ECS CLASSICS

H.H. Uhlig Remembered

by Robert P. Frankenthal

Professor Herbert H. Uhlig was a man for all seasons. Or as one of his former students, Milton Stern, said in 1981 when the Corrosion Division honored Professor Uhlig with an international symposium on the occasion of his 75th birthday, Professor Uhlig was "a teacher, scholar, philosopher, mentor, and friend" (1). Here, I will discuss Professor Uhlig as a scientist and a teacher; as an active participant in The Electrochemical Society; and most importantly, as a human being who sought the best in others and inspired all who came in contact with him.

Henry Herbert Uhlig was born March 3, 1907 in Haledon, a small community in northern New Jersey. Early in his life, he showed a keen interest in chemistry and physics, devoting most of his free time to experiments at home and to reading at the local library. After getting his bachelor's degree in chemistry from Brown University in 1929, he entered graduate school at MIT and obtained his doctorate in physical chemistry under Professors John Kirkwood and Frederick Keyes. His doctoral dissertation was entitled "Dependence of the Dielectric Constants of Gases on Temperature and Density."

Initially, Dr. Uhlig wanted to pursue a career in biochemistry, and he went to work with Duncan MacInnes at the Rockefeller Institute for Medical Research in New York City, who at that time was interested in the physical chemistry of biological cell models. This was his introduction to electrochemistry and The Electrochemical Society. Professor MacInnes was very active in the Society at that time, becoming President in 1936 and receiving the Edward Goodrich Acheson Award in 1948. However, the Depression made funding difficult, and Dr. Uhlig was soon forced to seek a job elsewhere. He joined Lever Brothers in Cambridge, Massachusetts as assistant chief chemist in charge of the analytical

laboratory responsible for overseeing the analysis of raw materials and quality control. But his heart was really in research and never in industrial administration. So when he was offered a position as Research Assistant in charge of the Corrosion Laboratory at MIT in 1936, he jumped at the opportunity to return to his alma mater to do research. For the next four years, Dr. Uhlig conducted research in corrosion and, in particular, on pitting corrosion of stainless steels in sea water.

In 1940, with the approach of World War II, Dr. Uhlig moved his corrosion research efforts to the General Electric Company Laboratories in Schenectady. During his six years at General Electric, besides doing research, he edited the *Corrosion Handbook*, which was published by John Wiley in 1948 under the sponsorship of The Electrochemical Society. The first book ever sponsored or published by the Society, the *Corrosion Handbook* is still in print and has sold almost 25,000 copies. Professor Uhlig graciously donated all royalties from the book to the Society and its Corrosion Division. It is also interesting to note that in the preface, Professor Uhlig stated that plans for the *Handbook* "in part led to the organization of the Corrosion Division within The Electrochemical Society in 1942" (2).

During his years in Schenectady, Professor Uhlig courted and married Greta Johnson, who had an enormous influence on his life. He, in turn, was a devoted husband and father. They had three daughters, Karin, Maida, and Kristin. After the war, in 1946, he returned to MIT as an Associate Professor and Director of the reestablished Corrosion Laboratory. In 1953, He was promoted to Professor in the Department of Metallurgy, a position he held until his retirement in 1972.

During these many years, he was one of the leading spokesmen in this country for corrosion and the many economic, safety, and health problems, it poses. He also consulted for many government agencies and was active on the National Research Council's Prevention of Deterioration Center.

But Professor Uhlig's primary interests and concerns were research and teaching. He developed one of the world's foremost corrosion research labs at MIT and devoted much time, effort, and energy to teaching and inspiring his students—not only graduate and post-doctoral students abut also many undergraduates as well. From what I learned from his students, and I talked to many of them, he was always available for advice and discussions. For example, after lecturing or consulting elsewhere, he would tell the students about his experience and the practical, as well as scientific, problems he encountered. This exposure undoubtedly broadened the student's quest for more and better understanding of corrosion science and for the continuing need for study and application. He was also an innovative educator and made his students aware of the scientific background and rigorous scientific foundations upon which corrosion science is built. Professor Uhlig felt strongly that his principal responsibility was the education of students.

All the while, Professor Uhlig's corrosion group flourished with graduate and post-doctoral students from around the world. His students enjoyed the friendly atmosphere that characterized the group. This first became evident to me when I spent a day at his Laboratory about 25 years ago. The enthusiasm and rapport within the group was obvious. The group extended beyond the lab and confines of MIT. The Uhligs frequently entertained the students to strengthen the friendly, cohesive atmosphere of the group. This led to an annual tradition of hiking up Mount Monadnock in New Hampshire, followed by tea at the base of the trail and supper in Winchester (3).

Over the years, Professor Uhlig taught, inspired, and graduated more than 100 M.S. and B.S. students, over 20 Ph.D. students, and about the same number of post-doctoral fellows. Many of these went on to university faculty positions, industrial and government research labs, and some reached the Boardroom of major corporations. As a teacher and scientist in corrosion science, he was always "encouraging, challenging, and prodding his students to push back the frontiers in search of answers to difficult questions"(1). Professor Carl Wagner, a colleague of Professor Uhlig at MIT and later Director of the Max-Planck Institut für Physikalische Chemie in Göttingen, attested eloquently to Professor Uhlig's influence as a scientist and teacher: "I believe it important to point out that Herbert Uhlig has contributed to our knowledge of the mechanism of corrosion and measures of corrosion protection not only by research on rather diversified problems but also as a stimulating teacher and a selfless organizer. So the effect of Uhlig's efforts as a whole is far greater than the effect attributable to his publications"(4).

Herbert and Greta Uhlig enjoying an outing in the winter woods.

One of the annual picnics at the Uhligs

Professor Uhlig and his students published more than 175 scientific papers over the years. And, in addition to the aforementioned *Corrosion Handbook*, Dr. Uhlig wrote an outstanding textbook *Corrosion and Corrosion Protection*, the third edition of which, co-authored by R.W. Revie, was published in 1985.

In 1982, on the occasion of his 75th birthday, MIT honored Professor Uhlig by naming its corrosion lab the "H.H. Uhlig Corrosion Laboratory." I would like to quote here an excerpt from a letter written by his successor as Director of the Corrosion Laboratory at MIT, Professor Ronald M. Latanision (5). "Indeed, a banquet and dedication ceremony was held on the evening of May 13. More than 120 of Professor Uhlig's faculty colleagues, contemporaries in corrosion science, students, and friends celebrated this occasion. I am personally very pleased to observe the tremendous admiration and respect that Professor Uhlig enjoys to this day among the current students in the Laboratory. This is a sentiment that seems to me to characterize the feelings of his contemporaries as well as the younger generations of corrosion scientists and engineers around the world. For all these reasons, we find it particularly fitting that Professor Uhlig's name be permanently associated with the Laboratory."

Professor Uhlig's research was concentrated mainly on basic corrosion science. As he said when he received the U.R. Evans Award from the Institution of Corrosion Science and Technology in Great Britain in 1980, "I was concerned with knowing why and how metals corrode, and the underlying science of steps that can be taken to reduce their rate of attack"(6).

His range of interests within corrosion science was broad. He and his students investigated the passivity of metals and alloys, pitting corrosion, stress corrosion, cracking, hydrogen embrittlement, corrosion fatigue, corrosion inhibition, and the early stages of oxidation. Each of these, as well as several others, was studied in depth, new insight was gained, and new hypotheses and theories were developed.

Professor Uhlig's work on the passivity of transition metals and alloys is perhaps best known. In particular, he asked why stainless steels are able to maintain a stable passivity and why a minimum concentration of 12% Cr is necessary for the stable passivity of ferrous alloys. Trying to answer these questions led to many investigations of the relation between *d*-band electron vacancies in transition metals and their tendency to fill with electrons from alloying components. He proposed and eloquently articulated the view that passivity is the result of a chemisorbed film of oxygen, whose existence and stability depends on the electron configuration of the underlying metal. These chemisorbed films are not diffusion barriers, as three-dimensional, insoluble oxygen films might be. They are much too thin for that purpose. Instead, the chemisorbed oxygen films acts by decreasing the rate of metal dissolution, that is by affecting the kinetics of the electron transfer process.

Another important conclusion from his studies on passivity was that the minimum ration of metals corresponding to passivity in binary alloy systems tends to be retained in the solid solution of tertiary and quaternary alloy systems. Electron sharing between alloyed species continues to dominate passive properties of more complex alloys, such as those that are likely to be used in real applications. Although much more remains to be understood, Professor Uhlig believed that effects of this kind will be of importance in designing corrosion-resistant alloys for specific environments.

In the area of pitting corrosion, Professor Uhlig's work confirmed the presence of a critical pitting potential that is necessary for pit initiation. This concept of a critical pitting potential has become a most important parameter in designing inhibitor systems or cathodic protection systems to prevent pitting in real-world applications.

Along these same lines, Professor Uhlig studied the mechanism by which corrosion inhibitors and passivators work. He developed the theory of competitive adsorption between the aggressive anion, such as chloride, that causes passive film breakdowns and the inhibiting ion that protects the metal.

In stress corrosion cracking, Professor Uhlig's research indicated that there exists a relationship between the critical potential and the corrosion potential that, in general, can account for the observed susceptibility or immunity of many alloys to stress corrosion cracking. He applied this relation to mild steels, high strength steels, stainless steels, and brasses in a variety of environments, including those containing inhibitors. He also found that resistance to stress corrosion cracking inherent to some alloys was not dependent on electrochemical parameters. For these exceptions, a crack sensitive path simply does not exist, largely because of dislocation patterns. In general, however, he concluded that the critical potential is a fundamental parameter relevant to the stress corrosion cracking mechanism, as well as to practical means for avoiding damage due to stress corrosion cracking.

Professor Uhlig's group studied the corrosion fatigue of mild steel and high-strength, low-alloy steels. They confirmed that the corrosion component of fatigue life depends on the magnitude of the uniform corrosion rate rather than on the presence of specific anions. This, of course, is contrary to the situation in stress corrosion cracking. Further, they concluded that pitting of the metal surface is not a necessary condition for the corrosion fatigue process. Other studies of theirs showed that the maximum applied potential for cathodic protection against corrosion fatigue nearly coincides with the potential needed to avoid uniform corrosion, and that the corrosion component of fatigue life reaches null just before the uniform corrosion rate reaches zero. All the evidence they gathered supports a mechanism of corrosion fatigue that depends on plastic deformation of surface grains enhanced by corrosion, thereby favoring the initiation and growth of cracks along slip planes that move alternately in one direction and then in the other direction.

Professor Uhlig's research on the initial stages of oxidation and the formation of thin oxide films resulted in the conclusion that the oxidation is controlled by electron transfer from metal to oxide. This explains why oxidation rates are sensitively influenced by metal grain orientation and Curie temperature, both of which affect the metal's work function. In addition to the studies already mentioned, Professor Uhlig and his students investigated hydrogen embrittlement, corrosion by organic solvents, and corrosion of intermetallic compounds.

Professor Uhlig did not shirk or retreat from controversy. To quote his second graduate student, Harry Gatos, "Poten-

(Above) Herbert Uhlig with R.M. Latanision, Director of the Uhlig Corrosion Laboratory (left) and G.J. Yurek.

(Left) Dr. Uhlig and students in 1968. From left to right sitting are: Mansfeld, Uhlig, and Duquette; Left to right standiung are: Revie, Böhni, Marques, O'Connor, and Lee.

tial controversy did not impede the pursuit and discussion of his ideas, either in his research or in his involvement with the Society"(7). Those who have attended the Gordon Research Conference on Corrosion know of the many active debates and discussions in which Professor Uhlig was involved—in particular on passivity, pitting, and stress corrosion cracking. To his credit, more light than heat was always generated.

Professor Uhlig was a particpant in the first Gordon Research Conference on Corrosion held in 1941. He was chairman of the 1946 Conference, the last to be held at the original site on Gibson Island in Maryland. Professor Uhlig also made another contribution to the Gordon Research Conference: He organized and led the annual hike up Mount Kearsarge. He was an enthusiastic outdoorsman, thoroughly enjoying hiking, mountain climbing, canoeing, skiing, skating, swimming, and many other outdoor activities. He shared his enthusiasm for swimming with his good friend Ulick R. Evans. On the occasion of receiving the U.R. Evans Award, Professor Uhlig described how he and Evans "reveled in the frigid water of the Cam River and of the Atlantic Ocean north of Boston in October"(6).

Professor Uhlig was a member of The Electrochemical Society for 56 years. For more than a half century, he gave much distinguished service to the Society, not only presenting papers and organizing symposia, but also active in running the Society and shaping its future. He was one of the founding fathers of the Corrosion Division and served as it chairman from 1944 to 1946. He was also chairman of the Theoretical Division (now the Physical Electrochemistry Division) from 1950 to 1951, Editor of the **Journal**, Chairman of the Publication Committee, and served the Society as both a Vice President (1952-1955) and President (1955-1956).

The Society honored Professor Uhlig on numerous occasions. He received the Palladium Medal in 1961 and the Edward Goodrich Acheson Award in 1988. He was named an Honorary Member of the Society in 1973. The Corrosion Division changed the name of its Outstanding Achievement Award to the H.H. Uhlig Award in 1983. He also received numerous other honors and awards from societies and institutions around the world. Among these were the Willis Rodney Whitney Award of NACE (1951) and the U.R. Evans Award of The British Institution of Corrosion Science and Technology (1980), named after his long time personal friend Ulick Evans.

In addition to his active participation in The Electrochemical Society and in the Gordon Research Conference on Corrosion, Professor Uhlig was involved in the International Corrosion Council, being its chairman (1975-1978), and the plenary lecturer at its first Congress in 1961. He also helped organize the First International Symposium on Passivity in 1957. At the Fourth International Symposium on Passivity, held in Airlie, Virginia in 1977, he delivered a memorable plenary lecture on the "History of Passivity"(8).

As I stated at the beginning, Professor Uhlig was, indeed, a man for all seasons. His legacy as an innovative educator, imaginative scientist, well-organized and highly motivated research director, and above all outstanding human being will live forever.

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