Teaching Awareness about Pollution from Sound and Combustion Emissions

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ABSTRACT

This paper intends to communicate what is being taught at the University of Puerto Rico regarding pollution from noise and exhaust gas emissions. These two topics are addressed in the senior level Mechanical Engineering Laboratory II course in which students get exposure to subjects otherwise not covered in other courses.

NOISE POLLUTION AND CONTROL EXPERIMENT

Introduction

Sounds are always present in our daily environment. Depending upon their level, sometimes these become unwanted and are known as “acoustic noise”. The latter may be originated from different sources such as pumps, compressors, pneumatic equipment, traffic or just a group of people talking loud. Despite its origin, it has undesirable effects that affect human behavior and health such as hearing damage, disturbance, annoyance and distraction, interference with speech communication and at high levels, can even damage material structures by acoustic fatigue[1-3].

Awareness of such effects is important for an engineer that frequently has to make decisions that affect the environment such as pollution created by unwanted sounds. One way to reduce the effect of these sounds is by attenuating them using acoustic absorbers that ultimately transform sound energy into heat. Sound absorbing materials are used in rooms, to reduce excess reverberation, which leads to poor speech intelligibility; in ventilation spaces; in loudspeaker cabinets, to suppress undesirable cabinet resonance; and in machine enclosures to reduce the buildup of reverberant noise inside, and thus to improve their performance.

The behavior of such materials is related to the frequency of the sound. Adult males respond to sound waves in the frequency range of 20 to 16,000 Hz. The speech zone lies in the frequency range of 500 to 2000 Hz. The most critical subrange for control of noise purposes is within frequencies from 2000 to 5000 Hz.

Class Management

In this course, during a semester, students get a total of three hours of theory related to acoustics. Topics covered are sound waves, effect of sound waves in people, sound rating measurement, transmission of sound, attenuation of sound with distance and noise control. During the class students use a sound level meter to measure different levels of sound around campus and in a noisy setup where loud music is played or people are shouting simultaneously. The experimental part deals with sound absorption and is described below.

Equipment

This experiment uses an acoustic impedance tube (P. A. Hilton, B-400)[4] for the determination of the sound absorption properties of different materials. The apparatus consists of a transparent plastic tube fitted at one end with a twin loudspeaker enclosure, and at the other with a heavy sample holder on which the sample material is mounted. A small microphone may be moved axially along the length of the tube and its position measured.

The loud speakers are fed with a variable common pure tone (single frequency) from a function generator and the sound waves produced pass along the tube sample. According to the type of material and frequency, part of the sound energy is absorbed, and the remainder reflected back along the tube. The latter is detected by the microphone.

Interference between the sound waves reflected from the sample and those traveling toward it set up a standing wave field whose amplitude varies with the position in the tube. With the aid of an oscilloscope, the amplitude of the maximum and minimum signals received by the traveling microphone may be measured. From these values the sound absorption coefficient, α , is calculated as follows

$$\alpha = \frac{4\ B}{\left(B+1\right)^2} \qquad (1)$$

where B is the ratio between the maximum and minimum voltage displayed by the oscilloscope,

$$B = \frac{V_{max}}{V_{min}} \qquad (2)$$

Sound Absorption Experiment

The experiment is done in groups of two students. They are responsible for studying the operation manual for the equipment and doing the experiments. Besides getting exposure to the sound absorption coefficient, they also have an opportunity to startup equipment on their own with small supervision. During the experiment they test two specimens, one of them is part of the standard equipment (carpet, mineral wool liner, padding) and the other one is custom made such as foam, acoustic ceiling tile, or wood among others. Figures 1 and 2 illustrate absorption coefficient results in the frequency range of 200 to 2300 Hz. Specimens tested correspond to painted pressboard acoustic ceiling tile (thickness = 0.75 inch) and to glasswool air conditioning ducting material with aluminum foil liner (thickness = 1 inch), respectively. Two curves are presented in Figure 2, one where the aluminum foil faces the incident sound and the other where the glasswool faces the incident sound; the effect of the aluminum foil as a sound reflecting material is evident.

Students learn from experiments that the sound absorption coefficient varies with the frequency and that acoustic absorbers have to be selected according to the purpose or type of sound.

POLLUTION FROM EMISSIONS EXPERIMENT

Introduction

One of the major sources of ambient air pollution is combustion products from fossil fuels. Spark-ignition and diesel engines account for a good part of it. Exhaust gases from spark-ignition engines contain nitrogen (nitric oxide, NO, and small amounts of nitrogen dioxide, NO_2 -collectively known as NO_x), carbon monoxide (CO), and organic compounds that are unburned or partially burned hydrocarbons (HC). During the past 25 years environmental standards related pollution from emissions have become more rigorous. This has forced the automotive industry continuously to redesign their engines and accessories such that air is polluted the least possible. Carbon monoxide (CO) emissions from an internal combustion engine are controlled primarily by the fuel/air ratio[5].

Class Management

Students taking this course have previously taken a Thermodynamics II course and had been exposed to the basics of combustion. In this laboratory they receive a two-hour lecture about the mechanism of formation of pollutants and dissociation and chemical equilibrium of combustion species[6-7]. Also, they predict the composition of products, for a range of air to fuel ratios of propane, without taking into consideration dissociation of species. Finally, they become aware of the existence of flammability limits.

Equipment

Students use a P. A. Hilton C491 Laboratory Combustion Unit[8] and an exhaust gas analyzer (NOVA, model 376SWP)[9]. The combustion equipment itself is a combustion chamber with a water cooled jacket, provided with sight glasses for flame observation. The exhaust gas analyzer can detect O_2 (%), CO_2 (%), CO(ppm), NO(ppm) and NO_2(ppm). Measurements done include air, propane and cooling water mass flow rates, water and air inlet temperature, water exit temperature, combustion products temperature and combustion gases temperature at the exhaust of the combustion chamber.

Experiment

The purposes of this experiment are to determine the composition of combustion products from a propane combustion for different air to fuel ratios, to identify the flame appearance qualitatively, and to determine the lower and higher flammability limits. During the experiment the mass flow rate of propane is kept constant and the mass flow rate of air is varied. In addition students carry out energy balances and heat transfer analyses.

Several aspects emerge from this laboratory. The first one is that students learn to respect fire. Safety becomes an important issue for combustion processes. Also, they become aware of the different types of flame shapes, length, color, sound and stability as the air to fuel ratio is varied. Finally, they realize that their predictions for the exhaust gas composition are different from what they measured.

Figures 3, 4, 5 and 6 illustrate composition results and exhaust temperature as a function of the equivalence ratio, defined as the actual mass fuel to air ratio (FA_m) to the stoichiometric mass fuel to air ratio. Equivalence ratios smaller than one show a fuel lean mixture whereas equivalence ratios higher than one represent fuel rich mixtures. Theoretical predictions show that the maximum composition of CO_2 occurs for the stoichiometric combustion (air to fuel mass ratio, AF_m= 15.6 or equivalence ratio, = 1), however in reality this value corresponds to a fuel rich combustion.

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BIOGRAPHICAL INFORMATION

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Luis M. Bocanegra is an Associate Professor at the Department of Mechanical Engineering of the University of Puerto Rico, Mayagüez Campus. His research is related to heat transfer and fluid dynamics. Also, he is author of several papers in conferences related to undergraduate laboratory teaching. Dr. Bocanegra holds a Diploma of Mechanical Engineer from Catholic University of Peru and MSME and Ph.D. from West Virginia University.

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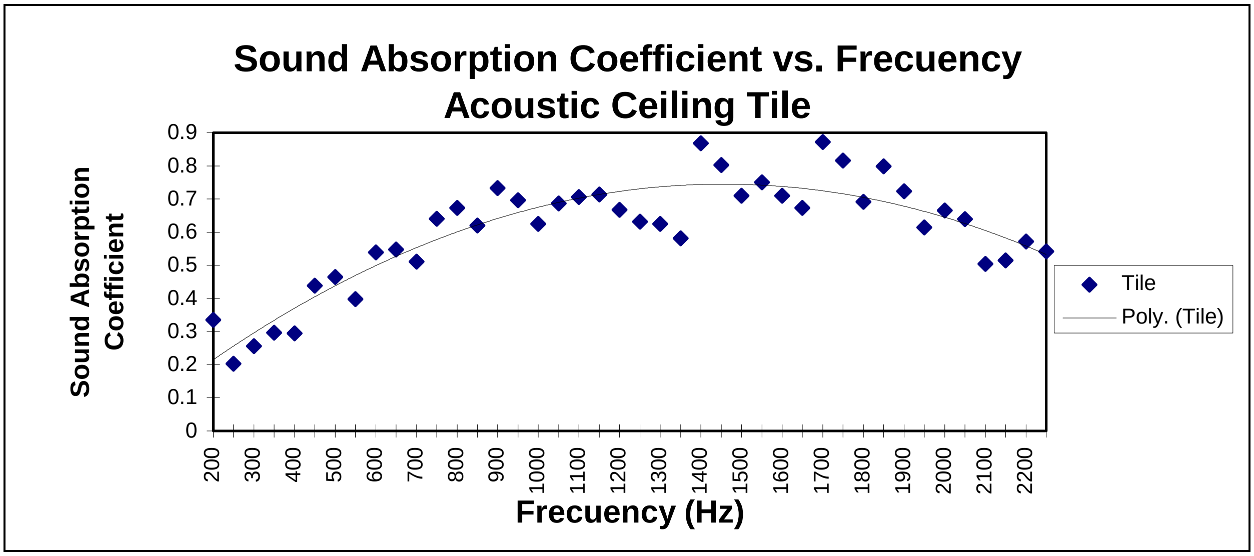

Figure 1: Sound absorption coefficient for painted pressboard acoustic ceiling tile.

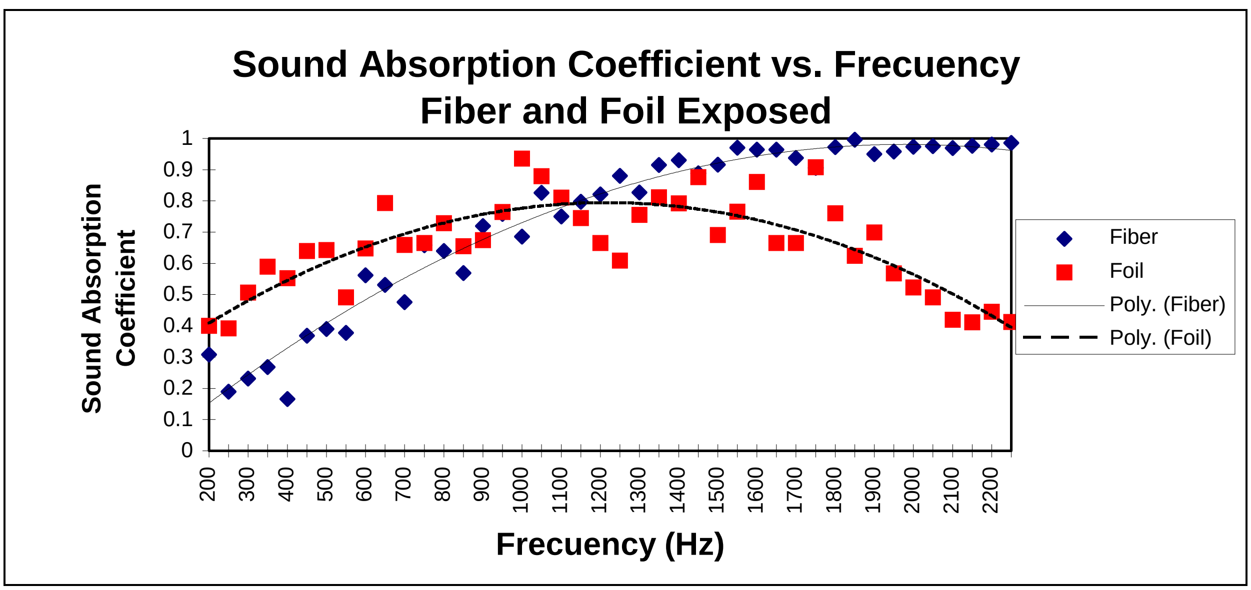

Figure 2: Sound absorption coefficient for glasswool air-conditioning ducting material with aluminum foil liner. Exposed surfaces were tested separately.

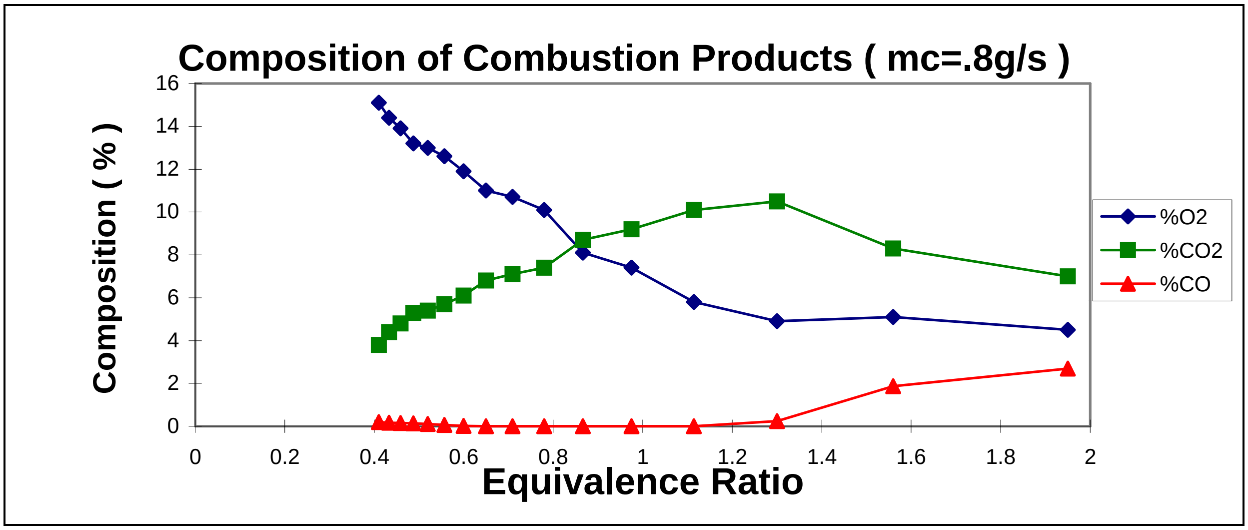

Figure 3 : Composition of combustion products from propane as a function of equivalence ratio for a propane mass flow rate equal to 0.8 g/s.

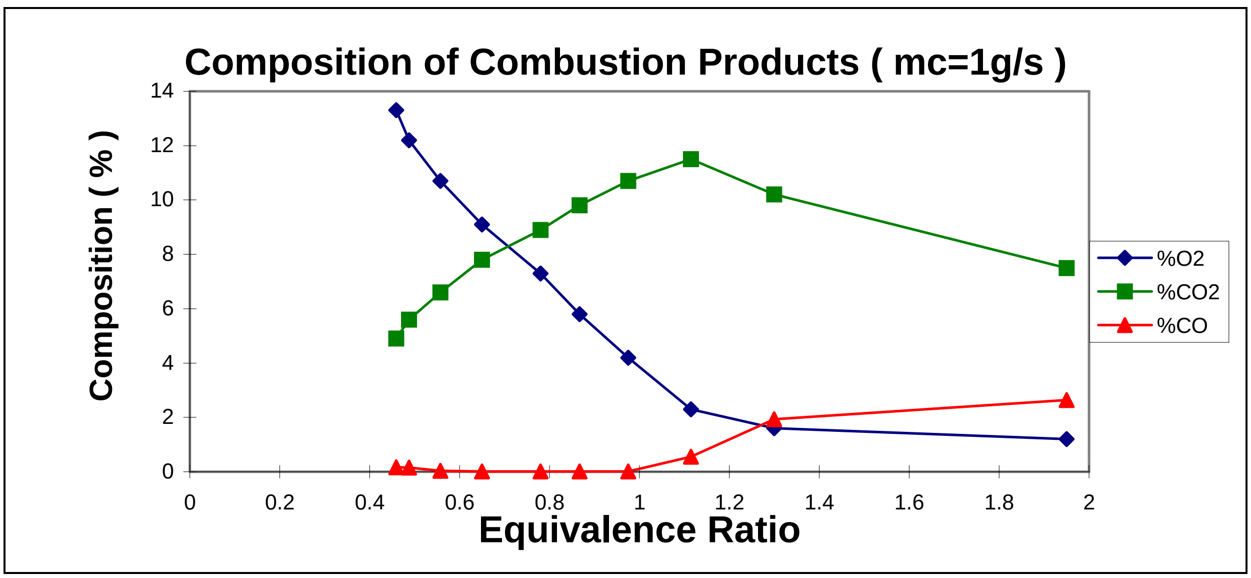

Figure 4 : Composition of combustion products from propane as a function of equivalence ratio for a propane mass flow rate equal to 1.0 g/s.

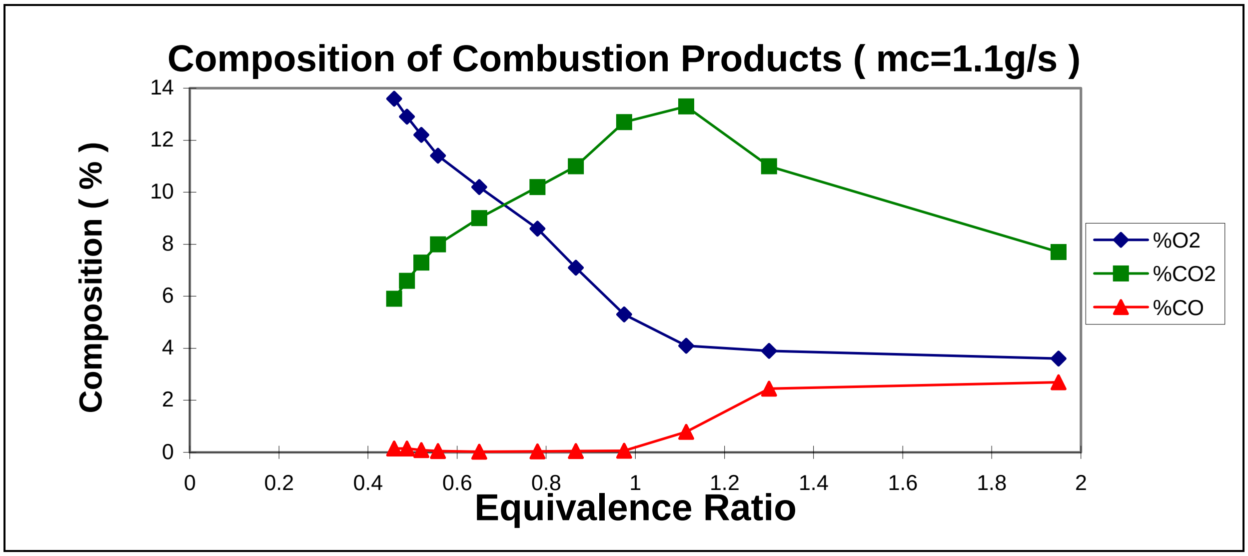

Figure 5 : Composition of combustion products from propane as a function of equivalence ratio for a propane mass flow rate equal to 1.1 g/s.

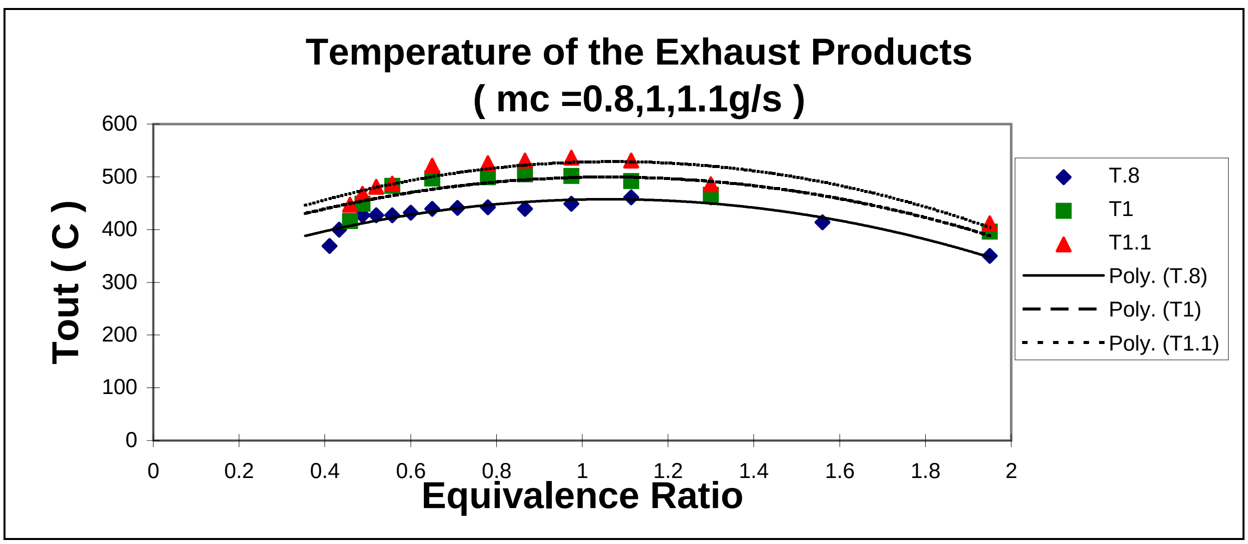

Figure 6: Exhaust gas temperature measured at the exit of the combustion chamber as a function of equivalence ratio for propane mass flow rates equal to 0.8, 1.0, and 1.1 g/s, respectively.