WHAT IS THE BEST MAINTENANCE STRATEGY FOR MEMBRANES AND ELECTRODE COATINGS IN CHLOR-ALKALI?

White Paper

INTRODUCTION

In the chlor-alkali industry, the maintenance of membranes, anode coatings, cathode coatings, etc can rapidly become challenging, especially for plants with many cells. Determining which membranes or coatings should be replaced, and when, is no easy task. Furthermore, with the hundreds of thousands of dollars or millions of dollars typically devoted to maintenance each year in a plant, depending on its size, engineers and plant managers are under scrutiny to demonstrate the effectiveness of all the money spent in maintenance.

With customers in chlor-alkali worldwide, R2 is uniquely positioned to identify the major maintenance strategies used in plants and assess their effectiveness. This white paper will first review the major maintenance practices seen in the chlor-alkali industry for membranes / anodes / cathodes: breakdown maintenance, preventive or time-based maintenance, and predictive or condition-based maintenance. It will also highlight the advantages and disadvantages of each of them. It will finally discuss the right KPI for maintenance.

MAINTENANCE STRATEGIES IN THE CHLOR-ALKALI INDUSTRY

In a recent survey of 232 European manufacturing and transport companies, Siemens and the CXP Group found that "93% of companies describe their maintenance processes as not very efficient which means there is plenty of room for improvement"[1]. This explains why so many companies are evaluating new maintenance strategies like predictive maintenance, especially those in the process industry.

Maintenance strategies in chlor-alkali can be broadly classified in two categories: reactive maintenance and proactive maintenance. Reactive maintenance consists in performing maintenance/replacement only when a failure occurs, while proactive maintenance aims to perform maintenance before a failure occurs. Proactive maintenance can be further broken down into preventive and predictive maintenance.

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[1] *"Digital Industrial Revolution with Predictive Maintenance", CXP Group and Siemens; Dr Milos Milojevic, Industry Analyst and Frank Nassah, VP Digital Business Innovations; May 2018, https://www.plm.automation.siemens.com/media/global/en/PAC_Predictive_Maintenance_Siemens_Executive_Summary_2018-71130_tcm27-33237.pdf*

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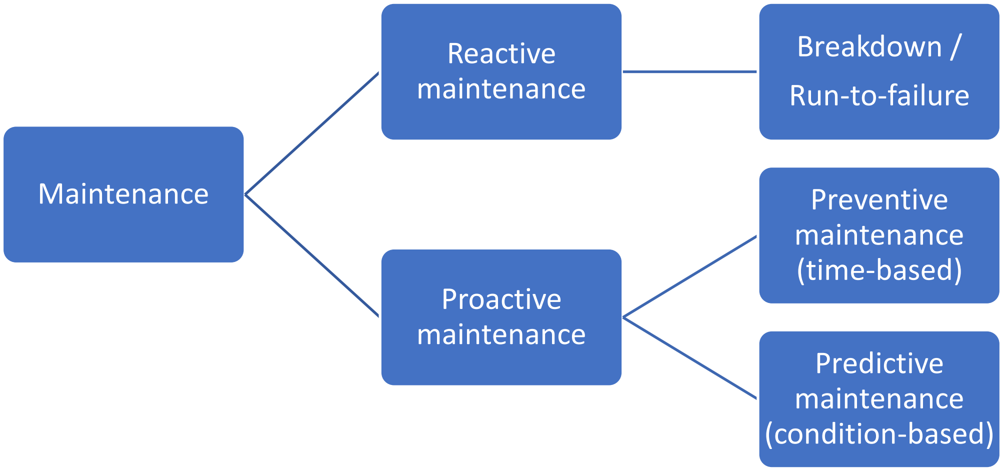

Figure 1: Maintenance Strategy Types

Reactive maintenance or breakdown maintenance

Maintenance engineers will usually apply a reactive maintenance strategy for non-crucial parts when failure has a low impact and cost. This approach involves letting the part run until it experiences a failure and then fixing it. Reactive maintenance is logistically very simple to implement, but the financial and operational impact of a sudden, unplanned process interruption due to a part failure can be tremendous. Operating a cell with a very degraded membrane / cathode / anode presents a high safety risk. For instance, an electrode with a highly degraded coating might lead to irreversible cell damage. **Therefore, almost no plants apply a pure breakdown maintenance strategy: they typically apply a mix of breakdown maintenance for less critical components with other maintenance approaches for more crucial components like membranes and electrodes.** Many maintenance engineers use breakdown maintenance to handle membranes with severe pinholes: as soon as they find out about the defective membrane, they will add it to the maintenance tasks during the next shutdown, or even shut down the electrolyser immediately in extreme cases.

Preventive maintenance or time-based maintenance

This strategy entails performing maintenance activities at fixed time or usage intervals, for instance every 6 months or after 1000 hours in service. A good example is changing the oil of a car every 10 000 km. Preventive or time-based maintenance will usually follow the manufacturer recommendations. On the positive side, time-based maintenance typically decreases maintenance costs versus reactive maintenance because maintenance activities are planned and not rushed, and it also reduces failure occurrence. On the negative side, preventive maintenance requires more planning than reactive maintenance, and parts might be replaced before their end of life.

Some chlor-alkali maintenance engineers use time-based maintenance and apply coating/membrane manufacturers recommendations to replace membranes roughly every 4 years and anode/cathode coatings every 8 years. **Although it is a better approach than breakdown maintenance, preventive maintenance fails to capture potential savings brought by individual cell analysis.** Indeed, depending on energy costs, chlor-alkali producers can save energy and/or increase throughput by replacing

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underperforming membranes with low current efficiency more often than the typical membrane lifetime period. Because of the high costs of electrodes and membranes replacements and the high energy consumption of electrolysis, preventive maintenance is not the best maintenance strategy for chlor-alkali.

Predictive maintenance or condition-based maintenance

Predictive maintenance tries to predict the failure before it happens by monitoring the part condition or performance, rather than using expected lifetime statistics. In the car example, instead of replacing the oil every 10 000 km, predictive maintenance recommends taking oil samples at regular intervals and replacing it when it goes below a threshold. This maintenance methodology is usually applied to critical assets that have significant repair costs or that have important impacts on the process should they fail.

The advantages of predictive maintenance are:

- Saves maintenance costs
- Decreases unplanned shutdowns due to sudden asset failure
- Reduces unnecessary replacement of healthy assets
- Increases throughput, thanks to higher asset availability

The disadvantages of predictive maintenance are:

- Requires more planning (time and effort)
- Requires personnel training to analyse the part condition data

Maintenance strategy	Description	Pros	Cons
Breakdown / run-to-failure	Maintenance when the part breaks	Simple to implement	Increases unplanned shutdowns Costly
Preventive / time-based	Maintenance at fixed time or usage intervals	Lower maintenance costs Reduced failure occurrences	Requires planning Parts might be replaced before end of life
Predictive / condition-based	Maintenance based on the part condition	Lowest maintenance costs Less unplanned shutdowns occurrences Increased throughput	Requires more planning Personnel training

Figure 2: Pros and Cons of Maintenance Strategies

Since it is the method that decreases the most the maintenance costs and the frequency of unplanned shutdowns, **predictive maintenance stands out as the best maintenance strategy for critical parts such as anodes/cathodes coatings and membranes, but this approach works only if the right key performance indicators (KPI) are used.** R2 has unfortunately seen too many plants using the wrong KPI, leading to the wrong decisions.

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PREDICTIVE MAINTENANCE WITH THE RIGHT KPI

Cell voltage for condition-based maintenance: a wrong KPI

Many plants use cell voltage for their maintenance. They will identify the outliers, the cells with very high voltage versus the others, and replace the anode and cathode coatings and the membranes of those cells. **This approach is flawed, because it fails to determine which component (anode, cathode, membrane) causes the high voltage.** In many cases, replacing only one of the 3 components is sufficient to bring the voltage down significantly. Assuming replacement costs of US $1500 per membrane, and US $2000 for an electrode recoating, a good maintenance of the cell can sometimes be achieved with only $1500, instead of $5500 (membrane + anode + cathode replacement).

In more technical terms, high voltage can stem from a high U_0 (the y-axis intercept of the cell projected voltage/current curve) or from a high k (the slope of the voltage/current curve), as shown in the equation below

$$U = U_0 + kj$$

where U is the cell voltage and j stands for the current density. A high U_0 generally originates from a cathode coating aging, while a high k value arises from anode or membrane aging. **U_0 and k are therefore much better KPIs for maintenance than cell voltage since they enable one to determine what asset causes the high voltage.**

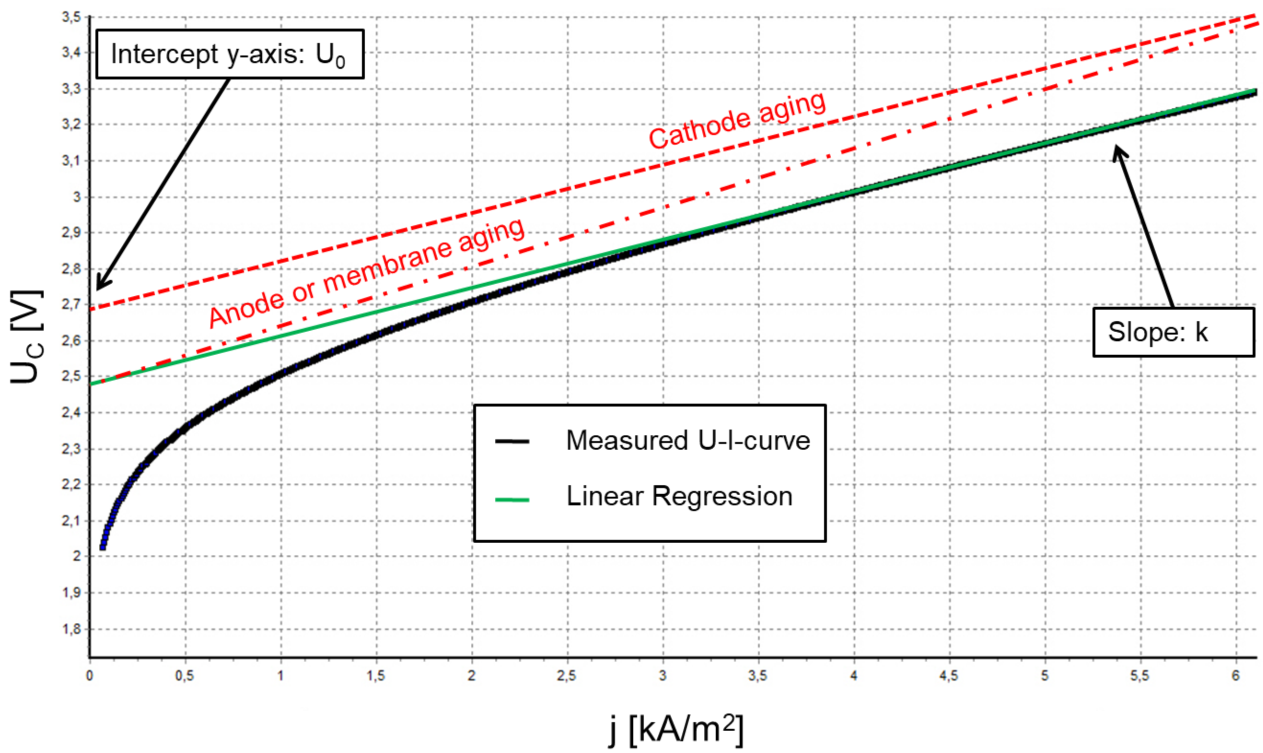

Figure 3: Cell Voltage Causes

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Specific power consumption for condition-based maintenance

Reducing cell voltage should not be the end goal of maintenance engineers: it should be to lower specific power consumption (SPC) and maximized throughput, and cell voltage is only one of their determinants. The power required to produce one ton of soda can be computed with the formula

$$SPC\left(\frac{kWh}{ton\ soda}\right) = \frac{U}{F \times CE} = \frac{U_0 + kj}{F \times CE}$$

where U is the cell voltage, CE is the current efficiency, F is the Faraday constant for NaOH (1.4923 kg/kAh) and j is the current density. Current efficiency, expressed as a percentage, is the amount of product actually produced divided by the amount of product that should have been generated in a perfect cell. **We therefore see from this equation that the best cell KPIs for maintenance purposes are U_0, k and CE, because they directly determine the specific power consumption.** However, there exists an even better approach to maximize the payback of maintenance budget: predictive maintenance with economics simulation.

Predictive maintenance with economics simulation

The only ingredient missing from using SPC for condition-based maintenance is that this method does not take into account the financial aspects of maintenance, such as replacement costs. Excluding heavily degraded assets that pose safety risks, which should be replaced right away, the decision to replace an asset should be driven by two factors:

- The extra cost to operate a degraded asset versus a new one, in terms of additional electrical consumption or lost production
- The cost to replace it (cost of the new asset + labor)

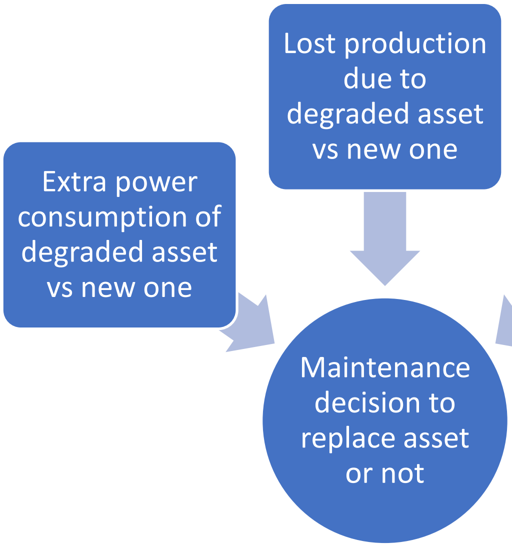

Figure 4: Predictive Maintenance with Economics Simulation

This is exactly what predictive maintenance with economics simulation does, by determining for each asset a replacement return on investment (ROI), which is calculated using the formula below:

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Replacement ROI = annual energy savings of new asset vs old one
+ annual increased production of new asset vs old one
- asset replacement cost (including labor)

Accordingly, several "what if" scenarios can be simulated so that underperforming assets (i.e., those with bad U_0, k and CE) can be replaced as soon their performance degrades, whereas overperforming assets can be kept longer than the recommended manufacturer lifetime.

R2'S CELL PERFORMANCE ANALYZER

R2's Cell Performance Analyzer (CPA) service was designed to enable chlor-alkali plants to run predictive maintenance scenarios with economics simulation, in order to maximize the payoff of their maintenance budget. Since each plant is unique in terms of production capacity, price per ton of soda and chlorine sold, etc, all these parameters are fully customizable. Moreover, R2 is able to analyze individual chlor-alkali plants to quantify the potential benefits of applying predictive maintenance.

Figure 5 depicts an example where membranes with a 2% loss in current efficiency are considered as underperformers. Here, 12 membranes should be replaced, generating production cost savings of US$ 33 000 / year, which represents savings of US$ 594 000 for the whole cell-room with 18 electrolysers.

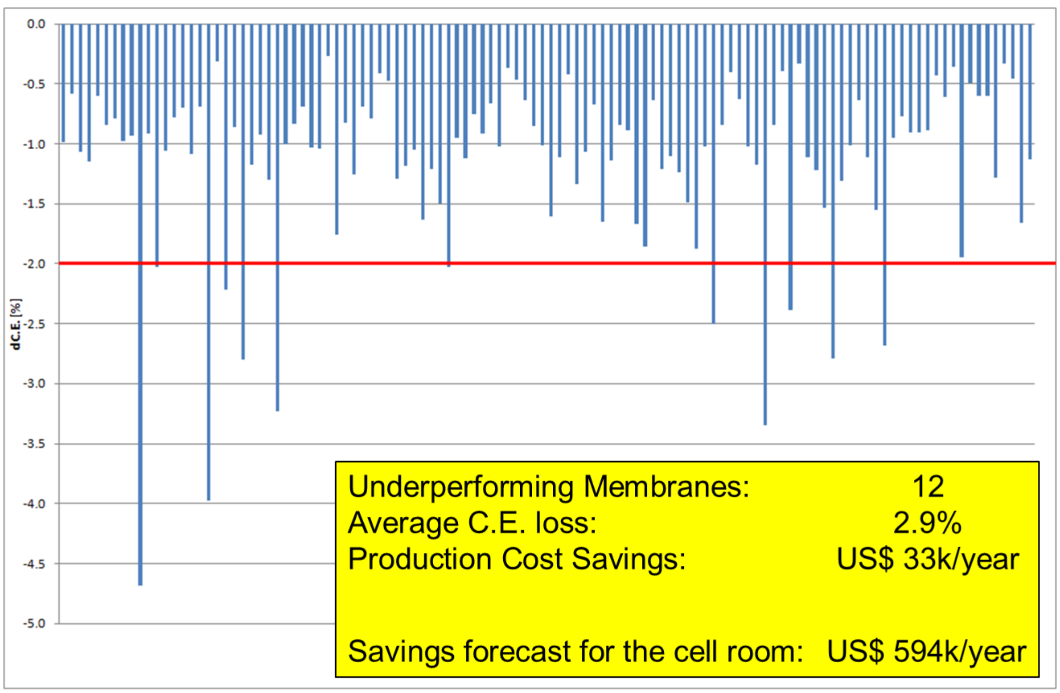

Figure 5: Example of Savings Offered by Replacing Underperforming Membranes

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CONCLUSION

This paper introduced the different maintenance strategies used in the chlor-alkali industry: breakdown maintenance (run assets up to failure), preventive maintenance (replace assets at specific time intervals) and predictive maintenance (replace assets based on their condition). While breakdown maintenance can be used for non-critical assets or for unplanned situations (e.g., severe pinholes in a membrane), predictive maintenance should be used for critical cell-room assets like membranes or electrode coatings in order to reduce maintenance budget and maximize its effectiveness. Preventive maintenance is an in-between, offering easier implementation, but higher maintenance costs than predictive maintenance.

This paper then demonstrated that cell voltage alone is not a correct KPI for maintenance decisions, because it fails to determine which asset (membrane, cathode, anode) brings about the degraded cell performance. The right KPIs for predictive maintenance are U_0, k and CE, since they allow for determining which asset is causing increased specific power consumption and/or decreased production. These KPIs should then be included a financial simulation that takes into account the asset replacement costs, as well the higher energy consumption costs and the lost production revenue of using a degraded asset versus a brand-new one. This is exactly what R2's Cell Performance Analyzer does.

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