Zero-Gap™ Cathode Technology

Décio Barros, De Nora do Brasil

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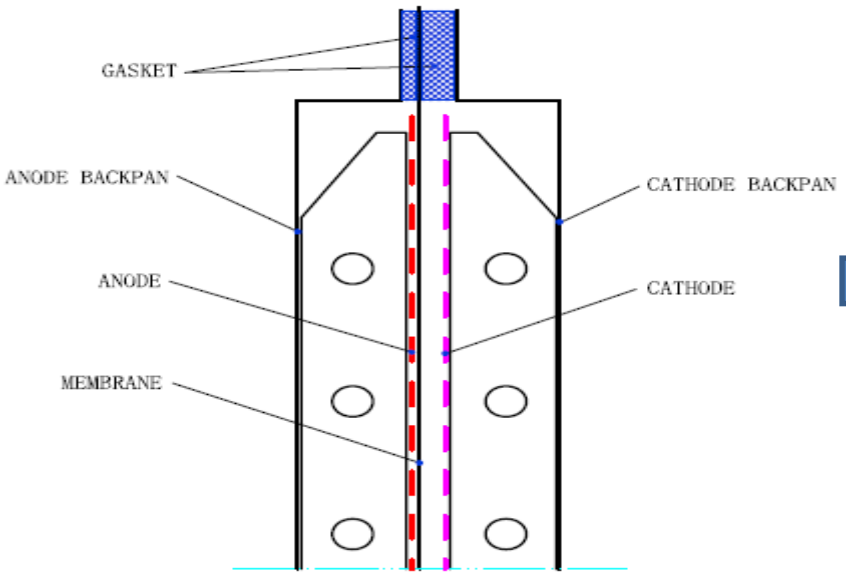
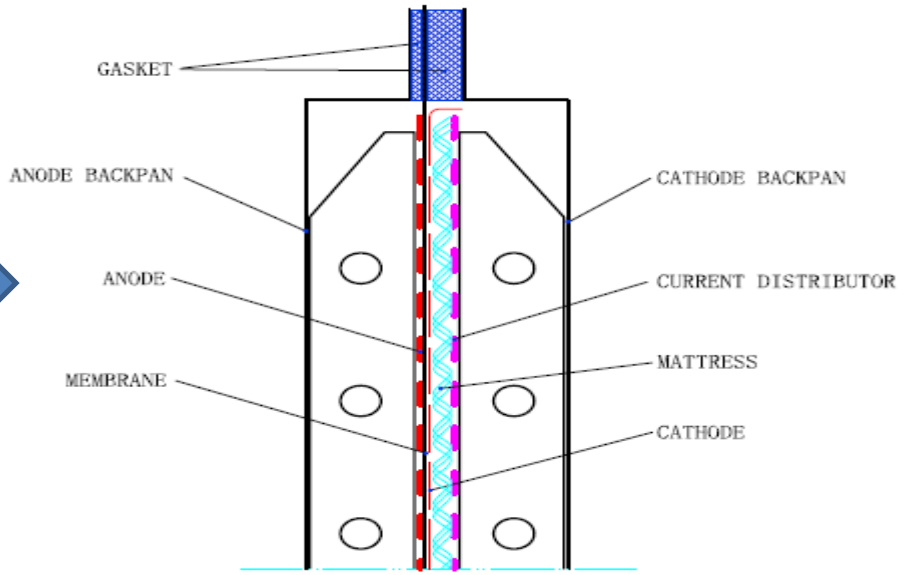
What is Zero Gap?

- De Nora – the original inventor of the cathodic Zero Gap configuration. The legacy comes back to the early ‘80s with the DD Electrolyzer.
- After it’s heyday in the ’80s and ’90s, when De Nora installed some million tons capacity, the technology was progressively fading in favor to the “narrow-gap” concept, allowed by the improved manufacturing techniques on bipolar elements .
- Since the mid ‘00s the Zero Gap concept is returning to it’s original prominence, benefiting from new design techniques, such as FEA analysis, and new cathode coatings specifically created for this application.

Comparison in IEM cell between FG and ZG



Schematic of Finite Gap



Schematic of Zero Gap

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Zero Gap Retrofit Purposes

- **Reducing the gap between anode and cathode**

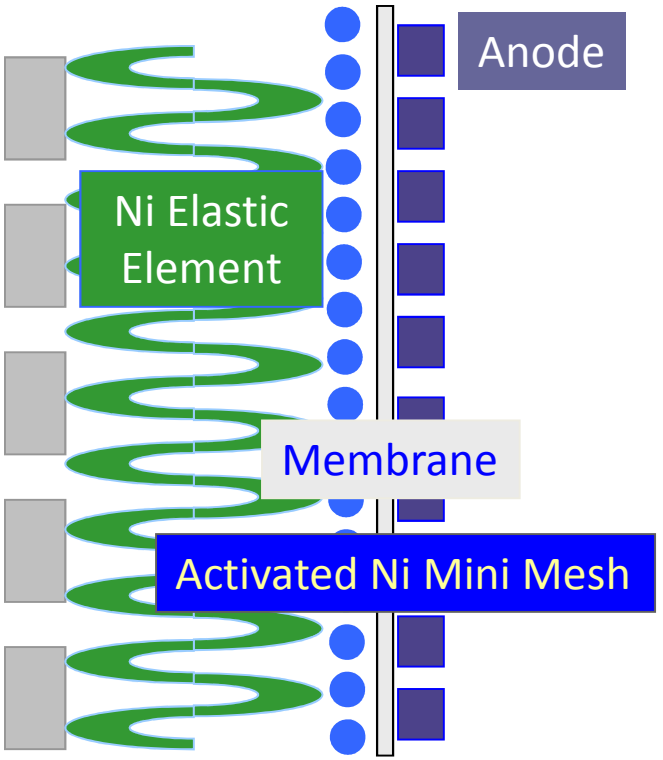
After ZG Retrofitting, both anode and cathode surfaces are in contact with the membrane, i.e. electrode gap equals to membrane thickness.

- **Achieving uniform current distribution**

The original anode and cathode mesh are not fully flat, this is creating some non uniformity in the current distribution. The elastic element can adjust its thickness following meshes profile, so the gap between anode and cathode is kept uniform.

Zero Gap Retrofit Concept

Zero Gap Configuration



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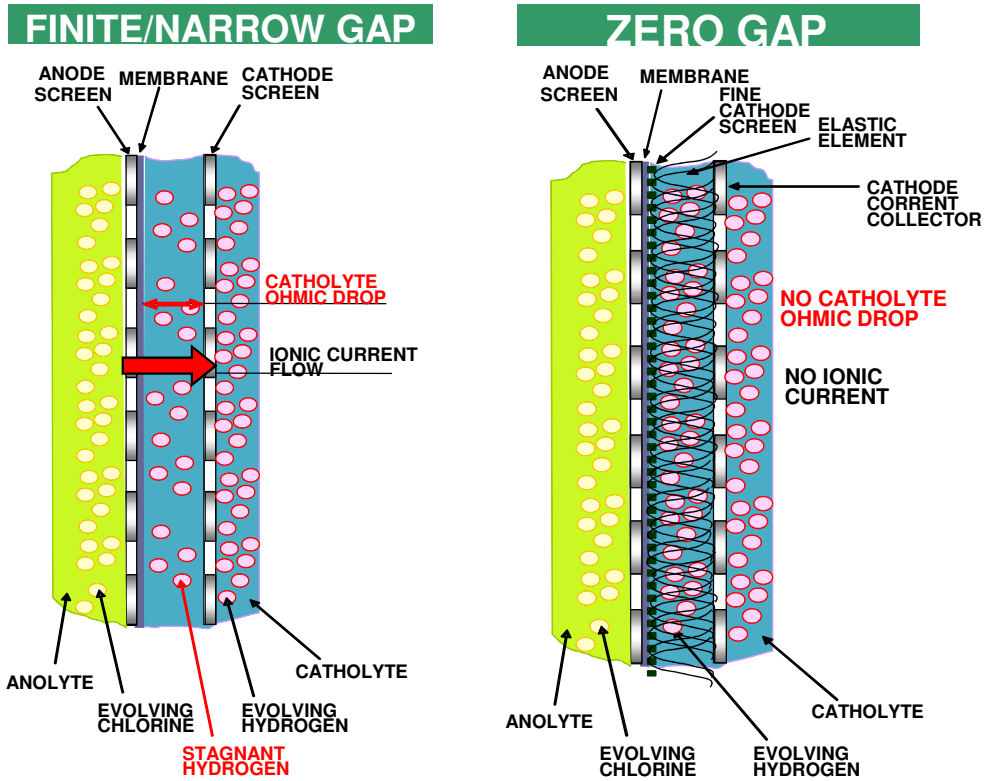
How Zero Gap concept works?



- Zero Gap totally removes the ohmic drop related to ionic transport through the catholyte gap
- That is obtained by installation of a package:
  - The old cathode screen is used as **current collector**
  - A **fine cathode screen** shifts up to gently touch the membrane
  - In between them an durable **elastic element** is inserted, to transport electrons by contact from the current collector to the fine cathode screen, and capable of compensating for mechanical tolerances with no harm for the membrane

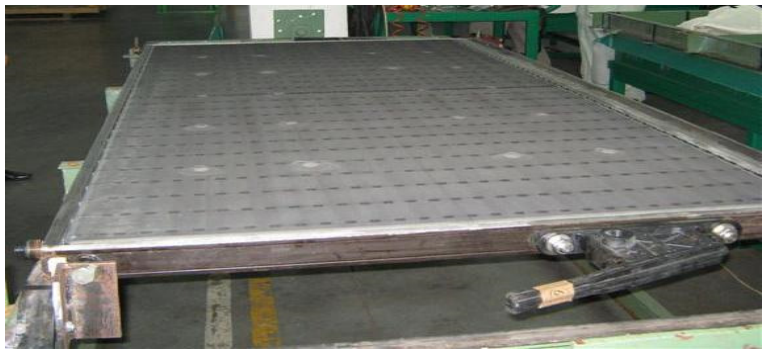
Zero Gap Retrofit – Technical Aspects

- Cathodic side
  - Elastic element fills the gap between cathode and membrane.
  - Low hydrogen evolution voltage cathode
  - Suitable for electricity conduct from current distributor to activated cathode.
  - No high pressure on membrane
  - Elasticity can last long time
- Anodic side
  - Anode configuration is the same as for usual remeshing procedure (no structural or performances change).

Zero Gap Retrofit package components

Current Collector

- **Original cathode** is used as a **current collector**
- Its functions are to provide proper **mechanical support** for the elastic element, proper **electrical contact** and proper shape to **allow hydrogen gas bubble release** to the back/bulk of cathode chamber.
- In few cases it is not suitable for all functions. Then it has to be replaced.
- In most cases it is sufficient to clean it and optionally remove old coating in a few spots for elastic element welding.



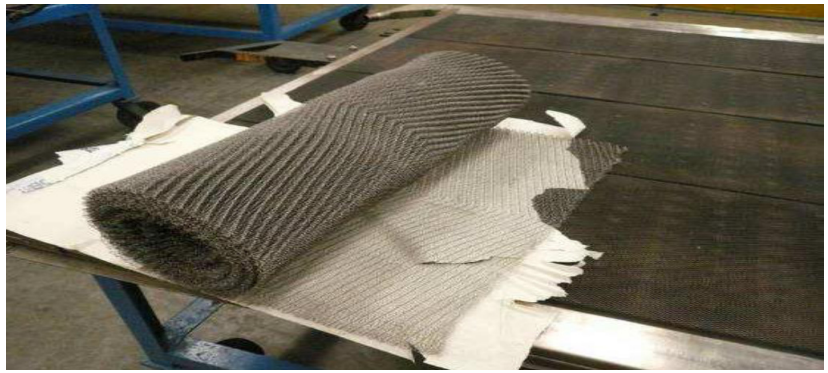
Zero Gap Retrofit package components

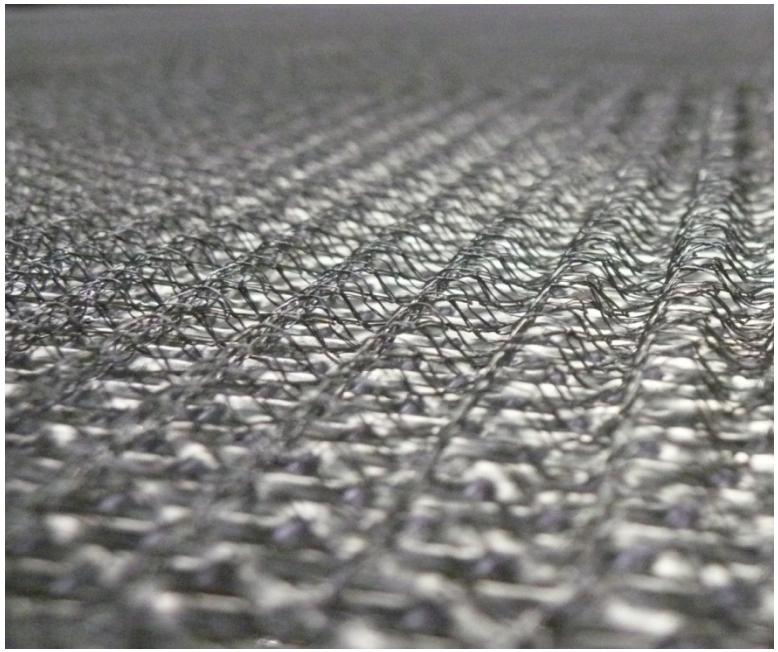
Role of the Elastic Element

- Elastic Element design plays a fundamental role.
- It is composed by a complex array of metallic wires, profiled in a precise shape to create the proper **elastic response**, needed for a **good electrical contact**.
- Construction characteristics are dosed, tailored to **fit different available gaps** (from 2.5 to 5 mm), aiming to deliver a constant and gentle mechanical pressure onto the membrane with no harm for its mechanical integrity.
- Elastic properties are selected in order to optimize both electrical contact and **good resistance to pressure fluctuations or reverse pressure** (e.g. during uncontrolled shutdown).
- The metallic wires pattern acts as **hydraulic means**, not preventing the mass transfer of NaOH and discharge of H_2 gas bubbles, so not disturbing the control of caustic soda concentration gradient onto the membrane surface, useful to keep optimal operating conditions and current efficiency in lifetime.

Zero Gap Retrofit package components

Nickel Elastic Element

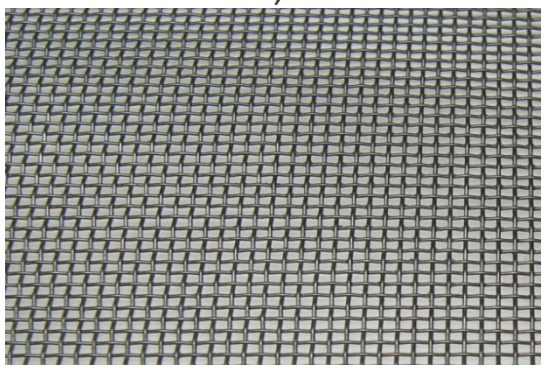


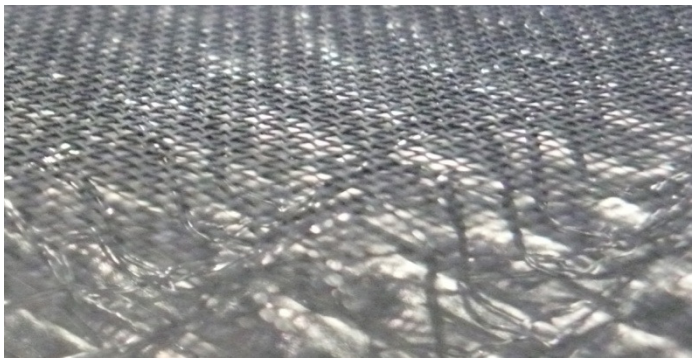


Zero Gap Retrofit package components

Cathode activated fine screen

- It is **not just a substrate** for cathode coating
- It is a component with specific **morphology and mechanical characteristics** to be coupled to elastic element and cope with the existing operating conditions and anode geometry
- Stiffness, wire diameter and weaving pattern are optimized to obtain mechanical intimate Zero Gap across the entire surface, so to secure best current distribution and **best utilization of last generation membranes**, thus best cell voltage

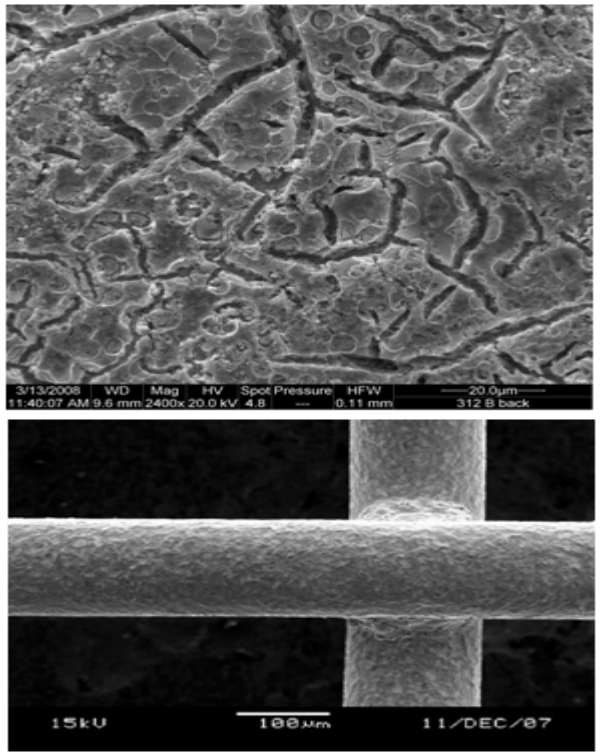




Zero Gap Retrofit package components

Cathode coating: a superiority factor

- **The most important factor** for effective durable energy saving
- Adapted to specific customer's conditions:
  - Current Density (from <3 to >6 kA/m^2)
  - Polarization (from no protection to highly protected)
  - Fe pollution (from tens to hundreds of ppb)
  - Cell configuration (monopolar or bipolar)
  - Load shedding (yes or not)
- All coatings are proven on industrial basis:
  - Noble Metals based
  - Designed to be offsets resistant (current reversal and catholyte poisoning)
  - Long durability of performance
  - High quality and industrial reproducibility
  - Multiple sites manufacturing
- All coatings derive from the recognized experience of De Nora as worldwide technology leader in electrochemistry



Zero Gap Retrofit – Achievable Targets

- Reduction of the electric path between the Membrane and the cathode: reduces the liquid electric resistance

Saving: 25mV for 2 mm Gap @ 4.25 kA/m^2

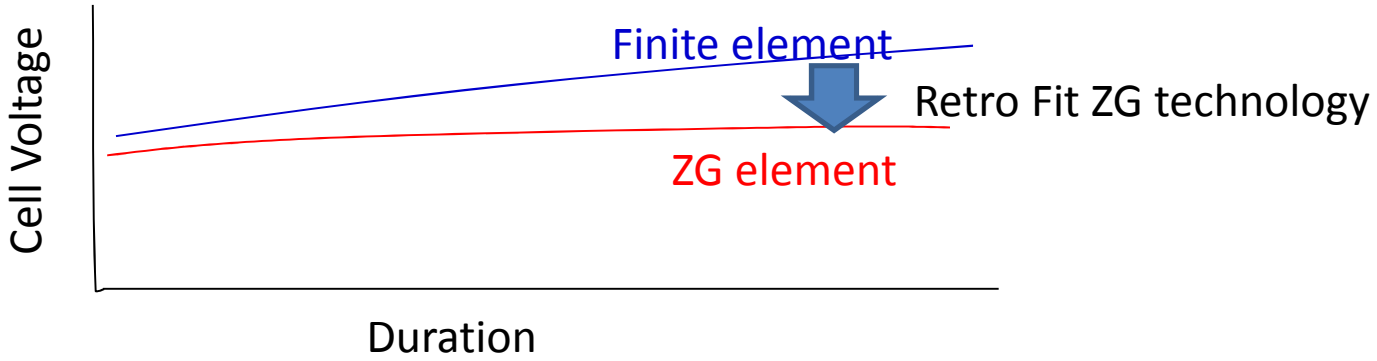
- Reduction of “bubble effect” by pushing the hydrogen gas bubbles on the rear (see next slides)

Saving: 60 mV @ 4.25 kA/m^2

- Obtaining more homogeneous current distribution through uniform gap between anode and cathode

Saving: 15 mV @ 4.25 kA/m^2

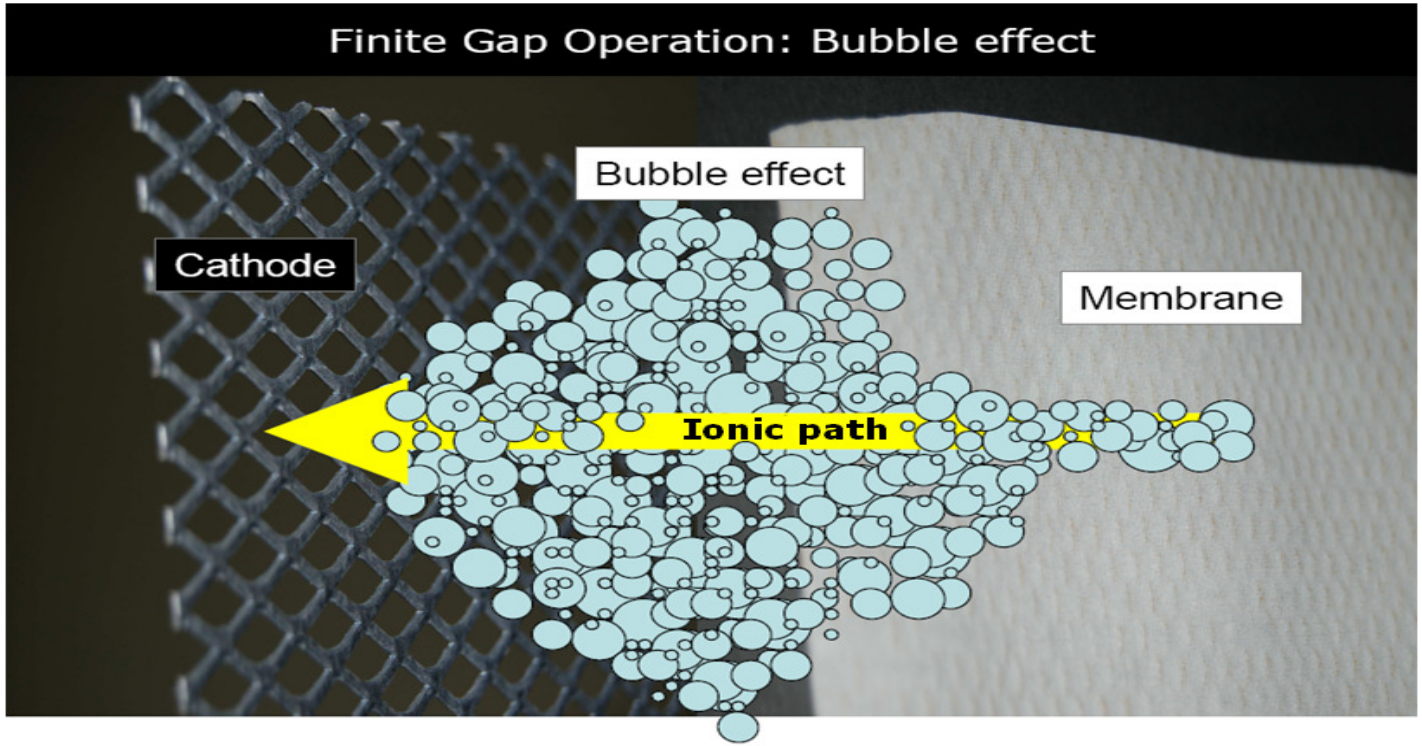
Targets and benefits



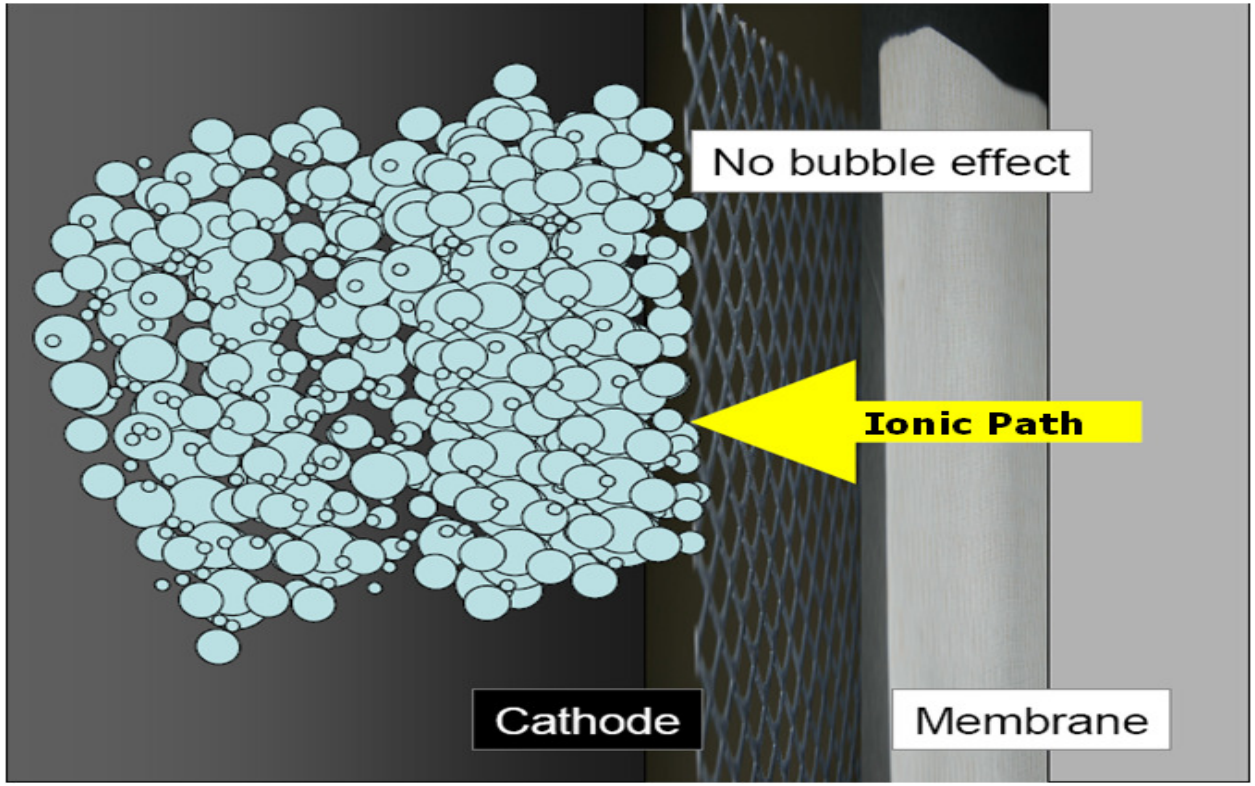
- Objective:
  - Reduction of Cell Voltage in old generation cells
  - Minor modification, with lower costs
  - Durable performances in the time
  - No modification for original process

- Timing:
  - Remembrane , Recoating

Zero Gap Retrofit – Bubble Effect (1)



Zero Gap Retrofit – Bubble Effect (2)



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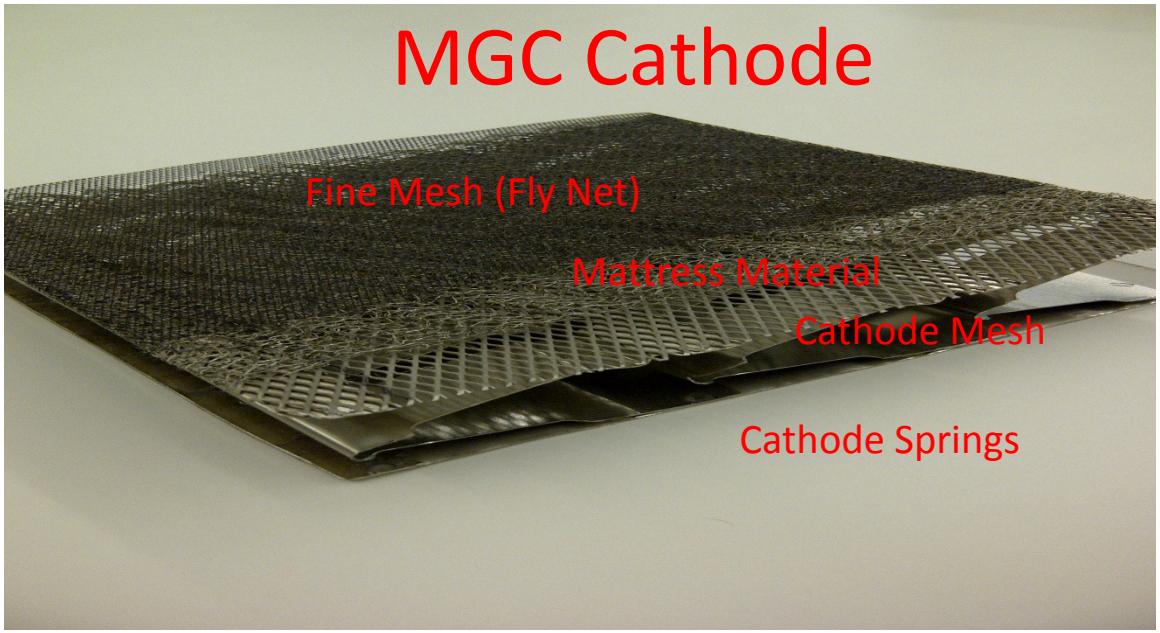
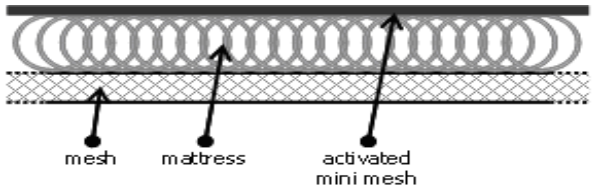
MGC Electrolyzer

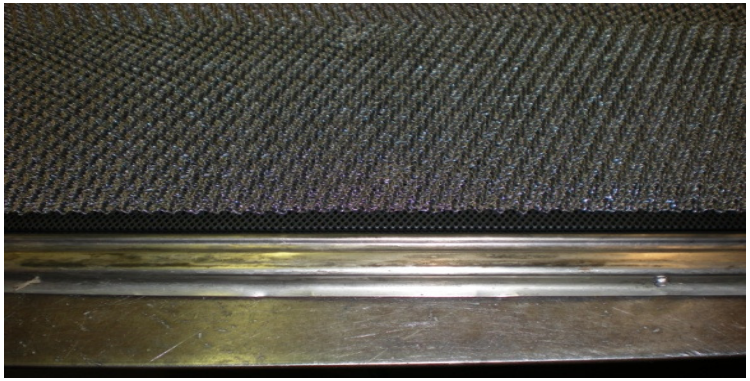
- ZG Design





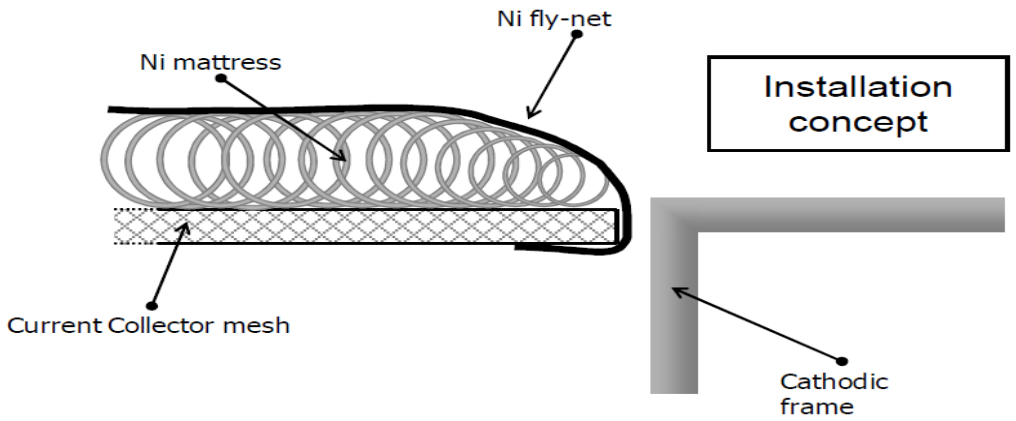
MGC Electrolyzer

- Components
  - Nickel Mattress: assuring a perfect “zero-gap” condition between cathode mesh and membrane (“Tailor Made” for each plant)
  - Activated Flynet: fine woven mesh, activated with a MMO coating specific for “zero-gap” applications, positioned on top of the Nickel Mattress



MGC Electrolyzer

- Easy Installation concept



- No change on the element structure

MGC Electrolyzer

- Assembling of mattress (spot welding in some points, local removal of old coating)

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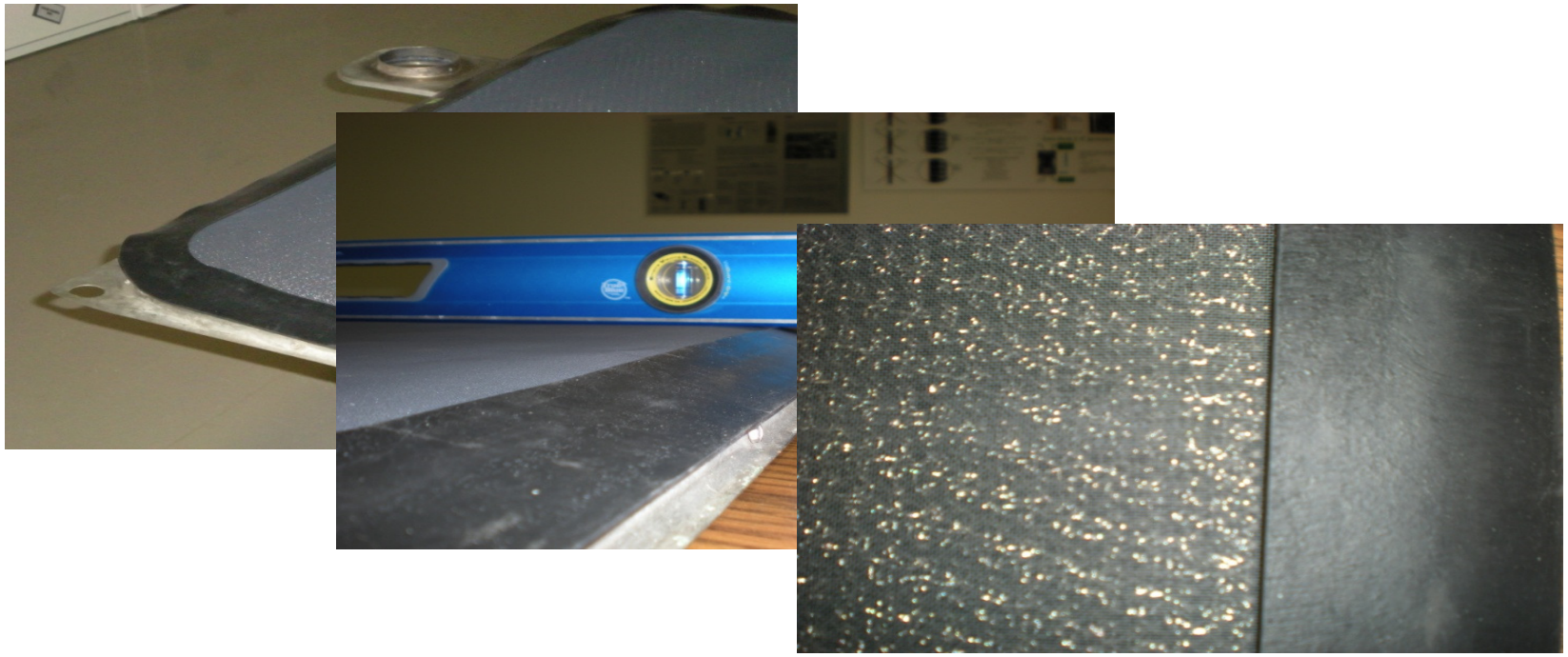
MGC Electrolyzer

- Assembling of activated flynet (insertion and bending below mesh)

MGC Electrolyzer

- Gasket installation



ZG Retrofitting Installation Summary

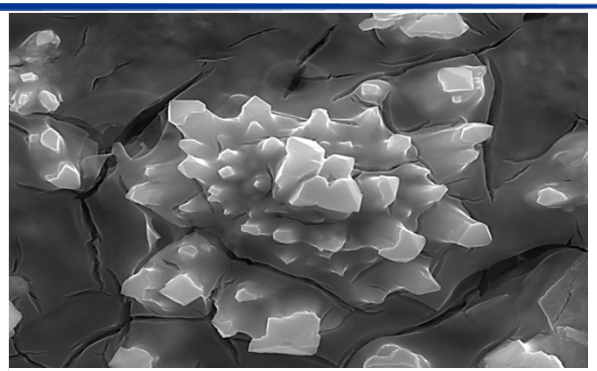
- Anode remeshing is like normal recoating procedure.
- Original cathode mesh is maintained and used as current distribution. No need of coating.
- Mattress is fixed on current distributor by resistant welding.
- Possible to retrofit cathode package on site.
- Flynet is installed on mattress. Welding is not used for Flynet.

Zero-Gap MGC - Characteristics

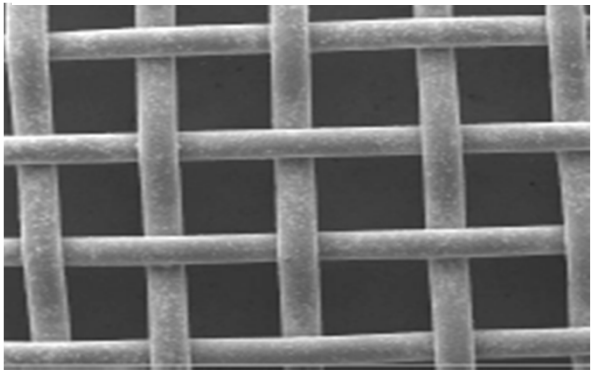
- Compensates for Fatigue of Cathode Springs
- Flat Cathode Profile – No “Pinch” Points
- Improved IR Drop (Anode-Cu Voltage)
- Cathode “Recoating” done by replacing Flynet at Site
- Coatings for Polarized and Non-Polarized Cell Rooms

NRG® family: Uniqueness

- Innovative precursor complexes
- Coating matrix without Nickel
- Pre-oriented crystal lattice
- Enhanced surface coverage
- Improved activity, stability and robustness to process upset
- Advanced manufacturing technologies
  - Strict control of parameters
  - Narrow distribution, homogeneity
  - Optimal utilization of the catalyst all over the surface



Enhanced catalytic sites



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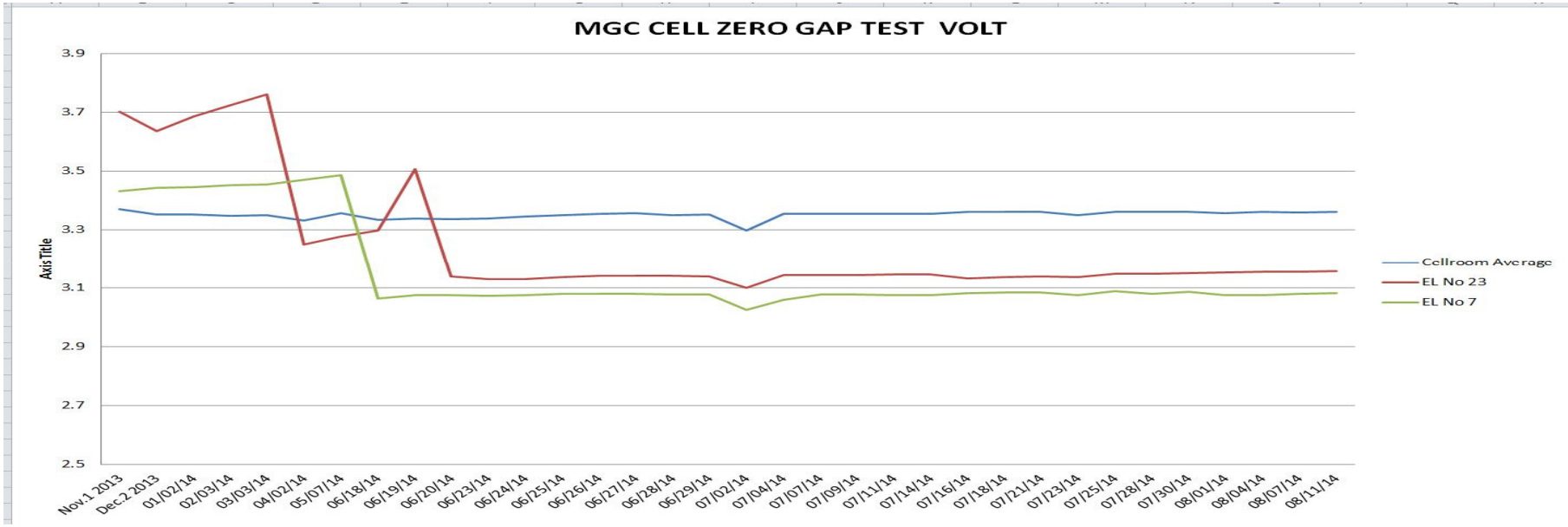
Commercial Reference ZG retrofit on MGC Electrolyzer



- Electrolyzers on line – 15 months
- Voltage savings ~ 190 mV @ 4.25 kA/m2

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Zero Gap Retrofit main features

- Zero Gap has a great opportunity for Power Saving, typically

  8-10% lower consumption than original figures

- Zero-Gap **MUST** be based on top quality components

- ✓ To overcome the risk of corrosion during shutdown

- ✓ To prevent mechanical stress and damage of the membrane by a gentle and even pushing of the fine cathode onto the membrane surface (and in same time resistant to reversal pressure fluctuations)

HOW?

- With De Nora specific cathode coatings, capable to secure reliable and durable power saving even at extreme operating conditions

- With De Nora Zero Gap retrofit package, suitable to be adapted to a plurality of technologies and electrolyzer models

Thank you for your attention

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