High Speed Bulk Plating for 50 to 500 Kilogram Loads

*Juergen Fischer**

Engineered Surfaces Center
University of North Dakota
Grand Forks, North Dakota, USA

Large charge, or loading, electrochemical plating of high purity aluminum on high strength steel screws proved to be unsuitable with a typical barrel plating process because of the lengthy plating time, and damage to the soft ductile pure aluminum screw coating caused during the process, especially on the edges and corners. Only small loads could be plated successfully in a plating barrel. A new device, described here, incorporates a perforated helical plating track which spirals upward along the outer perimeter of a vertical cylindrical tube, contained in a larger covered static cylindrical container. The lower part of the helical plating track is immersed in electrolyte. The upper part is where rinsing and cleaning of the plated products occurs. Part mixing is accomplished by specially designed overhanging steps in the helical plating track. The bulk product touches cathodic contact points imbedded in the helical track. Anodes are placed above and below the perforated plating track where plating current can reach the wide, evenly dispersed bulk from the top and the bottom. The vibration of the plating device is regulated so that an approximately 2-centimeter layer of product can be in constant contact with the cathodic contact points in the track. The gliding part movement on the track and the high plating speed ensures that damage of the sensitive soft aluminum coating is not significant. The layer of product moves upward at a speed of around 3 cm/sec on the nonconductive track. Near the electrolyte surface, a movable segment in the track directs the parts into a channel where they fall back to the lowest part of the plating helix and restart their way back up the helical plating track. The plating speed of this device reaches 80% of the rack plating speed and is four to five times faster than that of typical plating barrels because of its geometric advantages and the intense vibrational movement of the electrolyte. While the discussion here centers on the plating of aluminum from a non-aqueous electrolyte, the principles are directly applicable to most commonly plated metals from aqueous solution. A continuous flow zinc plating process would be possible with this technique.

Keywords: Bulk plating, large loads, barrel plating alternative, aluminum plating

Introduction

In response to hazardous material concerns, around 1980, the first countries started to ban toxic cadmium as corrosion protective plating for metal components. One alternative was aluminum plating. For aluminum plating technology to be economically successful, a bulk plating device accommodating loads up to 500 kg or more seemed necessary.

* *Corresponding author:*
Dr. Juergen Fischer
Engineered Surfaces Center
University of North Dakota
4201 James Ray Drive (Suite 1100)
Grand Forks, ND 58202
Phone: (701) 757-5144
Email: JuergenFischer@mail.und.nodak.edu

The intent was to enable screw manufacturers to plate their products including nuts and washers with aluminum with this device. Such large loading would ensure a reasonable cost for the plating. Large-load electrochemical plating of high strength steel screws with high purity aluminum has proven to be unsuitable with a standard barrel plating process because of the lengthy plating time involved. During the barrel plating process, damage was caused to the soft ductile pure aluminum screw coatings, especially at the edges and corners. Only loads lighter than 10 kg were successfully plated in a barrel.

A new bulk plating device was developed as described in several U.S. patents.[1-7] The design starting point was the vibrating basket from Vibrobot, SA** in which up to 15 kg of small sensitive parts could be plated quickly and evenly in bulk. This vibrating basket design moves parts in a circle by vibration. The parts are mixed by a ramp in the track. This general principal was incorporated into the design of our developed device (Fig. 1) for loads of around 500 kg. The plating device incorporates a 30-centimeter wide perforated circular helical plating track, having a 1.0- and 1.6-meter inner and outer diameter respectfully, that spirals eight times upwardly along the outer perimeter of a 0.9-meter diameter vertical cylindrical tube (similar to the flighting of a material handling auger), all contained in a larger covered cylindrical container. The lower five-eighths of the helix track is immersed in the electrolyte where the plating occurs. The upper three-eighths is where rinsing and cleaning of the plated products occurs. Mixing of the parts during plating is accomplished by ten specially designed overhanging steps in the helical plating track. The bulk product touches cathodic contact points imbedded in the helical track. The cathodic contacts are special screws connecting the plating track segments to the holders at the central pipe (Fig. 2). Anodes are placed above and below the perforated plating track where plating current can reach the wide, evenly dispersed load from the top and the bottom. The vibration of the plating device is regulated so that the product can be in constant contact with the cathodic contact points. To avoid contact between the vibrating center and the static outer vessel that

** *Vibrobot SA, Route des Provins 36, CH-2087 Cornaux, Switzerland.*

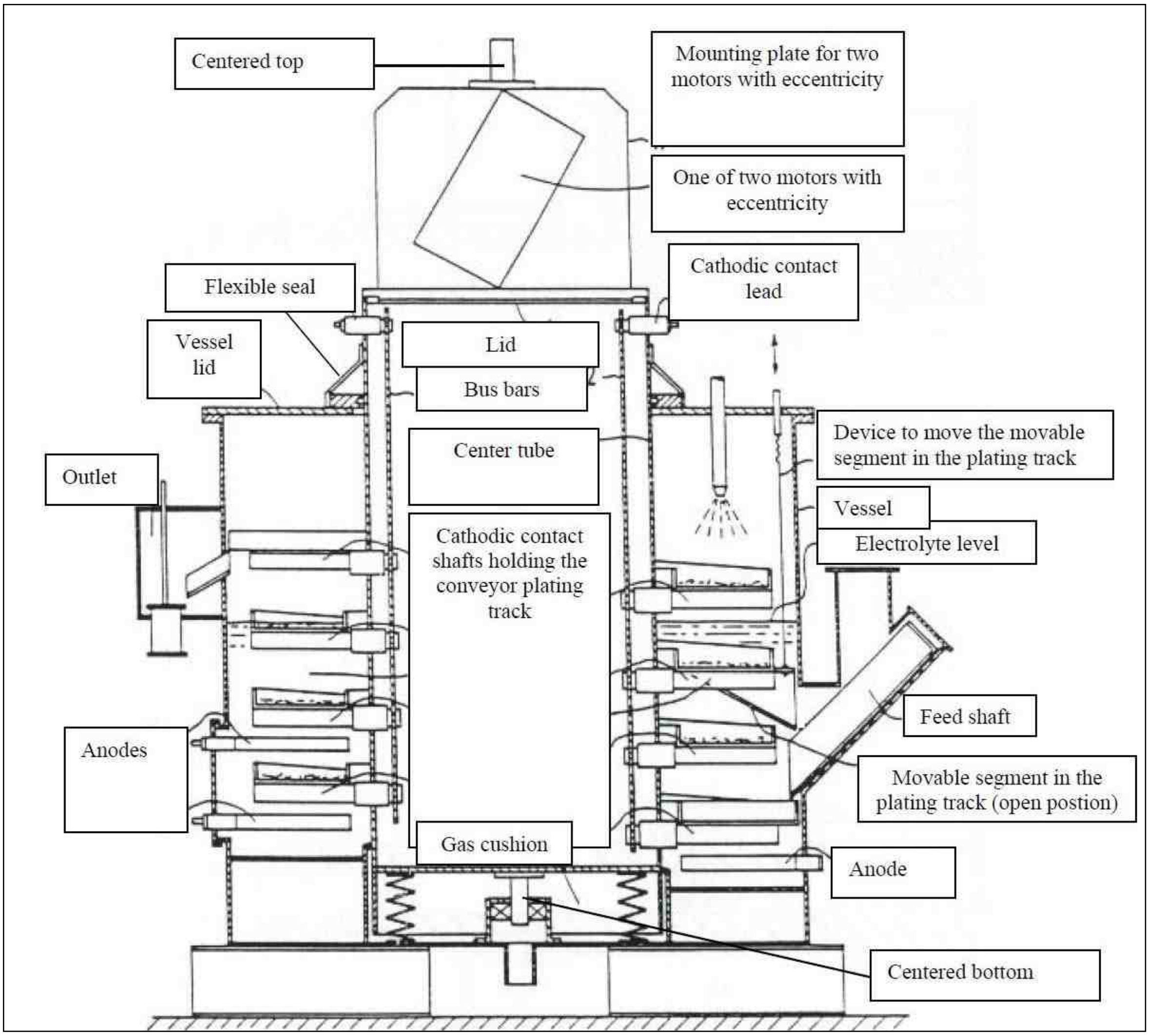

Figure 1 - High speed plating device for aluminum plating.

holds the anodes, the bottom and the top of the central tube is centered and held by static cylinders.

For this plating device, two of the largest motors with eccentricity available at that time were needed to overcome the damping of the liquid to the movement. This limited the size of the overall apparatus. Essential for the correct vibration was the approximately 25-centimeter nitrogen cushion (Fig. 1) beneath the central tube to ensure a sufficient vertical component of the movement. To protect the air and moisture sensitive electrolyte a tight flexible connection with the PTFE liner between the vibrating center tube and the static vessel was mounted.

The bulk moves upward and falls through an opening in the plating track onto the lower end of the plating helix. The opening is established by a movable track segment. The outer side of this element can be lowered (open) or pulled up (closed). When the plating is completed the vibration is stopped, the opening in the runway is closed and the electrolyte is pumped into a storage container. Then, at a higher vibrational frequency (20 to 25 Hertz), the plated product is conveyed up the helical track and sprayed with hot solvent to remove the electrolyte from the parts. At the top of the conveyor track, the moving product falls into a storage tank that is later evacuated to remove the solvent.

At this time, the patents[2-7] are the only published information about this research project. The development effort during that time is described with additional details in this paper.

Research and development performed

Material

The construction materials for the bulk plating device are subject to the properties of the electrolyte. These materials needed to withstand a potassium fluoride complex with aluminum alkyls dissolved in toluene at 105°C. Linen or cotton-reinforced phenolic resin showed the best performance for the perforated helical track that is subject to the abrasive action of the vibrating, rubbing steel parts in this chemically challenging environment. Harder glass fiber reinforced phenolic resin abraded more rapidly. The metal parts such as the vibrating center tube and the outer vessel body are electrically insulated by a coating of phenolic resin which contains around 50 wt% aluminum oxide.

Perforation of the conveyor runway

The perforations in the helical track are 2.5-millimeter diameter holes. The perforation area percentage must be high enough to ensure that the current from the lower anodes can reach the product evenly. Plating tests with flat panels as cathodes and various perforated resin plates were performed under aluminum rack plating conditions. The optimal distance between the cathode and the perforated metal plate was chosen to be 3 mm. Uniform plating of the metal plate was reached when the perforation ratio was higher than 35%, which was the value chosen for the perforation percentage of the plating track. No perforations were located near the contact points in order not to disturb plating of the contact point. Flat parts like washers will often have no distance between the moving work pieces and the track.

Contacting the bulk

The cathodic contact points in the 30-centimeter wide helical track are flat, round, 2-centimeter diameter screw heads. The contacts are 0.5 mm below the level of the track and surrounded by a 1-millimeter gap. This ensures that no plated aluminum from the contact points smears onto the plating track. Approximately six screws connect each track segment with the central tube as shown in Fig. 2. There is a row of contacts at about every 30 cm.

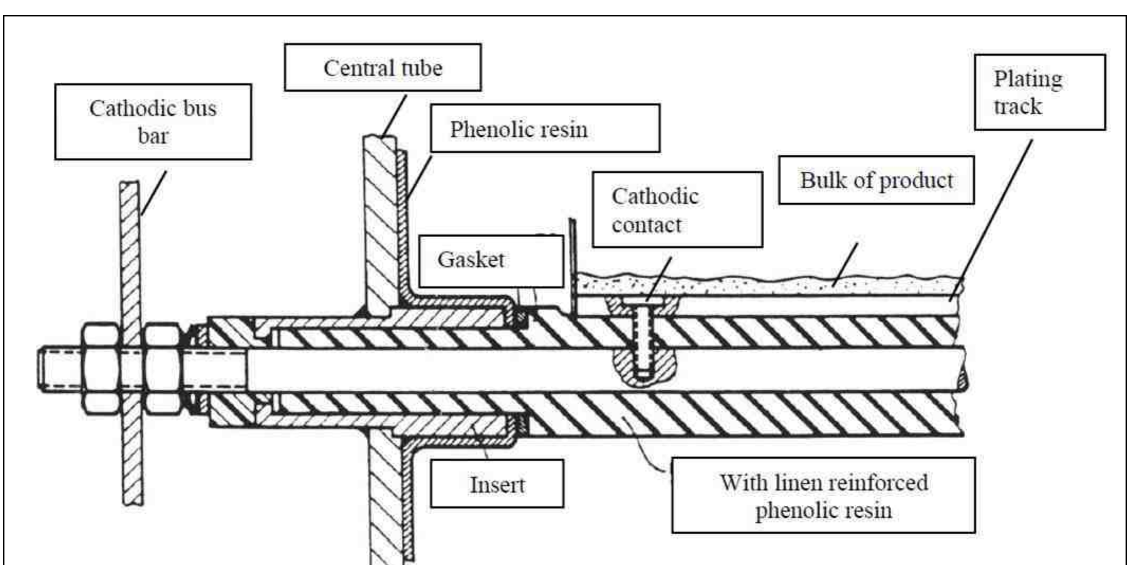

Figure 2 - Cathodic contact of the bulk product.

Special attention was needed regarding the careful adjustment of the movement of the plating device (angle, amplitude and frequency) and the ascending angle of the helical plating track. Because of the given product spectrum and the given general construction with the anodes above/beneath the helical plating track and the mixing steps, a minimum distance between the individual levels of the helix was determined. To get an upward movement of the material a minimum frequency and amplitude was required, which led to a minimum outer diameter of 1.6 m for the plating helix.

Tests were initially performed with vibrating helical devices in water, followed by zinc plating being investigated with vibrating conveyors. Subsequently, a small aluminum plating device, shown in Figs. 3 and 4, was built. The cell voltage during plating versus the frequency was measured for an amplitude of 3.7 mm (measured at the outside wall) and varying loads of M5×16 screws measured in product layers. The results are shown in Fig. 5. The operation frequencies for this plating device are near the 3 cm/sec dashed bulk velocity line for different loads (2 to 7 layers M5×16).

The optimal movement of the product was an upward gliding on the plating track, meaning the parts slid up the track and were not thrown upwards. There was a constant electrical contact between the cathodic contacts and the product and the damage caused by the movement was remarkably less than that encountered in a bulk plating barrel. To make similar movements occur in a larger version of the plating device, an amplitude of 8 to 12 mm (measured at the outside of the plating track) and a frequency around 14 Hertz was required. The product needed to cover the plating track evenly, which required an approximately 2-centimeter thick product layer. This resulted in five small parts layers such as short M4 screws or two layers for larger M10 screws. If the frequency is too low or the amplitude too short, the material coverage thickness of the plating track will vary. Below the mixing steps there will be more product per unit area and above the mixing steps there will be much less. If the contact points in this area are over-exposed, disturbing amounts of aluminum can be deposited on them and the load will not be well connected electrically.

After several plating runs in the 1.6-meter diameter aluminum plating device, unwanted dendrites grew on the vessel and the center tube where the insulating phenolic resin coating was not perfect or damaged. The dendrites disappeared after switching the vessel and the center tube to anodic polarity.

Movement of the parts in the vibrating plating device

The inner diameter of the 30-centimeter wide helical plating track was 1.0 m. The angle of ascent was smaller than 3.5° to ensure the upward gliding movement of the parts on the plating track and the even thickness of the bulk on the track.

Light flat parts were hard to convey because of their tendency to float. It is very difficult to transport spheres with this type of vibratory tracking. Also, shapes similar to spheres like short screws with a round head are harder to transport, especially after the plating is completed and the electrolyte is drained when the conveyor is to be cleared. This was accomplished at the highest frequency to shorten the process time and also minimize the plated material damage during this process step.

Figure 3 - Test apparatus for vibratory aluminum bulk plating without cooling equipment and storage tanks.

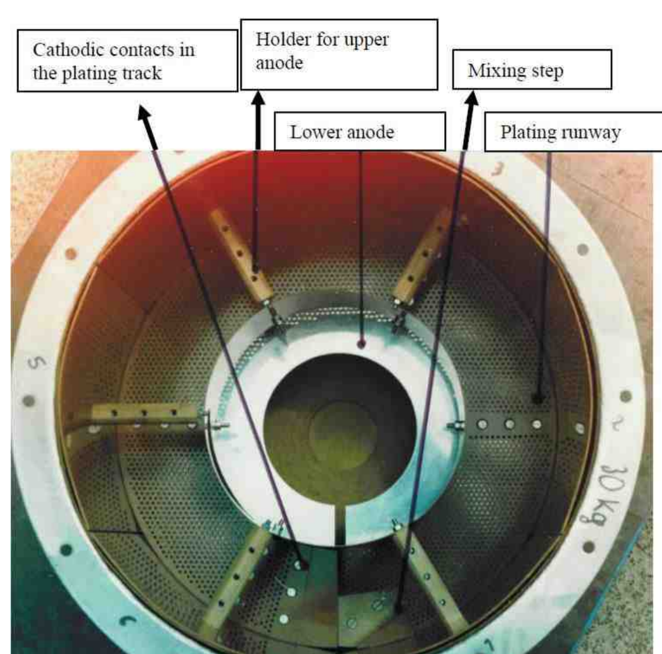

Figure 4 - View into the vibratory test plating cell without upper anode and inner sidewall of the plating track.

At the end of processing, single parts need to be cleared from the track. Bulk loading significantly improves the forward movement of parts. Single parts are harder to convey. They have the tendency to jump and dance on the plating track, sometimes with little tendency to move forward especially in the non-perforated area around the contact points. To give these parts more guidance and forward movement, the plating track was tilted 0.7° to the outside. This caused the single parts to go to the outside and the forward transport was improved. For example, a single medium long screw could roll on a horizontal helical plating track during transport. Since the plating track has tilt to the outside, the screw will roll outward where the amplitude is higher and the ascending angle lower. The wall will align the screw in the transport direction, making it close to impossible for the screw to roll. The screw will thus move forward faster. For some parts, tilting the track was not enough, and a groove in the outer part of the track was designed.

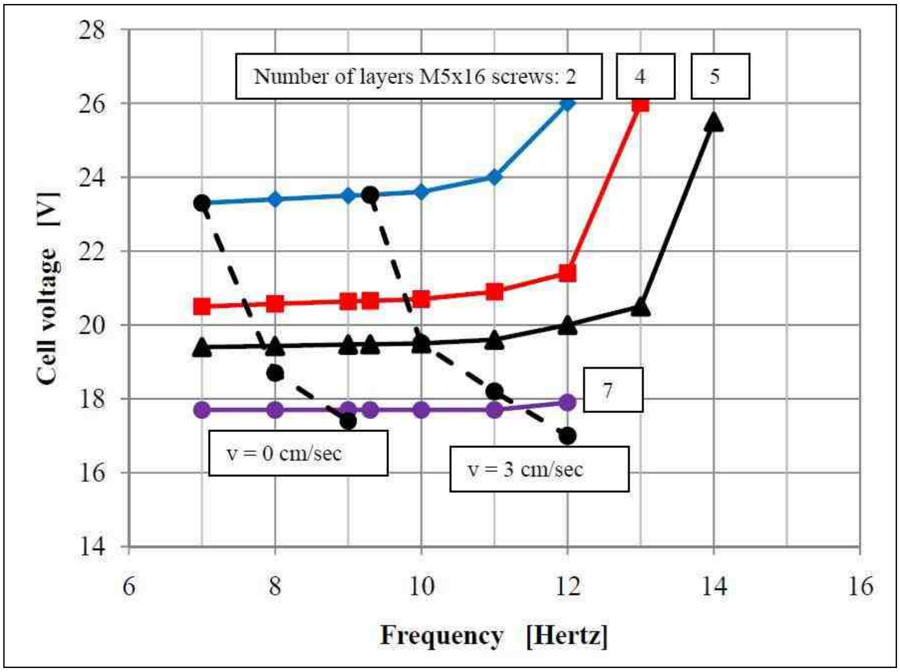

Figure 5 - Cell voltage versus frequency for different loads of M5×16 screws in the small vibrating test vessel for aluminum plating as shown in Figs. 3 and 4. The dashed lines mark where the parts start/stop moving (v = 0 cm/sec) and where they move at 3 cm/sec.

Occasionally, it was necessary to dump a chain onto the plating track at the end of the clearing sequence where the parts were cleaned with sprayed solvent and transported into the outlet vacuum chamber. The chain is as easy to transport as a bulk load of parts. With the chain, the remaining parts were wiped from the plating track.

During plating a variety of part motions is possible and everything possible will happen sometime. Long screws can stay vertical on the vibrating plating helix for a certain time. Thin parts or ridges could stick in the 1-millimeter gaps between the track segments or the gap around the contacting points. This barrier will block the product flow. To prevent a short circuit between the cathode and anode, the anodes are screened by a non-conductive perforated plastic plate, and the length of the products plated is limited accordingly.

The abrasive action of the steel parts on the phenolic resin plating track produced dust which fell through the perforation and partially on the flat anodes and the parts on the track beneath. It was important to circulate and filter the liquid ten times per hour to ensure smooth plating with pure aluminum. One-micrometer cotton filter candles were used. After 100 test runs, it was observed that the plating track wore out faster in the perforated area than in the non-perforated area around the contact points. Over time, the unevenness of the plating track will add resistance to the product flow and the frequency of the motors would need to be increased.

Borescopes in glass tubes were connected to cameras and monitors and provided a view of important areas in the plating device. It was important to ensure that the cathodic contact points on top of the mixing step were covered and the speed of the product was around 3 cm/sec. If the selected frequency of the vibratory motors was too low, there would be less product per unit area before the mixing step than after it and the speed of the parts was less than 3 cm/sec.

The motors with eccentricity limit the size of the plating device. If the plating track goes five times around the center tube and has an outer diameter of 1.6 m, two of the biggest motors with eccentricity available at that time were required to overcome the damping of the vibratory movement in the electrolyte and provide proper movement of the parts.

Intermixing of the bulk load

Intermixing of the bulk load occurred twice during one run around the central tube. First, the mixing was tested in the smaller plating device shown in Figs. 3 and 4. In Fig. 4, a mixing device can be seen that is similar to the construction of the commercially available vibrating basket. This turning baffle did produce resistance to the flow of the parts. To overcome that resistance, the frequency and amplitude were increased. This resulted in damage to the aluminum coating on the tips and corners during the plating process. After removing the turning baffle as a mixing device, this problem disappeared. However, the mixing by a simple step in the track was then insufficient. As the parts passed over the mixing step, the parts on top of the bulk load stayed on top and the parts on the bottom stayed at the bottom. Consequently, the amount of aluminum plated on the parts varied excessively. The plate thickness on many of the screws was either insufficient and these screws failed the salt spray test, or excessive and the parts did not meet the geometric specifications. The solution to this was a straight overhanging step where the parts fell onto a pile of parts where they could roll forwards or backwards. Perfect mixing also occurred when the parts fell from the upper plating level down the movable track segment and back to the beginning of the track. Overall, as a result, parts were plated much more evenly than in conventional barrel plating.

Plating speed

The average plating speed varied with the number of product layers on the plating track. The average plating speed was high if only two product layers were on the helical plating track, which was possible with larger parts like M10×20 screws. Small parts like M4×10 screws required three product layers to ensure that the parts moved properly and all the contact points were covered with product at all times.

The average bulk plating speed was approximately 80% of the rack plating speed because:

- there were only a few product layers on the plating track,
- the plating occurred from the top and also through the perforation from the bottom,
- the vibration ensured good electrolyte mixing at the part surfaces,
- the distances between cathode/product and anodes did not vary much at different places in the plating device, which led to a high average current density, and
- the throwing power of the electrolyte was good. In the case of the aluminum plating electrolyte the throwing power was comparable to an aqueous cadmium plating electrolyte.

This high plating speed did not change with the length of the plating track. It is fair to say that the plating speed in this device is four to five times higher than in a plating barrel handling the same amount of product.

Vibratory conveyor plating devices were built for bulk loads of around 500 kg, depending on the product and the number of product layers on the track. If the plating speed were as high as encountered in some zinc plating electrolytes, continuous bulk plating would be possible. The parts could be plated by running once through the device. In this case a solution must be found if the product needs to be switched and the different products are not allowed to mix.

Summary

High speed bulk plating was performed in a vibrating spiral conveyor. The conveyor was placed in a static vessel partially filled with an aluminum plating electrolyte. The perforated helical plating track was connected with cathodic holders to the vibrating center tube. The plating track was filled with two to seven layers of product. The anodes reach in between the spiral of the plating track. The even layer of widely spread out parts on the perforated plating track was plated from the bottom and from the top with a speed as high as 80% of the speed of rack plating. This was four to five times higher than the speed in a conventional plating barrel with the same amount of product. In some cases continuous bulk plating is possible with this device.

Acknowledgements

Thanks go to Siemens AG who granted permission to publish the research and development I performed in this area. Thanks go to my supervisor Siegfried Birkle and for the construction contributions to my late colleague Johann Gehring.

References

1. M.F. Nolan & E.J. Storie, U.S. patent 3,649,490 (1972).
2. S. Birkle & J. Gehring, U.S. patent 4,670,120 (1987).
3. S. Birkle & J. Gehring, U.S. patent 4,701,248 (1987).
4. S. Birkle & J. Gehring, U.S. patent 4,969,985 (1990).
5. S. Birkle, *et al*., U.S. patent 5,215,641 (1993).
6. S. Birkle, J. Gehring & W. Nippe, U.S. patent 5,244,564 (1993).
7. J. Fischer, *et al*., U.S. patent 5,496,456 (1996).

About the author

Dr. Juergen Fischer *is a Chemical Engineer with significant experience in both electrochemistry and chemistry. He is currently employed as a Senior Engineer with the Engineered Surfaces Center (ESC) within the School of Engineering and Mines at the University of North Dakota. Dr. Fischer started his career as a Chemistry laboratory assistant for BASF in Ludwigshafen, Germany. He then pursued his educational career earning his B.S. in Chemical Engineering at the Engineers School in Darmstadt, Germany, as well as his M.S. and Ph.D. in Chemical Engineering at the Technical University of Darmstadt in Darmstadt, Germany. Dr. Fischer was employed for eight years as an R&D Manager and Chemical Engineer at AlumiPlate, Inc. in Coon Rapids, Minnesota. Highlights of his career include R&D of advanced processes concerning water electrolysis, acid recovery and aluminum plating and chemical engineering for a water electrolysis plant, four aluminum plating plants, an acid recovery plant, and two recycling systems including vacuum rectification and evaporation. Dr. Fischer holds five patents / patent applications.*