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Technical Reference

Topic: Electrocoating with TECTRON™ Membrane Electrode Cells

Electrodeposition (electrocoating or E-coat) is a well established, widely used process for painting metal. This process uses an electrical charge to deposit an organic coating on a conductive substrate with the use of DC electricity. In a typical system, the voltage is held constant and the total electrical current will vary proportionally with the amount of paintable surface area. Electrocoat systems are used as a primer or finish coat in almost every area of metal finishing, including the appliance, automotive, and industrial markets.

Many advancements have been made in equipment design over the years, but the fundamentals of the process have not changed: Pre-treat, Application, and Curing. The remainder of this discussion will focus on the Application process as it applies to E-coat, and why it is important to have a quality Membrane Electrode Cell system in the paint tank.

BOX CELLS vs. TUBULAR CELLS

The traditional means of applying E-coat paint has been to use bare stainless steel plates as the opposing electrode. Later came the anolyte system, which included the use of membrane sheets placed in front of the bare plate to allow anolyte solution to reside between the membrane and plate. The membrane is attached in front of the plate by means of a bolted rubber gasket seal around all four edges of the "box". Thus, the term "Box Cell". However, this method does not produce any flow in the dialysis medium. The purpose of using membrane between the electrode and the paint bath is to control the paint's pH (or acid balance) through an electro-chemical process called electro-dialysis.

The most obvious disadvantages with the box cell are its weight and size. An overhead crane is required to install or remove the box cell for maintenance. This takes excessive time and manpower. Also, when one box cell stops functioning, a great deal of electrode area is lost, thus, hindering the system's ability to deposit enough paint on the product. This also causes the other cells to generate excessive heat due to high current densities. Box cells are notorious for leaking around the gaskets. This is caused by higher current densities around the edges of the plate, associated heat, and wear at the edges. Box cells are not very consistent in the amount of acid they remove due to the inconsistent flow patterns throughout the interior of the cell.

In more recent years, the tubular anode cell has been introduced to the market. The tubular anode cell has not changed the basic concept of electro-dialysis, but it has drastically revolutionized the efficiency of the application process. It should be noted that there is nothing subtle about the differences between tubular anode cells designs. There are some very important technical issues that warranted the development of the tubular cell. Unless those issues are addressed in the design of the tubular anode cell, then its improvements over the box cell are merely cosmetic.

TUBULAR MEMBRANE ELECTRODE CELLS

Four important characteristics to observe when considering the purchase of a tubular membrane electrode cell are: **Inner Support, Flow**, **Membrane**, and **Steel**.

Inner Support

It is important to have a uniform and consistent flow around the entire electrode in order to flush out oxygen molecules that cause pitting in the stainless steel. This will also provide cooling for the electrode and remove bacterial matter, which can obstruct flow. In addition, the UFSc TECTRON patented inner support design provides a medium for strong consistent flow between the membrane surface and the inner support structure. This will prevent iron oxides from forming a layer on the surface of the membrane. A layer of iron will create more than enough resistance to restrict the flow of electrical current.

The patented design of the UFSc TECTRON inner support is what holds the geometric shape of the membrane shell structure as well as providing a means of separating the inside surface of the membrane from the support grid. This is done with molded plastic ridges that run parallel to the length of the tubular support grid. This is important to ensure that the anolyte flow is able to flush away iron deposits between the membrane and the inner support grid. When a stainless steel electrode wears, iron is drawn out of the stainless steel into the anolyte solution within the anode cell. Since this iron carries a positive charge and is in soluble form, much of it migrates toward the membrane. Some passes through the membrane, and the remainder attempts to form a layer on the inside surface of it.

It is important to flush this soluble iron away before any iron oxide build-up occurs on the membrane surface. This iron oxide sludge layer will present a significant amount of electrical resistance over time on the surface of the membrane. This drastically hinders the power transfer characteristics of the anode cell and causes it to run very hot.

Flow

UFSc injects the anolyte solution into the TECTRON Membrane Electrode Cell through the center of the electrode with a ring seal at the bottom. This patented method forces the liquid upward evenly around the entire electrode, flushing out the unwanted elements, thus causing the UFSc TECTRON Membrane Electrode Cell to last two to three times longer than any other anode cell on the market.

Good cooling and circulation will maintain the integrity of the membrane for longer periods of time in addition to keeping the inside surface of the membrane clean. This will minimize the electrical resistance of the membrane and, in turn, minimize power dissipation. When power is dissipated in the membrane, the cell is loading the circuit and using up energy that is not being delivered to the work package.

Membrane

The quality of the membrane plays a crucial role in the performance of the anode cell. Its intended purpose is to remove acid and pass electrical current. The electrical resistance and pore size of the membrane will vary between anode cell manufacturers. UFSc uses a high quality membrane material that provides premiere operating characteristics, including ultra-low electrical resistance and superior consistency in its chemical selectivity. This gives the anode cell extremely efficient electrical power transfer and chemical transfer characteristics.

Steel

UFSc stainless steel electrodes are tubular and are made from Schedule 40 stainless steel pipe. The electrode fits inside the membrane shell and is then submerged in the paint bath. The anolyte supply tubing goes down the center of the electrode and is sealed at the bottom with a C-ring on the inside of the pipe. This is also a patented feature of the TECTRON Cell. We normally use Schedule 40 electrodes because they last longer and only cost an additional $3 per linear foot compared to Schedule 10.

> **NOTE:** When using stainless steel 316L bare electrodes (floor or side), make sure no more than 15% to 20% of the total anode area is bare. This "rule of thumb" is used for three reasons:
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> 1. Stainless steel electrodes give up their iron content when they degrade in an E-coat application.
> 2. Using too much bare anode area and not enough flushable anode area may hinder the system's ability to remove enough acid from the paint bath; therefore, making it difficult to control the pH.
> 3. Iron loss is greatly accelerated at higher current densities (above 5 amps per square foot).

IRON CONTAMINATION

Excessive iron content in the anolyte fluid is not caused by high conductivity; rather, high conductivity is a symptom of excessive iron content and/or low anolyte pH. The higher the iron content, the darker the anolyte fluid, and the higher the conductivity.

Iron contamination can result at very low parts per million levels (i.e. approximately 20 ppm) when using acrylic or light colored paints. Darker cationic epoxies are not as sensitive to iron but still have unique acceptable iron level limitations. Even though bare electrodes offer advantages from a throw-power perspective, their use must be limited to keep acceptable levels of soluble iron in the E-coat paint bath. Contact your paint supplier for assistance in this area.

Check with your paint supplier about using a "nitric acid based" additive in the anolyte system to prolong the life of the electrodes. This additive will protect the electrodes from irreversible corrosion, which is caused by chlorides that reside in D.I. water systems. Nitric acid will form a wax-type layer on the stainless steel, which prevents chlorides from attaching themselves to the electrode's molecular structure.

In the case of using TECTRON flushable anode cells, the majority of the iron content is flushed away by the anolyte fluid. Therefore, only small traces are allowed to enter the paint. This flushing advantage applies only where UFSc TECTRON cells are being used. However, since all membrane is porous, iron transfer can never be completely eliminated.

Ruthenium oxide (RuO) coated titanium electrodes are used when iron contamination is of great concern such as when using cationic acrylic paints. They are also used when consistently operating at high current densities (perhaps above 5 amps per square foot) and when using lighter colors. Ruthenium oxide is an inert material and withstands higher temperatures for longer periods of time. Since it does not contain iron, the anolyte solution will be transparent and the purity of the paint bath is unaltered.

On the downside, ruthenium oxide electrodes are about two to three times the cost of stainless steel and carry a six to eight week lead-time. They must also be handled very carefully to prevent scratching the ruthenium oxide coating. If the coating is scratched or gouged, the electrode must be replaced since bare titanium will burn up almost instantly.

MEMBRANE ELECTRODE CELL MAINTENANCE

The inevitable question will always arise, “How do I know which cells are working and which ones are not?” This is a situation that has traditionally plagued the E-coat industry. However, there is a way to prevent the need to ever ask this question. Electrical current through each individual anode cell must be monitored.

By measuring only the total electrical current and displaying it on the front panel of the DC rectifier power source, the total load on the family of anode cells in the system can be evaluated. However, evaluating the total load says nothing about how this electrical current is distributed. The only way to evaluate the performance of the paint “application” process is to measure and record the electrical current through each individual anode cell in the system. Without this information, the “application” process is really running blind.

It is important to understand that the anode cell is not the load. The part being painted is the load. Therefore, all the anode cells work together to pass the electrical current to the part being painted. This makes it very important to the cell’s performance to have a membrane with a very low electrical resistance. Otherwise, the anode cell will load the circuit and electrical power is dissipated within the membrane. This is a waste of energy and is very costly over time.

If one or more cells fail (meaning little or no electrical current flowing), the surrounding cells must pick up the extra load. When the cells are allowed to operate at these higher current levels or densities, the electrodes will rapidly deteriorate and the electrical resistance of their membrane will rise at a faster rate because the membrane is burning up. This causes a domino effect that will eventually destroy every anode cell in the paint tank unless a Current Monitor™ system is installed.

This is why electrical current in each anode cell is monitored. If this practice is not used, then troubleshooting lends itself to guesswork. In a downtime situation, this guessing approach is very expensive. By monitoring the electrical current through each individual anode cell, these problems will never occur.

On a monorail system, the anode cells at the entrance to the tank will draw much more electrical current than those in other locations since the electrical resistance of a bare metal part is much lower than that of a part that has been coated with paint. However, on a program hoist system, the electrical current through each anode cell should be close to the same since all the cells are approximately equidistant from the part being painted. However, if the performance of one or more anode cells begins to drop off, the system will become unbalanced and the currents will no longer be equal. When this occurs, the domino effect still applies.

It is important to remember that anode cells do not draw any current. They simply allow electrical current to pass through on its way to the work-piece being painted. Therefore, the actual load is the work-piece. The work-piece gradually becomes insulated by the layer of paint that is deposited on the metal surface. Thus, the voltage drop across the paint layer on the work-piece will start out at a minimum and reach a maximum as deposition time expires and film thickness increases.

Each cell in the E-coat tank is wired in parallel with the rectifier. Individual current paths from each cell to the work-piece are actually series circuits within a parallel branch. This means that the current passing through each cell is the same current that passes through the paint bath and through the film when the work-piece passes in front of that cell. Therefore, if the cell is not passing current, the cell will not cause any paint to be deposited on the work-piece.

Since current flow is a linear function with resistance, the user can now determine the exact resistance of the series path between the electrode and the part being painted. This is accomplished by using Ohm's Law which states E=I x R where E=Voltage, I=Amps, and R=Resistance. To determine the total resistance of a series branch, simply divide the rectifier (or zone) voltage setting by the individual cell's amp draw (i.e. R=E/I). The result is: high current = low membrane resistance, low current = high membrane resistance.

Every cell competes electrically with the resistance of the paint bath and the film layer, therefore electrical resistance of each individual cell's membrane becomes the only significant variable. The resistance of the paint is very low, while the resistance of the film layer is initially low but becomes very high as paint deposition progresses. With new TECTRON Cells, the majority (about 98%) of the voltage supplied by the rectifier is dropped across the paint film layer. The remainder (about 2%) of the voltage is dropped across the membrane. These ratios have been tested by various paint manufacturers in a laboratory setting and are known to be true.

A high series resistance taken into consideration with film thickness and voltage setting is enough information to determine the approximate electrical resistance of the membrane. The end-user can then determine the optimum time for replacement of membrane shells. This practice will fine-tune material costs, maximize energy efficiency, determine optimal conveyor speed or dwell time, and maximize production.

While the resistance of the paint film increases with thickness, the voltage dropped across the film will increase and the current through the film will decrease. If the work-piece were left in the tank indefinitely, the resistance, current, and voltage will eventually stabilize at the paint film layer and work will cease. (This would be an extreme case since most dwell times do not exceed 3 minutes.)

To overcome problems with achieving sufficient film build, the E-coat system operator has traditionally increased the voltage setting on the rectifier to overcome the resistance in the membrane. There is nothing wrong with this as long as the operator knows the electrical limitations of his system. This information can only be obtained by monitoring the electrical current through each cell in the paint tank. (Remember: the electrical resistance of the membrane increases with age.) There will always come a time when increasing the voltage will no longer work. Eventually, the electrical resistance of the membrane in each cell will be so high that even the maximum voltage setting on the rectifier will not be enough to push a sufficient amount of current through the cells. If the cell is not passing current, the applied voltage is rendered virtually ineffective.

It is important to remember that the workload of nonfunctioning cells is transferred to the neighboring cells in the paint tank. Increasing the voltage in this case will produce more film build at the expense of overloading every cell in the tank. The problem could have been fixed by replacing only the membrane shells that were loading the circuit. By merely increasing the voltage, the operator is going to reach a point where every cell in the tank will be overdriven and destroyed.

When an E-coat system is new, the operator needs to log the currents through each individual cell at start-up. The first time the film thickness drops out of spec, the current should be logged again. This will allow the operator to know which cells in the tank caused the loss of film thickness by comparing these current readings to those recorded at start-up. By knowing the starting and cut-off points by amp-draw, the operator will be able to accurately predict when the film thickness is about to fall out of spec. At that point only the "weak" cells in the tank should be replaced to avoid overdriving the others. It is important to remember that the cells will not always wear at the same rate due to the geometry of the parts being painted and cell location.

It is scientifically impossible to predict when film thickness is about to fall out of spec by monitoring only total current. Current in a parallel circuit divides through each branch according to resistance.

Example:

With a reading of 700 amps there may be a problem coating. If there are 50 cells in the tank and the system is drawing a total of 700 amps, this is not an indication that all of the cells are working. The amount of painted surface area is the only factor that determines amp draw. A system that has only 30 of the 50 cells working may still have a reading of 700 amps.

These numbers are just examples, not actual limits. Just increasing the voltage will eventually prematurely destroy every cell in the tank.

<u>CURRENT MONITOR™ SYSTEM</u>

The UFSc Current Monitor System is made up of one shunt and two fuse kits per cell and one master control panel, which monitors each individual cell in the tank. UFSc will supply the master panel at no charge when Membrane Electrode Cells, Shunts, and Fuse Kits are purchased from UFSc. The master control panels are available in 16, 32, 48, and 64-point versions. One "point" represents one monitored anode cell. If more than one panel is required, they will still be provided at no charge.

When operating the UFSc Current Monitor panel, simply select the corresponding control switch for a given cell location. The current through that cell will then appear in the digital display (with green back-lighting). Since the meter will only display "zero" when no switches are selected, the power switch on the front of the panel should be left in the off position to prolong the life of the display.

> **NOTE:** The condition of an electrode is determined by its weight not by its amp draw. An electrode that is passing 20 amps will pass it whether it is new or old. However, the monitoring system will indicate excessive current densities and will lead directly to the cells with worn electrodes. The maximum recommended current density for any anode cell is 5 amps per square foot. This means that a cell with 3 square feet should not draw more than 15 amps, unless they are among the leading cells in a monorail system, which will be hit by a surge current every time a new unpainted part enters the tank.

If one or more cells fail, the total current will not change. The cells that are still functioning will carry the additional load. If this load is excessive, the remaining cells will burn up in a short time. This includes the electrode and the membrane shell.

UFS Corporation is dedicated to providing quality, innovative solutions to the electrocoating industry. We have over 20 years experience and leadership in finishing system consultation, anode cell manufacturing, Membrane Electrode System design, on-site service and installation assistance.