
<tr>
<td>Cu</td>
<td>0.82</td>
<td>63.44</td>
<td>95.80</td>
<td>61.98</td>
</tr>
<tr>
<td>Pb</td>
<td>—</td>
<td>1.75</td>
<td>0.32</td>
<td>1.12</td>
</tr>
<tr>
<td>Al</td>
<td>4.58</td>
<td>0.13</td>
<td>0.53</td>
<td>0.92</td>
</tr>
<tr>
<td>Sn</td>
<td>—</td>
<td>0.40</td>
<td>0.79</td>
<td>0.44</td>
</tr>
<tr>
<td>Si</td>
<td>0.20</td>
<td>7.7 × 10⁻²</td>
<td>0.59</td>
<td>0.22</td>
</tr>
<tr>
<td>Ni</td>
<td>3 × 10⁻²</td>
<td>0.30</td>
<td>0.14</td>
<td>0.22</td>
</tr>
<tr>
<td>Fe</td>
<td>4 × 10⁻²</td>
<td>0.14</td>
<td>0.10</td>
<td>0.11</td>
</tr>
<tr>
<td>P</td>
<td>2 × 10⁻³</td>
<td>0.13</td>
<td>2.6 × 10⁻²</td>
<td>8.4 × 10⁻²</td>
</tr>
<tr>
<td>Bi</td>
<td>—</td>
<td>—</td>
<td>0.30</td>
<td>7.6 × 10⁻²</td>
</tr>
</tbody>
</table>
Table 1. Cont.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Zinc Fraction</th>
<th>Brass Fraction</th>
<th>Copper Fraction</th>
<th>Estimated in Concentrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl</td>
<td>0.11</td>
<td>$3.7 \times 10^{-2}$</td>
<td>$9.1 \times 10^{-2}$</td>
<td>$6.2 \times 10^{-2}$</td>
</tr>
<tr>
<td>S</td>
<td>$4.2 \times 10^{-2}$</td>
<td>$2.9 \times 10^{-2}$</td>
<td>0.12</td>
<td>$5.4 \times 10^{-2}$</td>
</tr>
<tr>
<td>Mg</td>
<td>0.11</td>
<td>$3.2 \times 10^{-3}$</td>
<td>$6.5 \times 10^{-2}$</td>
<td>$5.2 \times 10^{-2}$</td>
</tr>
<tr>
<td>W</td>
<td>0.31</td>
<td>—</td>
<td>—</td>
<td>$4.7 \times 10^{-2}$</td>
</tr>
<tr>
<td>Ca</td>
<td>$3.1 \times 10^{-2}$</td>
<td>—</td>
<td>0.13</td>
<td>$3.8 \times 10^{-2}$</td>
</tr>
<tr>
<td>As</td>
<td>—</td>
<td>—</td>
<td>$5.9 \times 10^{-2}$</td>
<td>$1.5 \times 10^{-2}$</td>
</tr>
<tr>
<td>Nb</td>
<td>—</td>
<td>—</td>
<td>$6 \times 10^{-3}$</td>
<td>$2 \times 10^{-3}$</td>
</tr>
<tr>
<td>Au</td>
<td></td>
<td></td>
<td>are not found</td>
<td></td>
</tr>
<tr>
<td>Ag</td>
<td></td>
<td></td>
<td>are not found</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. Microstructure of the granules: (a) zinc fraction; (b) brass fraction; (c) copper fraction.
As can be seen from the given data, the chemical composition of the granules and inclusions in the zinc fraction is not locally homogeneous. The zinc granules are represented by the predominant zinc phase with inclusions on the grain boundaries. The crystals contain from 78.08 to 97.98 wt. % zinc. Inclusions were zinc-based formations and contained from 67.75 to 83.91 wt. % zinc.

Brass fraction granules represented a solid solution of zinc in copper with rounded lead-based inclusions. The main components in the solid solution are copper (from 38.57 to 63.94 wt. %) and zinc (from 21.18 to 36.31 wt. %). The inclusions contained lead (from 71.57 to 76.48 wt. %) in their base.

The copper fraction is represented by elemental copper with hair-like inclusions containing up to 84.06 wt. % copper and other impurity elements.

When the data obtained for the composition of the collective pellet concentrate were analyzed, it was clear that the main elements to be recovered are copper, zinc, lead and tin. It should be noted that there was a very uneven distribution of metals even in one pellet in each of the fractions, separated by colour. Besides, the solubility limits of the metals and elements, such as carbon in zinc and brass, are exceeded by a multiple. This can be explained by the variable composition of the raw materials used to extract the metal concentrate and the extraction technology that involves grinding and milling the slag,

Table 2. Elemental composition corresponding to the points 1–22 in Figure 2.

<table>
<thead>
<tr>
<th>No.</th>
<th>Elements, wt. %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>O</td>
</tr>
<tr>
<td>Zinc fraction</td>
<td></td>
</tr>
<tr>
<td>Point 1</td>
<td>13.85</td>
</tr>
<tr>
<td>Point 2</td>
<td>6.38</td>
</tr>
<tr>
<td>Point 3</td>
<td>12.96</td>
</tr>
<tr>
<td>Point 4</td>
<td>–</td>
</tr>
<tr>
<td>Point 5</td>
<td>–</td>
</tr>
<tr>
<td>Point 6</td>
<td>–</td>
</tr>
<tr>
<td>Point 7</td>
<td>–</td>
</tr>
<tr>
<td>Point 8</td>
<td>–</td>
</tr>
<tr>
<td>Brass fraction</td>
<td></td>
</tr>
<tr>
<td>Point 9</td>
<td>5.00</td>
</tr>
<tr>
<td>Point 10</td>
<td>6.02</td>
</tr>
<tr>
<td>Point 11</td>
<td>–</td>
</tr>
<tr>
<td>Point 12</td>
<td>1.83</td>
</tr>
<tr>
<td>Point 13</td>
<td>4.42</td>
</tr>
<tr>
<td>Point 14</td>
<td>4.54</td>
</tr>
<tr>
<td>Point 15</td>
<td>–</td>
</tr>
<tr>
<td>Point 16</td>
<td>15.53</td>
</tr>
<tr>
<td>Copper fraction</td>
<td></td>
</tr>
<tr>
<td>Point 17</td>
<td>11.69</td>
</tr>
<tr>
<td>Point 18</td>
<td>8.42</td>
</tr>
<tr>
<td>Point 19</td>
<td>11.97</td>
</tr>
<tr>
<td>Point 20</td>
<td>16.15</td>
</tr>
<tr>
<td>Point 21</td>
<td>–</td>
</tr>
<tr>
<td>Point 22</td>
<td>–</td>
</tr>
</tbody>
</table>
which may result in a mechanical melting process. The diversity of the composition, local distribution and metal content of the collective concentrate determines the complexity of the technological process of its recycling.

4. Choice of Concentrate Processing Technology

When the physical properties of the main extracted metals such as the melting temperature and value of saturated vapour pressure are considered, elements can be divided into easily melting zinc, lead, tin and copper, having a melting temperature of 1084.87 °C, and easily volatile zinc, average volatile lead and hardly volatile copper and tin. In addition, copper and tin that transfers into the vapour phase at moderate temperatures is almost impossible. Moreover, if zinc’s boiling point at atmospheric pressure (101.33 kPa) is 907 °C, then the vapour pressure of lead at copper’s melting point is 0.33 kPa.

It is found, based on what is stated above, that it is reasonable to transfer volatile constituents to the vapour phase and further to the condensate and to accumulate non-volatile constituents in the distillation residue.

5. Results and Discussion

Distilling zinc directly from the concentrate at a temperature of 800–900 °C was attempted, with other metals left in the residue. The work on vacuum distillation of various metals was carried out by us earlier [21–23]. The process was performed at 0.13 kPa under vacuum for 1 h. It was found that zinc was not completely removed from zinc and brass granules. The residual zinc granules retained their shape in the form of a shell that is thicker than the original size after heat treatment and zinc evaporation (Figure 5).

![Figure 5. Zinc granule after evaporation of zinc in a vacuum at 800 °C.](image)

The content of elements in the granule shell varies in the range, mass %: zinc—from 0.08 to 6.32; copper—from 6.81 to 56.84; aluminium—from 12.21 to 52.44; iron—from 0.30 to 0.43; local lead—18.52; oxygen—17.88; magnesium—0.72; tungsten—0.40.

The granules changed colour from yellow to brownish red (copper), as the zinc content decreases in them when zinc is distilled from a brass fraction (Figure 6).

![Figure 6. Brass granules after evaporation of zinc at temperature (in °C) of (a) 800; (b) 1000.](image)
The zinc concentration in the brass granules after distillation at 1000 °C did not exceed 7 wt. %.

The copper fraction granules did not undergo any changes during thermo-vacuum treatment.

The specified experiments have shown the impossibility of the direct zinc sublimation process with a sufficient extraction degree from the concentrate because of the formation of refractory coatings on zinc granules that contain a considerable quantity of metal and because of difficulties caused by diffusion of zinc from the solid solution with copper-brass to the evaporation surface.

The process intended to reprocess with the pre-melting of the collective metallic concentrate under the excessive pressure of the reducing gas phase into brass blanks [24] with a following vacuum distillation of zinc and lead from the obtained alloy was tested.

The process of co-evaporation of mainly zinc, at first, then lead and zinc from blister brass at a self-regulated pressure reduction (as zinc evaporates) from atmospheric to the fore-vacuum and co-vapor phase condensation in one condenser is implemented based on the analysis of the state diagrams of the considered systems.

The vacuum distillation process for volatile constituents from blister brass, having wt. %: Cu—77.40; Zn—16.60; Pb—4.07; Sn—1.80 in its composition, was performed under crucible melting conditions at a temperature of 1000–1050 °C over 4 h with a slow reduction of pressure from 92 kPa (pressure at Almaty) to 30 Pa at the end of the process. The evaporation area was 1.13 × 10⁻² m². The collective condensate from a condenser was drained into the unheated crucible. The distillation products were extracted from the vacuum furnace in solid form after filling with inert gas and cooling. The collective condensate was extracted and remelted in an argon atmosphere to separate the zinc and lead layers. Zinc extraction from the blister brass to zinc condensate was over 99% at 98.7 wt. %, the lead-to-lead condensate was 96.35% at 95.29 wt. %. Copper and tin were 97.44% and 92.40% concentrated in the distillation residue with increases to 97.01 and 2.14 wt. %, respectively.

The main shortcoming of this variant of collective metal-concentrate processing was the increased removal of melt droplets by the zinc steam flow at the small zinc distillation stage at the specified temperatures and the creation of vacuum during the technological process. Besides, the high aggressiveness of the vapour phase towards structural materials caused difficulties associated with the need to protect steel products with materials that are inert towards zinc.

The mentioned shortcomings and analysis of processing methods for similar or zinc content-close raw materials and intermediate products of metallurgical production showed the expediency to use collective metal concentrate melting with zinc stripping in a highly reducing atmosphere, as it takes place during the electric melting of silver foam in the lead refining scheme [25], and to receive a copper-based alloy where tin and low-volatility-at-atmospheric-pressure lead will be concentrated in the residue [26].

An example of the distribution of the metal impurities in the copper alloy obtained after zinc stripping is shown in Table 3.

It is obvious that copper is almost completely (more than 98%) concentrated in the distillation residue and zinc in the condensate by 90.87%. An increase of a degree of extraction of zinc in condensate and a decrease of its concentration in copper alloy can be reached by an increase of the distillation process duration; however, the latter should be determined by economic feasibility.

The composition of impurities in copper alloy obtained in other melts under similar conditions, as well as for comparison of standards [27,28] of bronze and blister copper grades, is shown in Table 4.
Table 3. Content and distribution of metals in smelting products of metal concentrate.

<table>
<thead>
<tr>
<th>Products</th>
<th>Mass in Relation to Concentrate, %</th>
<th>Cu</th>
<th>Zn</th>
<th>Pb</th>
<th>Sn</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Content, %</td>
<td>Distribution, %</td>
<td>Content, %</td>
<td>Distribution, %</td>
<td>Content, %</td>
</tr>
<tr>
<td>Concentrate</td>
<td>100</td>
<td>62.30</td>
<td>100</td>
<td>33.80</td>
<td>100</td>
<td>0.54</td>
</tr>
<tr>
<td>Coke breeze</td>
<td>2.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Metal impurities in copper alloy after zinc stripping.

<table>
<thead>
<tr>
<th>Copper Alloy</th>
<th>Copper Content, wt %</th>
<th>Impurities Content, wt. %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zn</td>
<td>Pb</td>
</tr>
<tr>
<td>Copper alloy 1</td>
<td>90</td>
<td>4.13</td>
</tr>
<tr>
<td>Copper alloy 2</td>
<td>89</td>
<td>4.87</td>
</tr>
<tr>
<td>Copper alloy 3</td>
<td>93</td>
<td>3.19</td>
</tr>
<tr>
<td>Copper alloy 4</td>
<td>96</td>
<td>2.21</td>
</tr>
<tr>
<td>Copper alloy 5</td>
<td>96</td>
<td>2.76</td>
</tr>
<tr>
<td>BrOCC4-4-2,5 alloy</td>
<td>86–93</td>
<td>3.0–5.0</td>
</tr>
<tr>
<td>BrOTCC4-4-4 alloy</td>
<td>85–90</td>
<td>3.0–5.0</td>
</tr>
<tr>
<td>MCh5 alloy</td>
<td>5–97.5</td>
<td>–</td>
</tr>
<tr>
<td>MCh6 alloy</td>
<td>6–96</td>
<td>0.60</td>
</tr>
</tbody>
</table>

When the non-ferrous metal contents in products (Tables 3 and 4) obtained by distillation smelting of the collective metal concentrate are analyzed, it is possible to see the part of them (alloys 1–3) that corresponds to BrOCC4-4-2,5 and BrOTCC4-4-4 [27] bronze grades, processed by pressure, except for tin admixture, or to MCh5 or MCh6 grades of blister copper (alloys 4, 5). If the composition of the bronzes is corrected for the tin content, they can be used to make bands and strips used in bearing sleeves. Alloys corresponding to the blister copper composition can be sent for electrolytic refining in copper smelting.

6. Conclusions

Thus, the recycling of basic metals and impurities is provided as a result of the electric melting of a polymetallic concentrate in a reducing atmosphere (natural gas was used as a reducing agent), and the obtained copper-based alloys and blister zinc can be sold as a commercial product.

It should be noted that the composition of melted copper alloy is not constant in content. A set of impurities indicates a high heterogeneity of the collective metallic concentrate and local distribution of elements in the alloy. Therefore, each party of melted copper alloy will require analytical traceability.

The blister zinc resulting from the distillation can be used in the desilverisation operation in the blister lead refining scheme.
The electro-thermal distillation unit intended to distillate zinc from silver froth of a lead plant, working in continuous mode and having a condenser for precipitation and a filling of smelted zinc in a liquid state, can be recommended as an industrial process equipment.

**Author Contributions:** Conceptualization, S.T.; methodology, S.T. and V.V.; investigation, S.T., A.N., N.B. and G.R.; data curation, V.V.; writing—original draft preparation, S.T. and V.V.; writing—review and editing, S.T. and A.N.; visualization, S.T. and V.V.; project administration, S.T. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the Ministry of Education and Science of the Republic of Kazakhstan (project AP08855494).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Acknowledgments:** The authors acknowledge the funding support from the Ministry of Education and Science of the Republic of Kazakhstan.

**Conflicts of Interest:** The authors declare no conflict of interest.

**References**


