Sound Speed Through Ethanol-Water Mixtures

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Introduction

Ethanol-water mixtures are used for many purposes. The most obvious use for them is in distilled spirits. Fundamentally, drinks like bourbon and vodka are mixtures of ethanol, EtOH, and water, while other physical and chemical properties come from the production process (i.e. the color of bourbon comes from the barrel). The traditional method of measuring the alcohol content of a distilled spirit involves a floating hydrometer; however, the floating hydrometer is not very accurate. A standard floating glass hydrometer cannot yield an accuracy of more than two or three gravity points (a common measurement for hydrometers). Floating hydrometers also frequently suffer from manufacturing errors (Dixon, n.d.). Another method involves the use of a digital hydrometer, such as the Anton-Paar Snap 51. This gives a very accurate measurement to 0.1% v/v. However, the Snap-51 is almost $4,000 (Anton Paar, n.d.). A distilled spirits manufacturer must choose between cost-effectiveness and accuracy.

Another use of EtOH-water mixtures is in the calibration of ultrasound technology (Jintamethasawata, et al., 2018). It is generally accepted that the sound speed, c through a solution of 9.6% EtOH at 20°C is 1540 m/s (Martin & Sprinks, 2001). Having an accurate and cheap measurement of c through water would also help ultrasound technology.

Theory

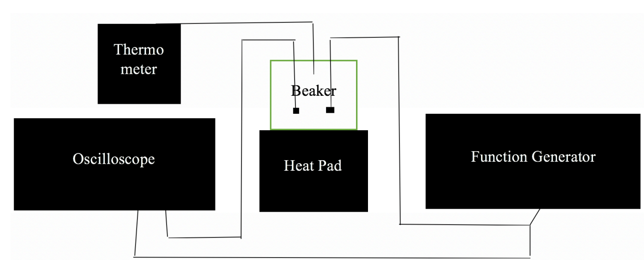
Sound speed, c, through liquids is calculated by the equation

$$c=\sqrt{(K/P)}$$

where K is the compressibility, and ρ is the density of the liquid (Engineering ToolBox). Generally, sound speed is not calculated using the equation, but rather through the time of flight method. K and ρ are often calculated using sound speed, not the other way around (Hurdle, 1986).

Experiment

In the initial data collection, the Tektronix AFG3022C function generator put out a pulse to two contact transducers. One was the source transducer, and the other was the receiving transducer. The signal between the transducers was measured by the Hewlett-Packard 54616B oscilloscope. A certain arbitrary amount of water and ethanol were mixed in a beaker. The ethanol concentration was measured using the Anton-Paar Snap 51. The Snap 51 is a digital hydrometer that measures ethanol content with 0.01 %v/v accuracy (Anton Paar, n.d.). The mixture was cooled by placing the beaker in a box of ice. After the mixture was cooled, it was placed on a heat pad. There was a magnetic stirrer in the mixture to make sure it was heated evenly. The stirrer distributed the heat evenly throughout the mixture, so that it was not warmer on the bottom. The contact transducers were then placed inside the mixture. The pulse was sent through, and the delay was measured by measuring the time between the pulse and the echo that came several microseconds later. This was done at several temperatures from about 10°C to 40°C. The temperature was measured in the initial data set with Omega HH81A and the HH82. The distance between the transducers was measured using vernier calipers, and the distance was divided by the time to find the sound speed.

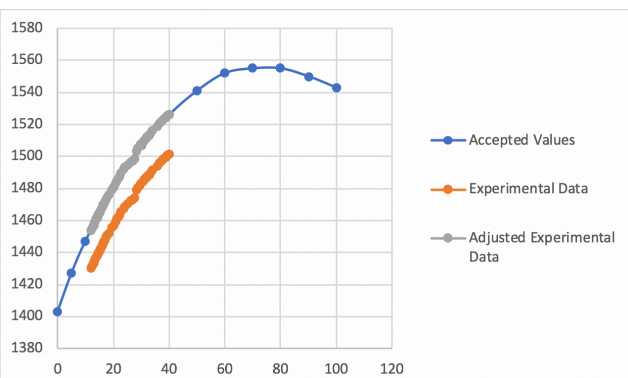


I attempted to use the two piezoelectric transducers to take data (Amazon, 2016). The contact transducers are very expensive, and an individual piezoelectric transducer costs less than a dollar. The transducers were glued to plexiglass and the intent was to put the transducers on plexiglass in the EtOH-water mixture to send a pulse through the transducers. For the first try with the piezoelectric transducers, a continuous sine wave was sent from the function generator. The receiving transducer received the sine wave. However, the continuous sine wave destroyed the piezoelectric transducers. When a pulse with 10% duty cycle was sent from the function generator, the receiving transducer could not pick up the signal. So, the piezoelectric transducers were abandoned.

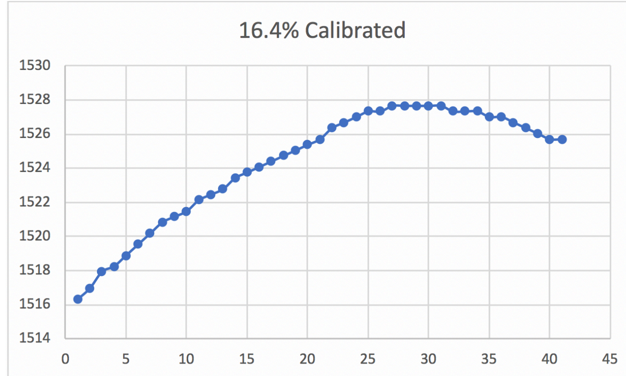
For the last three data sets, the procedure was the same as it was with the contact transducers; however, the temperature was measured with a thermistor, the Omega 44007. The thermistor was attached to an Arduino Uno. The Arduino code for the thermistor is attached. The code was based off of a code found online (ada, n.d.). Some of the constants in the code were adjusted to match the specific thermistor that was used.

Results

The readings taken throughout the semester are in the attached excel file. There were two sets of data taken. The first set was taken with the contact transducers, the Omega HH81A and the HH82, and with the thermistor. The calibration for the first "device" was done using a test run of pure water. The values were slightly lower than in the accepted values for water. The experimental data was calibrated by multiplying the data by 0.980788293736, making the values close to the accepted values.



As seen in the chart, with the adjustment made, the adjusted experimental values match the accepted values well.



There was only one other data set that was at the exact same distance as the pure water data set, the 16.4% EtOH data set. Because the other sets did not have the same distance between the transducers, they are unfortunately unable to be calibrated. The experimental data's error is probably because of the uncertainty of the measurement of distance between the transducers. The second data sets used the same contact transducers and a thermistor to measure the temperature. These data sets unfortunately differed from the accepted values enough that they were not able to be calibrated. The most likely source of error in these measurements is the transducers, although this has not been proven.

There is some error that is a byproduct of the instruments used. There is some error in reading the oscilloscope. The time difference measurement, the only reading obtained from the oscilloscope, is "0.2% of full scale" (Agilent Technologies, 2001). The readings on the oscilloscope are sometimes very noisy, and the peak of the signal was difficult to read at times. There is an error in my reading of the oscilloscope of 0.01 microseconds. The thermometer used for the initial taking of data is "0.1% of rdg. 0.7°C" (Omega, n.d.). This means that the error is 0.1% of whatever the measurement is, and that the absolute error is 0.7°C (Kyoritsu, n.d.). The thermistor has an error of 0.5°C from 0-70°C (Omega, n.d.). The experiment does not require going beyond that range. Probably, the largest source of error was the distance between the transducers. The distance was measured between the transducers both before and after on many of the trails and the difference was as high as 35 mm. For the data calculations, the distance measurement after the experiment was used, as it was more reliable. When putting the transducers in, there was far more difficulty while trying to fit them in place perfectly, which led to some error; however, there was a far less chance for error while taking them out.

Conclusion

In the future, more work needs to be done on the project. Currently the transducers need to be replaced. Ideally some cheaper transducer would be used. The device must be able to send out a pulse and measure the time difference without an oscilloscope or a function generator. Ideally this would all be done using an Arduino, which is cheap, easy, and far more compact than the current setup. In addition, the calculation of EtOH percentage needs to be done.

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