An Interview with Dr. Stuart Nelson

We recently met Dr. Stuart Nelson during the 50th Annual Microwave Power Symposium (IMPI-50, Orlando Florida, June 21-23, 2016), where he gave a plenary talk in the opening session. His spotlight presentation reviewed his agriculture-oriented research on dielectric properties, conducted in the US Department of Agriculture, Agriculture Research Service (USDA/ARS). Dr. Nelson, a Fellow of AAAS, IEEE and IMPI, agreed to share with our AMPERE-Newsletter readers some aspects of his rich experience in the fields of dielectrics and microwave heating, spanned over more than 6 decades. Though Dr. Nelson is very well known to many of us (and his pioneering studies and papers have surely been learnt by many other researchers worldwide), we first present a brief summary of his professional biography and achievements, as a preface to the Interview.

Stuart Nelson was born in 1927. He grew up on a farm in northeastern Nebraska, U.S.A., where he attended a one-room country elementary school and graduated from High School in the small town of Pilger, NE, in 1944. He enrolled immediately in Engineering on a Regents scholarship at the University of Nebraska to secure more education before expecting to serve in the U. S. military service during World War II. Two years later, he enlisted in the U. S. Navy and spent one year in the Navy electronics school at Treasure Island Navy Base in San Francisco Bay. Upon graduation, he served the remainder of his 2-year enlistment as the senior Electronics Technician aboard the U.S.S. Bausell, flagship of Destroyer Division 12 in the Pacific theater.

Upon discharge from the Navy, Stuart returned to the University of Nebraska where he completed a B. S. and M. S. in Agricultural Engineering, and an M.A. in Physics. He joined the U.S. Dep't of Agriculture (USDA) research program at the University of Nebraska in 1954. Several years later, he took leave for a year's study at Iowa State University, and a few years later completed the Ph.D. in Engineering with a dissertation on the Frequency Dependence of the Dielectric Properties of Wheat and the Rice Weevil.

Research

Dr. Nelson's research with the USDA dealt with the use of radio-frequency (RF) dielectric heating for agricultural applications. It was conducted in the Dep't of Agricultural Engineering at the University of Nebraska, Lincoln, and involved dielectric properties measurements and use of RF energy for stored-grain insect control, seed treatment to improve germination and control fungi, RF treatment of soybeans to improve nutritional value, and sensing moisture content of grain and seed.

In 1976, Dr. Nelson moved his laboratory to the USDA Russell Research Center, Athens, Georgia, continuing dielectric properties measurements research, and initiating studies on fruits, vegetables and pecans. Advances in techniques for measuring moisture content in grain and seed with RF and microwave techniques followed, along with quality sensing research on fruits and vegetables, pecans, and food and poultry products. Contract research on dielectric properties of coal and minerals for the U.S. Dep't of Energy and the U.S. Bureau of Mines supplemented these studies.

Publications

Dr. Nelson has about 800 publications to his credit, including articles in more than 50 different engineering and scientific journals, in conference and symposia proceedings, book chapters, patents, and a book summarizing 65 years of research on dielectric properties of agricultural materials and their applications.

Recognition and Awards

Dr. Nelson's work has been recognized by election as a Fellow of the American Society of Agricultural and Biological Engineers (ASABE), the Institute of Electrical and Electronics Engineers (IEEE), the International Microwave Power Institute (IMPI), and the American Association for the Advancement of Science

(AAAS). Additional significant honors include election to the National Academy of Engineering, the IMPI Decade Award, the National Society of Professional Engineers Founders Gold Medal as the 1985 Federal Engineer of the Year, the ASABE McCormick-Case Gold Medal for Significant Engineering Achievement in Agriculture, the Georgia Engineering Foundation Medal of Honor, an Honorary Dr. Sc. from the University of Nebraska, induction into the University of Nebraska Biological Systems Engineering Hall of Fame, and the USDA, ARS Science Hall of Fame. Dr. Nelson was also selected to receive the 2016 IEEE Instrumentation and Measurement Society's Career Excellence Award.

Current position

Dr. Nelson retired in 2007 with 55 years of federal service and has continued working as a Collaborator in the USDA laboratory that he established at the Russell Research Center in Athens, Georgia.

Early research

Studies on dielectric heating for agricultural applications were conducted with a modified commercial 3-kW dielectric heater operating at 40 MHz (Fig. 1). Grain, seed, and insect samples were treated in small polystyrene boxes between parallel plate electrodes for set exposure periods. The RF electrode voltage between the electrodes was measured with an RF voltmeter, and the electric field intensity in the materials was calculated based on the thicknesses of the material layers and their dielectric properties.

Figure 1. A modified 3-KW industrial dielectric heater used for research.

Resulting temperatures in the sample materials were determined by use of a recording thermocouple potentiometer and extrapolation that took the cooling of the samples into account upon removal from the dielectric heater (Fig. 2). Thus, the parameters describing the treatments, frequency, time of exposure, electric field intensity, and resulting sample temperatures, along with the measured dielectric properties and moisture contents of the sample materials, were all known factors describing the treatments.

Figure 2. Measuring temperatures of treated samples.

Seed treatment

Performance of untreated control and treated seed samples was determined by laboratory germination tests and greenhouse and field emergence tests to assess improvements attributable to the RF heating treatments. Experiments were conducted with more than 80 different plant species. Many did not respond favorably but some did. In particular, germination of alfalfa seed with high percentages of hard seed (seed coat impermeable to water) were consistently and markedly increased (Fig. 3). The treatment was safe for the seed, because favorable effects of the treatment were observed in seed held in storage for up to 21 years after treatment.

Insect control

Similar RF dielectric heating treatments, of infested wheat and other grain samples for a few seconds, controlled several species of stored-grain insects effectively. Experiments showed that many insect species that infest grain and cereal products can be controlled by short exposures to

RF electric fields that do not damage the host material. Generally, for successful RF insect-control treatments, resulting temperatures in host materials of this kind ranged between 40 and 90 °C, depending upon the characteristics of the host material, the insect species and developmental stage, and the nature of the RF or microwave treatment. These methods have not been practical, because they are too costly compared to conventional chemical and physical control methods.

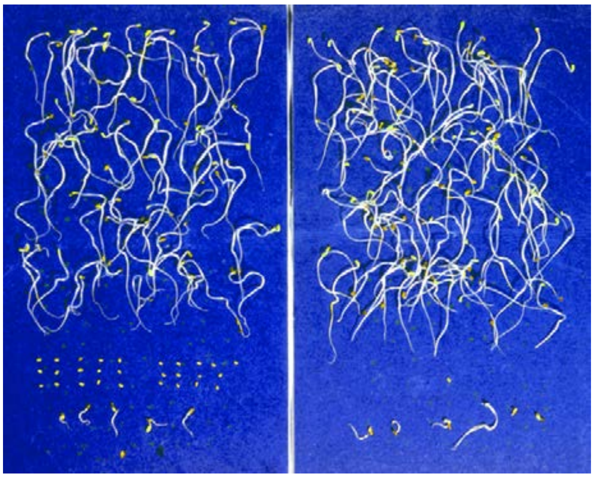

Figure 3. Alfalfa seed germination. Left: untreated control. Right: treated sample. (Separated into normal seedlings, hard seed, abnormal seedlings, and dead seed).

Dielectric properties

Since dielectric properties of materials involved in dielectric heating applications are important in predicting the behavior of those materials, and because those properties of the materials were not known, it was necessary to develop techniques for measuring the dielectric properties of the materials of interest. Because the early dielectric heating studies were conducted at 40 MHz, a reliable method for dielectric properties measurement was developed with a Boonton Q-Meter (Fig. 4) for the range from 1 to 50 MHz, and many measurements in this frequency range were made for grain, seed, insects, and other materials. Because the dielectric properties of these materials vary with frequency, and because selective heating of insects in grain could be possible, knowledge of dielectric properties over wider frequency ranges was needed. Therefore, techniques for measuring these properties over other frequency ranges were developed, Figs. 5 and 6. Results of measurements on insects and grain showed that the best selective heating of the insects could be achieved between 10 and 100 MHz, as shown in Fig. 7.

Nutritional value improvement

Raw soybeans contain a natural trypsin inhibitor that prevents monogastric animals and humans from utilizing the full nutritional value to be realized through efficient digestion by the trypsin enzyme. Steam treatment or extrusion processes are generally used for inactivation of the trypsin inhibitor before feeding soybeans to farm animals.

Studies involving animal feeding tests and biochemical analyses showed that dielectric heating at 40 MHz or at 2,450 MHz were very effective in improving the nutritional value of soybeans. Also dielectric heating of pecans at 40 MHz (Fig. 8) revealed that treatment was effective in improving the quality of the nuts in storage. Quality of pecans normally deteriorates rapidly after harvest unless held in refrigerated storage at temperatures of 0 °C or lower, because of fatty acids oxidation.

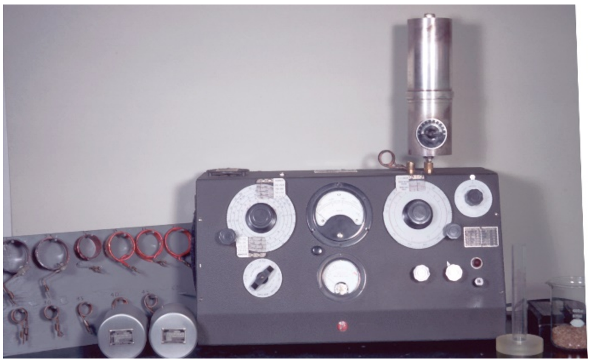

Figure 4. A Q-meter and sample holder for grain and seed for measurements at 1 to 50 MHz.

Figure 5. Admittance meter system for dielectric measurements in the range of 200 to 500 MHz.

Figure 6. An X-Band system for 8- to 12-GHz dielectric measurements.

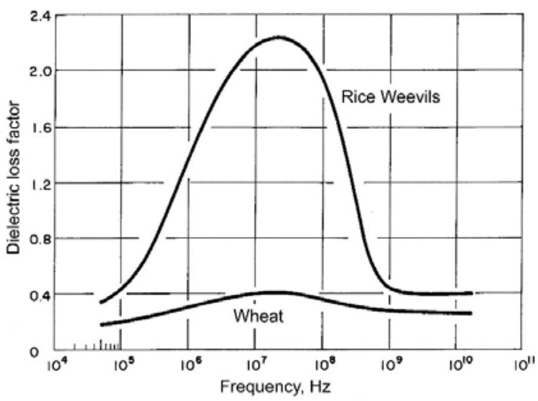

Figure 7. Dielectric loss factor for wheat and rice weevils.

Coal and mineral studies

Because of capability developed for measuring dielectric properties of materials over wide frequency ranges, assistance was sought for research programs in the U.S. Dep't of Energy on coal utilization and by the U.S. Bureau of Mines in rock fragmentation through dielectric heating. Measurements were taken between 1 and 12 GHz on pulverized coal samples of different types, different bulk densities, and containing different amounts of pyrite. Frequency dependence of the different coal fractions was studied, and some experiments were conducted on selective heating of pyrite. Excellent linear relationships between the square root of the dielectric constant and bulk density were noted that permitted reliable determination of dielectric properties of the solid coal by extrapolation to the solid material density.

Figure 8. Pecan kernels on lower electrode of the dielectric heater.

Measurements of the dielectric properties of dry pulverized and purified samples of ten minerals of interest in the Bureau of Mines rock fragmentation program were taken between 1 and 22 GHz. Particle densities were determined with the aid of pycnometer measurements, and the dielectric properties of the solid materials were calculated by using the Landau and Lifshitz – Looyenga dielectric mixture equation. The frequency dependence of the dielectric properties was thus determined in the 1-to-22-GHz frequency range.

Moisture and quality sensing

Uses of dielectric properties of agricultural products for sensing important quality attributes of such products were also explored. Dielectric properties measurements on grain, seed, and other products revealed high correlations between those properties and moisture content. Moisture content is an essential factor in determining whether grain and seed can be safely stored without spoiling. Moisture meters, electronic Instruments sensing these dielectric properties, have been used for more than 80 years, but the dielectric properties of grain and seed were not measured and reported until the 1950's. Availability of dielectric properties data and their dependence on various factors, including frequency, were important in improving the reliability of grain moisture meters over the past several decades. More recent development of techniques at microwave frequencies for sensing moisture in granular materials independent of bulk density has enabled future development of reliable monitoring of moisture content and bulk density in flowing granular materials.

Microwave measurements have also provided the sensing of kernel moisture content in unshelled peanuts (Fig. 9). Kernel moisture content is the main criterion used for decisions in the drying, grading, sale, and storage of peanuts. Therefore, the ability to sense kernel moisture content in unshelled pod peanuts with microwave instruments offers potential for real improvements in efficiency in drying, processing and handling of peanuts.

Figure 9. Microwave moisture meter for peanut kernel moisture measurement

Microwave dielectric properties of many fruits and vegetables have been measured and studied for possible use in detecting quality. Efforts were made to find good correlations between the dielectric properties of several types of melons and their sweetness, but no relationships were discovered that offered promise for practical use. Similar studies involving frequency dependence of dielectric properties and quality of fresh chicken meat and development of suitable sensors are currently under way.

Questions and Answers:

Q: You served in the American Navy as an electronics technician at the end of World War II. What is your perspective of military technologies converted to civilian uses (e.g. from radar to microwave heating)?

A: Your example is certainly a well-known civilian application of technology developed for military use. As the magnetrons used in radar were adapted for microwave power applications, and particularly as their costs were reduced, microwave heating grew substantially, with microwave ovens in the home becoming ubiquitous. There are many other examples, I am sure, but one that comes to mind, in agriculture, is the development of instrumentation used in modern grain harvesting equipment, where yield is monitored during the operation and utilized in connection with global positioning systems to provide information important in managing farming operations. One of the parameters monitored is the moisture content of the grain being harvested, and our research has contributed to its developments in on-combine moisture measurement.

Q: You have two Masters degrees, one in agricultural engineering and the other in physics. How would you compare these two professions? Are they indeed different cultures?

A: In the field of physics, I believe that the emphasis is on understanding fundamental principles and development of theories that explain matter and energy and their interactions, including those in mechanics, heat, optics, electricity, magnetism, radiation, atomic structure, and nuclear phenomena. Use of mathematics is most helpful in expressing these relationships. In engineering, understanding the fundamental principles of physics and mathematics is also important, but there is more emphasis on using these principles in the design and development of things and systems that are useful to mankind.

There is naturally a lot of overlapping in the interests of physicists and engineers, and mutual contributions by each field to the work of the other are very common. However, I would suggest that differences in cultures of the two fields are characterized by interests in fundamentals and in applications.

Q: You were elected as a member of the prestigious National Academy of Engineering (and as a Fellow of four other major associations as well). Can you tell us please about the role and influence of the NAE?

A: The National Academy of Engineering (NAE) was established in 1964 to advise the federal government, along with the National Academy of Sciences, and now also the National Academy of Medicine, on matters of national interest. The NAE also sponsors engineering programs to meet national needs, encourages education and research, and recognizes the superior achievements of engineers. The NAE advises the Congress and the executive branch of the government, when called upon by any department or agency, on matters of national importance that are pertinent to engineering. It conducts studies on such issues, reviews programs, and prepares reports and recommendations. The NAE is also tasked with identifying and illuminating issues at the intersections of engineering, technology, and society that impact the quality of life. Studies, symposia, and public information activities are carried out both independently by the NAE Program Office and jointly with other units of the National Academies. The results of these activities are published as reports and proceedings that add to the growing body of knowledge on engineering and technology practice and policy.

Q: It seems that your applicative work has also led you to theoretical studies and to “pure” scientific research. As a scientist working for a government agency, how do you see the tension between curiosity-driven (so called “pure”) science and the application-oriented research?

A: In conducting applied research, I would expect that one often encounters a need for a better understanding of the principles and the influence of important variables. In these instances, some basic or “pure” research may be necessary to satisfactorily reach the goals of the applied research. In our work with permittivity measurements on pulverized mineral samples, we faced the need to determine the permittivity of solid materials from measurements on pulverized samples. This may not be a particularly good illustration of “pure” scientific research, but we explored the density dependence of the permittivity with measurements on the powdered samples at many different bulk densities and found essentially linear relationships between the square roots and cube roots of the dielectric constants and bulk density, which permitted reliable extrapolation of the dielectric constants to the densities of the solid materials. These relationships were consistent with certain permittivity mixture equations, and we checked the data with several of the well established mixture equations and determined those that worked best. Thus, complex calculations with the complex refractive index mixture equation and the Landau&Lifshitz-Looyenga mixture equation provided means to determine both components of the complex permittivities desired.

As a scientist working in the USDA Agricultural Research Service for more than 50 years, I found the environment for productive research very favorable, and was able to take the research in whatever direction I thought was advisable. Although there were well established general goals for the research, the direction depended very much on the individual scientist and his or her interests and capabilities. Thus, a mixture of basic and applied research could be used as appropriate for making progress toward the solution of problems.

Q: Have you noticed a change in this regard in the government approach over the years?

A: Yes, there have been changes. During the past twenty or thirty years, I believe there has been increasing demand on the scientist’s time for planning and formally documenting planned research and progress. And, unfortunately, in my opinion, I believe that the tedious documentation of personal performance and training to meet administrative requirements have continued to increase even more over the past few years. However, we can be thankful that technological advancements have enabled researchers to get more accomplished in their remaining time.

Q: How is your work on agriculture-oriented dielectrics relevant to other granular and powdered materials in general?

A: Starting with observations on the density dependence of the dielectric properties of particulate materials such as whole-kernel wheat, ground wheat flour and pulverized coal samples, we studied functions useful for extrapolating dielectric properties of these materials to those of the solid materials. Then we checked these functions and several dielectric mixture equations for relating the dielectric constants and loss factors of pulverized and solid plastics, very low loss Rexolite and reasonably lossy Kynar, through permittivity measurements at 2.45, 11.5 and 22 GHz on both solid and pulverized samples of these materials. This work established the reliability of the complex refractive index and Landau & Lifshitz - Looyenga mixture equations for relating the dielectric properties of the solid and pulverized forms of the materials. These relationships were also used to obtain the dielectric properties of ten solid mineral materials from permittivity measurements in the range from 1 to 22 GHz on pulverized and purified samples of those minerals. These relationships are expected to be useful for granular and powdered materials in general, unless their dielectric properties are far different from those already tested, and they may then still provide reasonable estimates.

Q: Following the recent IMPI-50 anniversary conference, where you presented a plenary talk, what are the main challenges in the microwave-heating field in your view for the next several years?

A: I cannot answer for specific applications in particular industrial fields, but from my work in the agricultural applications, there are some common problems that will apply generally to most other areas. One challenge for those attempting to apply microwave heating is to be sure that they understand the fundamental principles. Since the dielectric properties of the materials are important in determining the absorption of microwave power and the subsequent heating of the materials, non-uniform heating will occur in mixtures of different materials. The temperature dependence of the dielectric properties of the materials is also important to understand. Differences in dielectric properties can be helpful if one is interested in selectively heating some of the materials in a mixture, insects in cereal grains, for example, and in such applications, microwave heating may offer an advantage over other means of heating.

Frequency dependence of the dielectric properties must also be understood in selecting the frequency for equipment operation if that is an option. In the example mentioned, insect in grain, the microwave frequencies do not offer selective heating of the insects, and, instead, that is achieved at lower frequencies between about 10 and 100 MHz. The principles of heat transfer and thermodynamics, as well as the attenuation and absorption of microwave energy as it flows through the materials, are important.

Probably the most challenging questions for new applications relate to evaluation of costs of microwave and related equipment and their operation, and the evaluation of economic advantages such as time saved and product quality improvement. Both are important in assessing the practicability of new applications.