Electromagnetic Levitation Silver Refining

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Market demand for the new technology

Silver is primarily used in two major markets: jewelry and solar panels. In both applications, silver is often alloyed with other metals, such as copper and silicon, which typically have a solubility of less than 0.4-0.6%. The phase diagrams for copper-silver and silver-silicon alloys exhibit similarities, making them amenable to similar crystallization refining processes. Crystallization is a common technique for refining silver and gold to achieve ultra-high purity levels (99.999% to 99.9999%). Vacuum metallurgical processes, including zone melting, direct solidification, and vertical floating zone melting, have been widely adopted for refining precious metals due to their ability to remove impurities effectively. These techniques are particularly valuable when dealing with high-concentration silver alloys (90% or more). While electrolysis is a viable option for refining high-concentration silver, it can be less efficient in terms of energy consumption and production time compared to vacuum metallurgical methods like zone melting or direct solidification. Kuntzler and Wernik conducted a study on refining silver using the zone melting technique. Their experiments, conducted in a graphite boat with induction heating in an argon atmosphere, demonstrated a significant increase in resistivity ratio (RR4), indicating improved purity.

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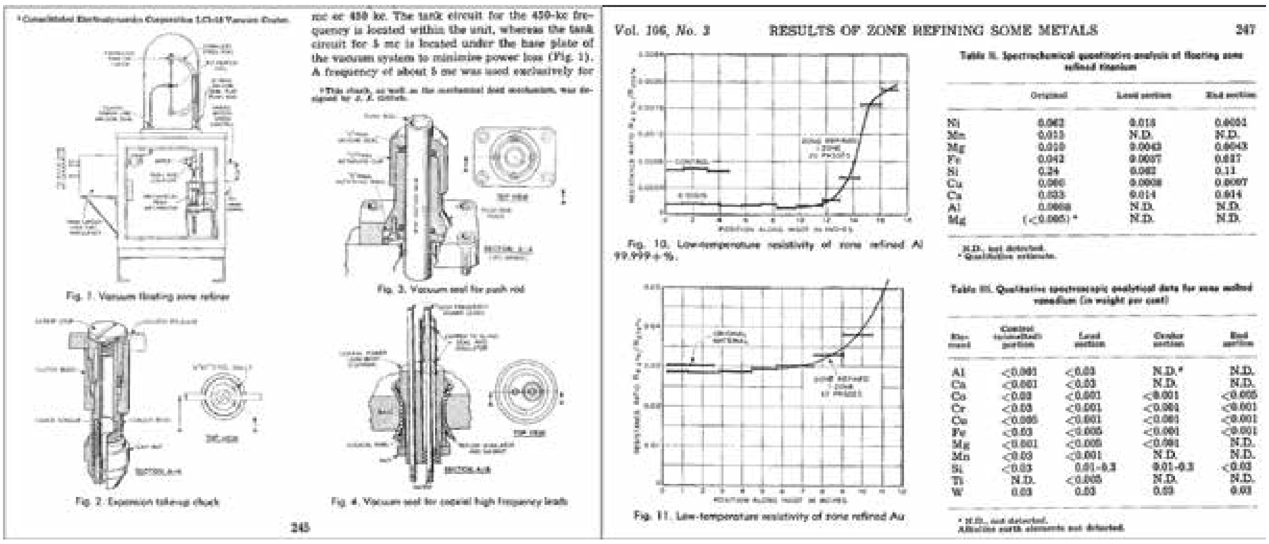
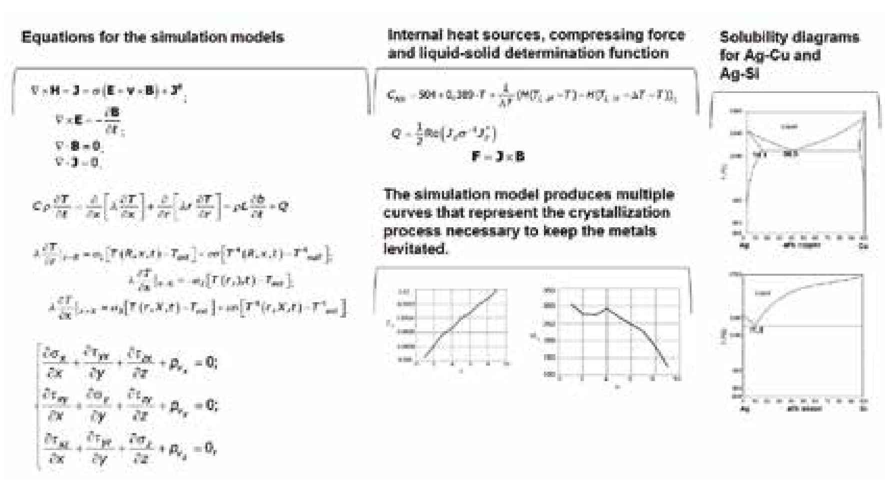


Paper screenshot Techniques and Results of Zone Refining Some Metals J. H. Wernick, D. Dorsi, and J. J. Byrnes Bell Telephone Laboratories, Inc., Murray Hill, New Jersey. JOURNAL OF THE ELECTROCHEMICAL SOCIETY. 1959.

Experimental Silver Refining Using Vacuum Metallurgy

This text describes an experimental furnace designed for horizontal zone melting of silver:

- Three Molten Zones: The machine utilizes three distinct molten zones for the refining process.
- Electromagnetic Field: An electromagnetic field with a frequency of 70-140 kHz is applied.
- Induction Coil Potential: The induction coil operates at a potential of 45 volts.
- Power: Each molten zone is supplied with 2 kW of power.
- Induction Coils: Eight isolated induction coils are used.
- Coil Dimensions: The water-cooled coils have an internal diameter of 5 mm and an external diameter of 6 mm.



Mathematical electrothermal model: Tracks changes during solidification.

Periodic crystallization algorithm: Maintains electromagnetic force distribution, even with impedance changes.

Continuous crystallization algorithm: Maintains electromagnetic force distribution, even with varying ingot heights.

Experimental furnace

Induction system

Materials

Silver Jewelry and Dish Scrap

The scrap material consists primarily of silver alloy (92.5% Ag, 6.5% Cu) with minor impurities (less than 1%) of elements like Ca, P, Si, Cr, Ta, Mg, and Pt. To obtain more accurate segregation coefficients, the molten silver was intentionally contaminated with additional copper and zinc. Measurements were taken from the center of the silver bar. Zinc is a common contaminant in jewelry manufacturing waste due to its use in soldering processes.

Metal	1 area	2 area	3 area
Silver	73,6%	66,6%	51%
Copper	11,9%	14,3%	17%
Zinc	7,7%	5,5%	4,34%

Zone Refining Parameters

Molten Zone Velocity: 0.9 mm/min

Graphite Internal Power Sources: 900 W

Temperature: 1200 °C

Molten Zone Length: 35-50 mm

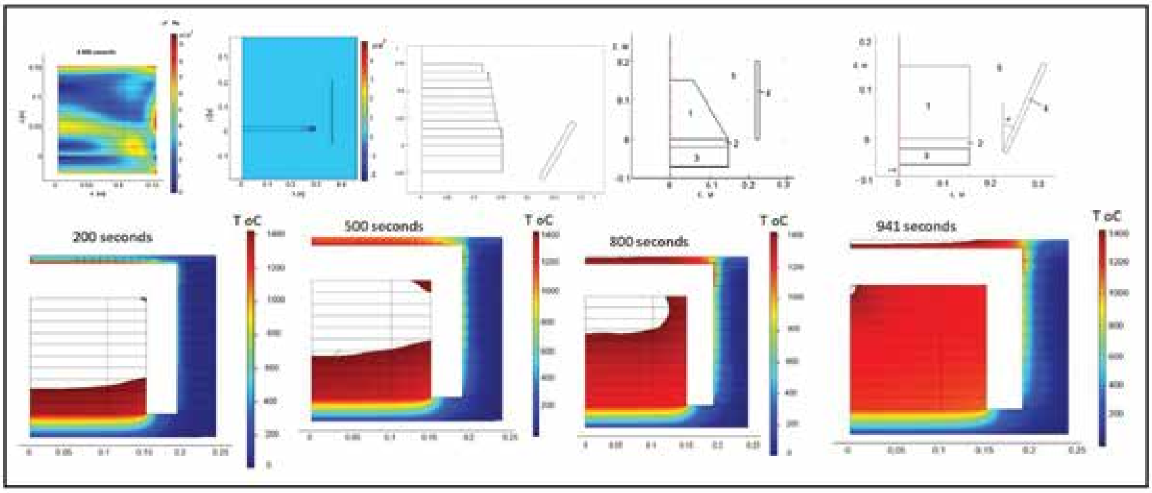
Number of Passes: 3

Commercial Silver Jewelry and Solar Panel Refining Using Vacuum Metallurgy

To develop a vacuum metallurgical recycling process for both jewelry and solar scrap, significant modifications to the electromagnetic field parameters and algorithms were necessary. Traditional flat induction coils were found to be unsuitable due to the high thermal conductivity of silver scrap and the need for multiple crystallization steps with impurity removal.

Algorithm Development and Simulation

These requirements led to the development of new algorithms for the induction system. Mathematical simulation models were created to predict the shape of the molten metal, compression ratio, internal heat source, process control algorithms, solidification direction, and velocity. By solving the system of differential electromagnetic, thermal, and hydrodynamic equations, a series of curves was generated that describe the conditions for levitational crystallization. The algorithms that control the sustainable operation of the electromagnetic coils are based on the relationships between system resistivity and voltage. The crystallization diagrams were designed to ensure solidification at a single point, concentrating impurities in a smaller area. For solar panel scrap, the crystallization process is designed to recover silver. In both silver and silicon solidification, the process should be terminated at the top of the ingot to create a specific area for impurity removal.



Parameter	Single load Electromagnetic system	Continuous Electromagnetic system
Load capacity	300 kg per hour	24 kg per hour
Ingot size	150 x 600 mm	150 x 300 mm
Inverter power	2 kW	80 kW
Electrical efficiency	0,3	0,35
Frequency range	450-500	450-500

Hermetically Sealed Crucibles: Minimal metal loss (less than 0.3%) is achieved using hermetically sealed crucibles.
Ultrasound Enhancement: Applying ultrasound at 1 MHz increases silver strength by 40%.
Impurity Removal: All precious metal impurities, except gold, can be effectively removed.
Product Range: The technology produces high-purity copper, silicon, and silver.
Process Acceleration: Creating multiple heating zones (5 zones, 1 kW each) speeds up the process.
Movement Speed: The heating zone moves at a rate of 0.5-1 mm/min.
Maximum Purity: The process can achieve a maximum purity of up to 99.999%.

Conclusion

Commercial Application Benefits:

- Minimal Metal Losses: Direct metal losses are reduced to 0.3%.
- Large-Scale Capacity: The crucible-free technology enables high-throughput processing.
- Reduced Carbon Footprint: The process has a lower environmental impact.
- Faster Scalability: The technology can be easily scaled up for increased production.
- No Companion Metal Loss: Copper and silicon are not lost during the process.
- High Automation: All processes are integrated within a single furnace, minimizing manual intervention.

Note: PhD thesis Dr. Ashot Navasardian