The paint and coatings industry faces several critical issues today. Consolidation, rising raw material and energy prices, and increasingly stringent regulatory requirements impact the daily activities of suppliers and manufacturers. Overall the goal remains to provide high performance paints and coatings at an affordable cost—in essence to meet the needs of the end user, whether a consumer or professional painting contractor. Remaining competitive with the large national paint and coatings manufacturers has become a significant challenge for smaller regional producers over the past several years. The growing regulatory pressures have become the primary concern of these players in the paint and coatings marketplace. Working closely with regulators on the one hand and customers on the other, as well as investing in innovative technologies, will be the keys to success, according to the companies participating in this roundtable discussion. JCT CoATINGSTech spoke with Anthony M. Ciepiel, president of The Flood Company; Jim Capitano, vice president of manufacturing with Duron, Inc.; and Tim Bosveld, vice president of marketing for Dunn Edwards.

JCT: What would you identify as the top three most critical issues facing the paint and coatings industry over the next five years? Why do you classify them as critical, and what impact will they have on the industry?

Anthony M. Ciepiel, Flood: The number one issue facing the industry is the need to create low-VOC (volatile organic compound) paints and coatings that do not compromise performance and can be economically produced. It is easy to create low-VOC formulations, but not easy to do so and maintain the level of performance demanded by the customer. It is yet another challenge to do so at an economic price.

Jim Capitano, Duron: For companies that operate in different geo-
ACQUIRING THE DATA: CELL AND INSTRUMENTATION

Figure 6 shows a typical cell for making impedance measurements. The cell is constructed in the same manner used in everyday electrochemical measurements, such as for studying corrosion. A sample electrode (working electrode), a reference electrode, and a counter electrode are immersed in an electrolyte solution (for instance, 5% NaCl in water). The reference electrode is typically a saturated calomel electrode (SCE) and the counter electrode is usually an inert material like a platinum mesh or a carbon rod. There may be a provision for stirring and for removing oxygen from the electrolyte.

The instrumentation (Figure 7) required includes a waveform generator to produce the sine waves and potentiostat to control the potential. It must control both the dc current as well as the added ac excitation voltage. The instrumentation must also contain a means of accurately measuring the ac components of both the voltage and the current and the phase relationship between them. This data is used to calculate the impedance of the cell. Because of the complexity of optimizing and coordinating these ac measurements, a computer is generally used to run the experiment and to display the results in real time.

Over the years, various techniques have been used to measure the current and voltage amplitudes and the phase relationship between them. Early measurements were done manually using an oscilloscope or an impedance bridge. Today, the measurements are computerized, and the ac components may be measured with a frequency response analyzer, with a lock-in amplifier, by using Sub-Harmonic Sampling, or by using a Fourier transform technique. All of these methods are capable of measuring the impedance with suitable accuracy. In a practical sense, more errors may be introduced by the potentiostat.

The data collected by the computer program should include the frequency of the ac waveform and either the magnitude and phase of the impedance at each frequency, or the real and imaginary components of the impedance, or, perhaps both. Most modern programs allow the display of either or both of these equivalent display formats, the Bode plot or the Nyquist plot. Other parameters, such as the dc current and dc voltage are often recorded as well, and can be useful in interpreting the data in some of the more complicated systems. This additional information is often not needed, however.

A small 5–10 mV amplitude ac signal is applied to the sample by the potentiostat and the current response is analyzed to extract the phase and amplitude relationship between the current and the voltage signals. In some applications, larger signals can be applied, but care must be taken to ensure that the system is linear over the ac voltage range. In studying base metal corrosion, larger amplitudes are almost never used.

Figure 7—A block diagram of the modern instrumentation used to make the EIS measurements. Often, more than one of these functional blocks are included in a single instrument, or even inside the computer.

Making EIS measurements at very high or very low frequencies, or at very high frequencies, is a difficult task. At any of these extremes you may be able to make the measurement, but it may not be a meaningful or useful one. At very high impedances and at very low frequencies, you may be measuring the characteristics of your cell geometry, or of the wiring, or of your potentiostat, and not the characteristics of your coating or corrosion reaction. Still, not all, potentiostat manufacturers will specify the impedance and frequency limits for making reliable and accurate measurements that reflect what you are trying to study. It is important to be aware of the limits. Figure 8 shows how the errors in these impedances depend on the frequency and on the impedance. For example, consider measuring a sample with a 10 ohm impedance at 50 Hz. Although the measurement may be possible with this potentiostat, Figure 8 indicates that the errors will be greater than 10% and 10/100.

The errors will be significantly greater since the impedance/frequency point is far from the dividing line.

OPEN LEAD CURVE

Fortunately, there is quick and simple way to test the sensitivity of an EIS system. To determine the maximum impedance that can be measured with a particular EIS instrument, run an EIS curve with no cell attached to the instrument. The voltage and current electrode leads must be connected to the analyzer.

Figure 9 shows how the errors in these impedances depend on the frequency and on the impedance. For example, consider measuring a sample with a 10 ohm impedance at 50 Hz. Although the measurement may be possible with this potentiostat, Figure 8 indicates that the errors will be greater than 10% and 10/100. Therefore, at 10 kHz, the highest sample impedance that can be measured with this instrument is 10 ohm. However, there will be substantial error in the measurement. At 0.1 Hz, the impedance can measure, at most, 1000 ohm. To be sure that the measured impedance has less than a few percent error in the magnitude, or less than a few degrees error in phase, the impedance must be 50 to 100 times lower than the limits estimated from this "Open Lead" experiment. At 0.1 Hz, then, the maximum impedance that can be measured with acceptable accuracy is 10 ohm.
SUMMARY

EIS is a general purpose electrochemical technique applicable to virtually all areas of electrochemistry. In this article, we have covered the basics of electrochemical impedance spectroscopy: the theory behind the measurements, the equipment and cells required for painted samples, how to use them, and an introduction to equivalent circuit modeling of the collected data.

The next article in the series will fo-

cus on the physical description of a coating on a metal surface, how that relates to circuit elements for data fitting, and, finally, the analysis of the different stages of coat-

ings degradation. In the final article, we will discuss how coatings scientists use the various methods available to get an understanding of failures modes of coatings.

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SME Hosts Energy and Fuel Cell Technologies Event

The Society of Manufacturing Engineers (SME). Dearborn, MI, will host the Advanced Energy and Fuel Cell Technologies conference and exposition on October 11-13, 2004 at Laurel Manor in Livonia, MI. Designed to "demystify" fuel cells for the manufacturing audience, the theme of the conference is "Manufacturing Challenges and Opportunities." Five keynote speakers and over 50 presentations are scheduled on the topics of reducing the cost of advanced energy technologies (AET), high tolerance materials, scalability of components, reliability, designing fuel cells for manufacturability, supplier requirements, and manufacturing management. Alternative energy and fuel cell displays will be provided by exhibitors. For more information, contact SME's Resource Center at 800.735.

4763, or visit www.sme.org. net.

NPCA to Host Annual Meeting October 24-26 in Chicago

Robert Kagan Named Keynote Speaker

The National Paint and Coatings Association (NPCA), Washington, D.C., will host its biennial meeting on October 24-26 at The Palmer House Hilton in Chicago, IL. The meeting will include tour sessions on subjects ranging from creating and sustaining business growth and efficiencies, to the political outlook for the 2004 general elections. Robert Kagan, senior associate at the Carnegie Endowment for International Peace and director of the Endowment's U.S. Leadership Project has been named keynote speaker for the meeting.

Mr. Kagan is an expert on the dynamics of power in the post-Cold War world. He writes extensively on domestic politics and U.S. strategy and diplomacy, including foreign policy, military strategy, and the defense budget. His latest book, Of Paradise and Power: America and Europe in the New World Order, a New York Times and Washington Post bestseller, analyzes the historical causes of the gulf between European and American perspectives on power and the forces that seem to be widening the rift inexorably. Mr. Kagan also writes a monthly column in the Washington Post and is a contributing editor to the Weekly Standard and the New Republic. The author of Twilight Struggle: American Power and Nicaragua, 1977-1990, he is a co-ed-

itor, with William Kristol, of Present Dangers: Crisis and Opportunity in American Foreign and Defense Policy (2004) and Mr. Kristol is the co-founder of the Project for a New American Century.

For additional information regarding NPCA's annual meeting, contact Dorothy Brawner at 202.462.6272 or dbrawner@paint.org, or visit www. paint.org/meetings/ annualreg.htm.

SME's Smart Coatings 2005 Symposium Seeks Papers

The Coatings Research Institute (CRI) of Eastern Michigan University (EMU), Ypsilanti, MI, is seeking technical papers for presentation at their Smart Coatings 2005 Symposium, to be held on February 2-4 at the Grosvenor Resort in Orlando, FL. Papers are encouraged on topics such as antimicrobial and biocidal coatings, organic nanotechnol-

ogy-based coatings, stimuli and response coatings, and self-assembled intelligent layers. Abstract submissions are due by September 1. Papers accepted for the symposium must sub-

mit a full paper by December 15. For additional information, visit www.

emich.edu/public/coatings/research/ smartcoatings/index.html, or contact Sandy Turner, CRI, at 734.487.2203; fax: 734.483.0853, or sandy.turner@

emich.edu.

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