Enhancement of Laboratory Experience by Addition of Advanced Techniques in Undergraduate Mechanical Engineering and Technology Programs

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Abstract:

College of Engineering at University of North Texas offers both Mechanical and Energy (MEEN) as well as Mechanical Engineering Technology (MEET) programs. Undergraduate students in both MEEN and MEET programs are required to successfully complete Engineering Materials laboratory (ENGR 3451) course. The content of the ENGR 3451 covers experiments on metallography, mechanical testing (hardness, tensile, impact test), and heat treatment on ferrous and none-ferrous alloys. Recently, in an effort to enhance the course contents, we have added two demonstrations one on friction welding process and the other on characterization of iron oxides/oxy-hydroxides using Fourier Transform Infrared Spectrophotometry (FTIR). It is shown that FTIR technique can identify the chemical form of iron oxides/oxy-hydroxides as well as quantify the amounts of each constituent in a multiphase sample. An example of the application of FTIR in characterization of corrosion products formed on ferrous and non-ferrous alloys used in power plants, petrochemical, and oil and gas industries is demonstrated. Results of a survey on undergraduate students' opinions on exposure to the analytical technique (FTIR) are presented.

Introduction:

Most mechanical engineering programs expose students to materials engineering topics at undergraduate level. Mechanical and Energy Engineering and Mechanical Engineering Technology programs at University of North Texas cover materials engineering topics in a lecture course (ENGR 3450) and its corresponding laboratory course (ENGR 3451). Students received a total of four credit hours (3 credit hours for lecture and 1 credit hour for the laboratory).

The content of the lecture course (ENGR 3450) includes traditional topics such as introduction to materials science and engineering, atomic structure, atomic and ionic arrangement, imperfections in the atomic and ionic arrangements, atom and ion movements in materials (some faculty skip the chapter on diffusion), mechanical properties, strain hardening and annealing, solid solutions and phase equilibrium, dispersion strengthening and eutectic phase diagrams, dispersion strengthening by phase transformations and heat treatment, heat treatment of steels and cast irons, nonferrous alloys, along with two chapters in polymers, one chapter in ceramics, and one chapter in composites.

The content of the laboratory course (ENGR 3451) varies to some extent depending on the faculty and a team of teaching assistants teaching multiple sections of the laboratory course but it general the coverage is in harmony with the lecture topics. Generally, students are introduced to the basics of the measurement tools and are introduced to the concept of errors in measurements in the first week followed by an experiment on X-ray diffraction where lattice parameters of carbon steel (a ferrous alloy) and Al-2024 (a nonferrous alloy) are measured. Metallography of ferrous and nonferrous alloys is done with emphasis on phase identification. Then, mechanical testing (hardness test, tensile test, and impact test) is done. The laboratory course is completed by heat treatment of ferrous alloys (covering quenching, normalizing, and annealing processes), and age hardening of aluminum alloys. Recently, an experiment on hardenability of steels is added to the course content. In hardenability experiment, the ease of Martensite phase (hardest phase in steels) formation in three ferrous alloys including SAE-AISI 1020, SAE-AISI 1040 and SAE-AISI 4340 representing low carbon, medium carbon and low alloy steel alloys, respectively is compared and contrasted [1].

As additional content to the laboratory course, we have added activities that involve demonstration of the modern techniques and tools in materials science and engineering with the hope to stimulate students' curiosity and to entice them to consider joining graduate programs either here at UNT or anywhere else. Following sections summarize an example of the additional activities along with a survey done in one of the laboratory sections. Our aim is to share our experience on success of these efforts with colleagues teaching a similar laboratory course.

Demonstration of Oxide Characterization Using Fourier Transform Infrared Spectrophotometry (FTIR):

Students were taken to the Corrosion Engineering Laboratory at UNT to deliver a demonstration on application of the FTIR technique. In this demonstration, the first author described the principles of the FTIR technique by directing the students' attention to the use of electromagnetic spectrum shown in Figure 1. Utilization of different wavelengths and frequencies (hence different energies) in different aspects of science and engineering was highlighted. In addition, the presenter highlighted the use of highly energetic gamma rays in performing nondestructive testing through radiography for crack detection and crack size measurement. Utilization of the X-rays in measurement of lattice parameters for crystalline materials and the calculation of residual stresses introduced in materials during manufacturing was highlighted. In such a presentation, one can describe the electromagnetic spectrum in a chronological order based on the wavelengths and focused on visible range where infrared waves reside and discuss the applications of IR beam in the FTIR spectrophotometry technique. Fundamental of the FTIR technique is schematically shown in Figure 2.

Sample Preparation for FTIR Analysis

100 mg of potassium bromide (KBr) was mixed with 2 mg of a sample (corrosion product collected from a failed pipe used in oil exploration project). Experiment protocol provide by the manufacturer of the instrument was followed to collect a spectrum of the sample. Resulting FTIR spectrum is shown in Figure 3. Preliminary analysis of the spectrum was done by comparing the fingerprint spectrum of the sample under investigation with a library of known FTIR spectra available for all iron oxides and oxy-hydroxides. Upon completion of the FTIR analysis, students were informed of advantages of the FTIR technique such as speed of analysis, minimum training required for the operation of the instrument, ease of data interpretation as well as a limitation of the technique. First author has successfully applied FTIR technique in characterization of iron oxides and hydroxides [2-7]. The latest publication [8] on application of the FTIR technique for quantitative analysis of different oxides and oxy-hydroxides of iron was provided to each student.

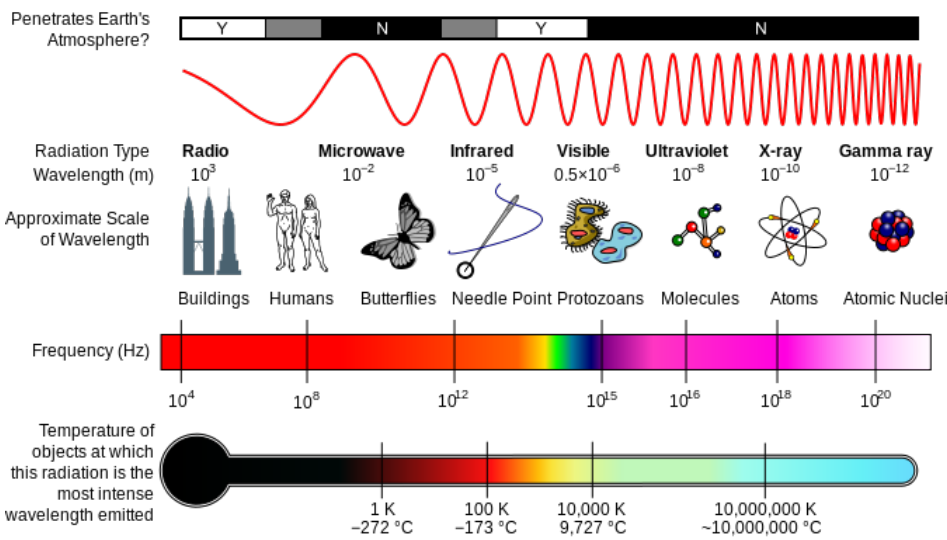

Figure 1: Electromagnetic spectrum

(source: https://en.wikipedia.org/wiki/Electromagnetic_spectrum#/media/File:EM_Spectrum_Properties_edit.svg)

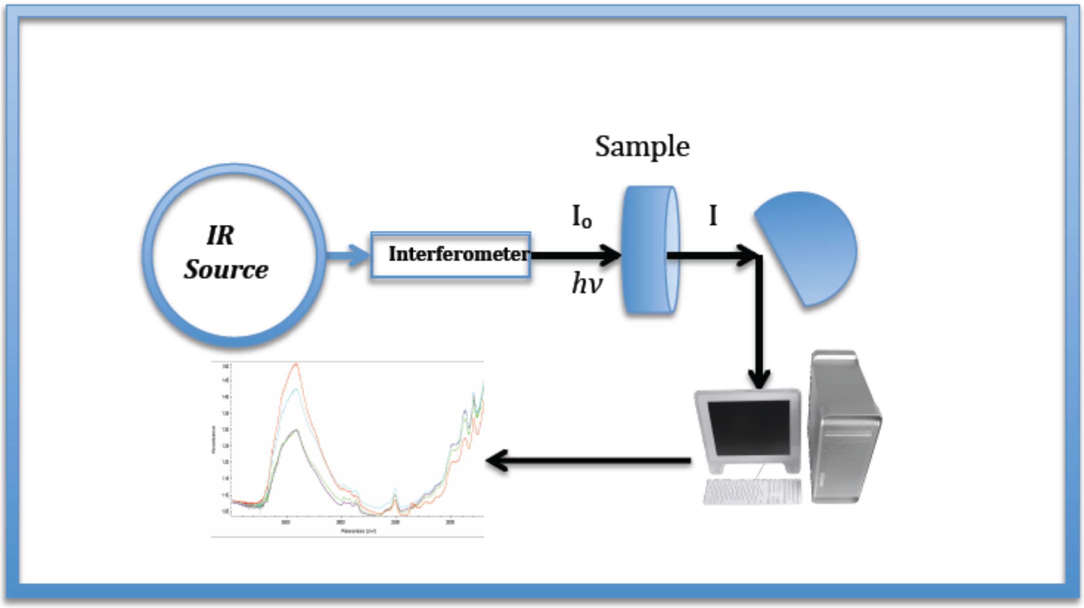

Figure 2: Schematic diagram of a typical FTIR system.

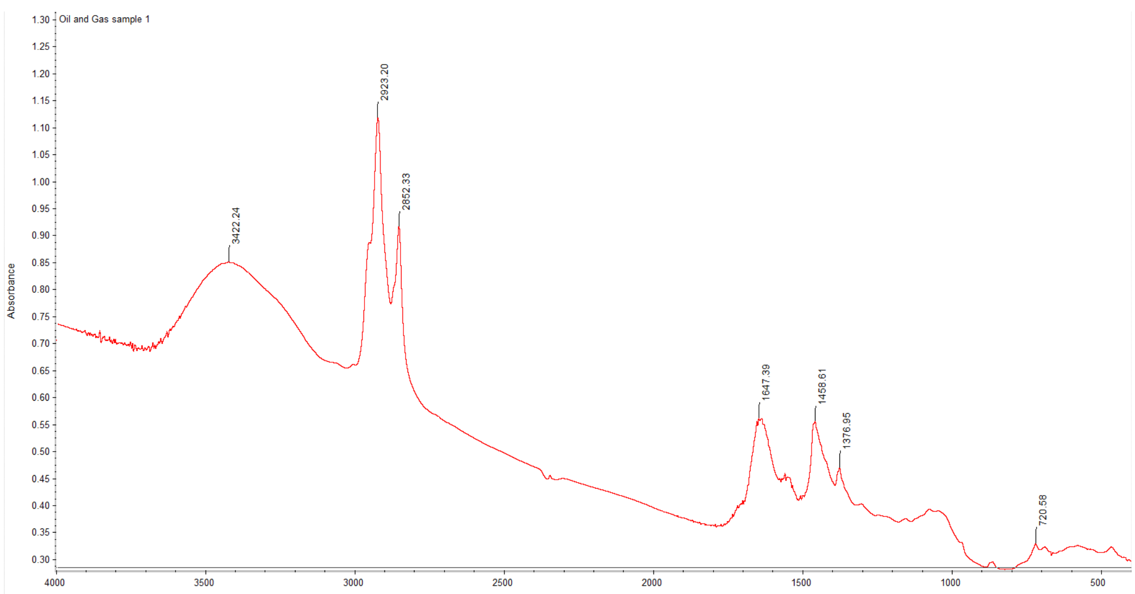

Figure 3: FTIR spectrum of corrosion product formed on a failed 3" pipe system used in oil and gas industry.

Assessment of FTIR demonstrations:

Table 1 presents a five-question survey on this enhancement activity that was administered at the conclusion of the FTIR demonstration. One of the objectives of this exercise was to gage the influence of such activity on enticement of students to consider pursuing an advance graduate degree. Therefore, the last question at the end of the survey (question #5) dealt with the effect of such demonstrations as stimulant of students' curiosity on science matters. Result of the survey with sample size of N=20 is presented in Figure 4. Data presented in Figure 4 show 98% of the students believe the demonstration was highly effective. All students believed they had an opportunity to observe application of spectrophotometry in characterization of engineering materials. 85% of students felt their curiosity was stimulated in application of FTIR in materials characterization. Nearly the same percentages of student agree or strongly agree that this demonstration successfully highlighted the role of advance instrumentation on materials research. The most important question (question #5) was added to gage the impact of the FTIR demonstration in planting a seed in students' minds to consider pursuing advanced degree and results show that most students were neutral, disagreed, or strongly disagreed.

Table 1: Survey for demonstration of advanced processing and materials characterization techniques.

Oxide Characterization using Fourier Transform Infrared Spectrophotometry (FTIR):

1. FTIR demonstration was highly effective:
    a. Strongly agree
    b. Agree
    c. Neutral
    d. Disagree
    e. Strongly disagree
2. FTIR demonstration provided an opportunity for students to observe application of spectrophotometry applications in Engineering Materials:
    a. Strongly agree
    b. Agree
    c. Neutral
    d. Disagree
    e. Strongly disagree
3. FTIR demonstration stimulated my curiosity in research issues related to importance of analytical techniques of characterization of materials:
    a. Strongly agree
    b. Agree
    c. Neutral
    d. Disagree
    e. Strongly disagree
4. FTIR demonstration highlighted the role of advanced instrumentation in Materials research:
    a. Strongly agree
    b. Agree
    c. Neutral
    d. Disagree
    e. Strongly disagree
5. FTIR demonstration enticed me to consider attending graduate school for an advanced degree:
    a. Strongly agree
    b. Agree
    c. Neutral
    d. Disagree
    e. Strongly disagree

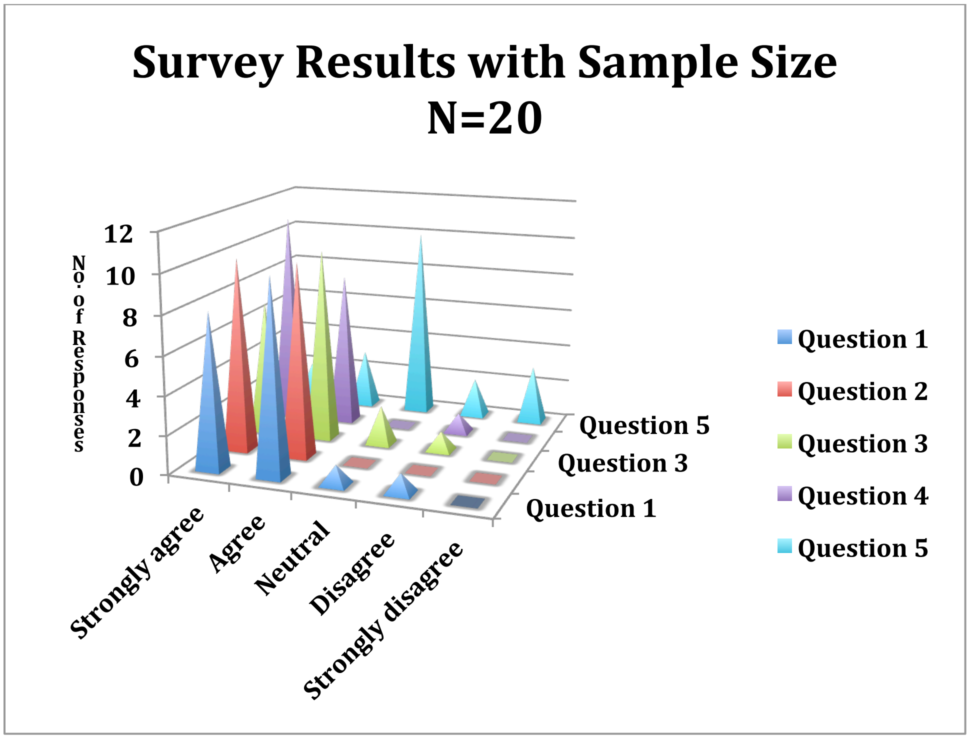

Figure 4: Result of the survey administrated after completion of FTIR demonstration.

Summary:

Purpose of this study was to assess the impact of additional activities to enhance the course content in the Engineering Materials Laboratory (ENGR 3451) that is an integral part of both Mechanical and Energy as well as Mechanical Engineering Technology programs in the College of Engineering at University of North Texas. Results of the survey show 98% of the students either strongly agree or agree that the demonstration was highly effective.

Furthermore, result of the survey indicated while the activity was effective to stimulate students' curiosity, the activity was not strong enough to entice students to seriously consider going for an advance degree. Other factors such as financial realities after graduation, family constraints, job placement and geographic locations are probably among a few critical factors dominating decision making of students in pursuing advanced degree.

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