Correction factors in determining speed of sound among freshmen in undergraduate physics laboratory

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Abstract. This paper deals to identify the correction factor in determining speed of sound that have been done by freshmen in undergraduate physics laboratory. Then, the result will be compared with speed of sound that determining by senior student. Both of them used the similar instrument, namely resonance tube with apparatus. The speed of sound indicated by senior was 333.38 ms⁻¹ with deviation to the theory about 3.98%. Meanwhile, for freshmen, the speed of sound experiment was categorised into three parts: accurate value (52.63%), middle value (31.58%) and lower value (15.79%). Based on analysis, some correction factors were suggested: human error in determining first and second harmonic, end correction of tube diameter, and another factors from environment, such as temperature, humidity, density, and pressure.

1. Introduction

Basic physics course on the speed of sound topic can be supported by laboratory-based experiment. Physics concept is not only about the concept but also about how the concept is obtained rationally [1]. Because of that, experiment activity allows students to dig more knowledge about sound waves, because they obtain hands-on experience in the lecture process. It will help them to be more competence as a pre-service teacher. A traditional experimental method can be used to determine the speed of sound in the air, studying sound waves harmonic in closed-tube [2]. Its instrument is called resonance tube with apparatus. It is consist of loudspeaker, amplifier, closed-tube with scales and a piston. Piston in the tube is moved to compress the gas. Before it is moved, the gas is undisturbed and having uniform density. The gas just in front of it is compressed when the piston is suddenly pushed, so the pressure and density in this region are now higher than before [3].

Changes of pressure because of a rapid movement of the piston, gives the sound as a result. It will be traveling pressure that is reflected at the bottom of the tube. The superposition of an incident and reflected waves give standing wave will have a node at one end and antinode at the other end. This is the fundamental frequency or first harmonic of the air column in the tube. This oscillation has the longest wavelength (λ), four times greater than the length of the air column (λ = 4L₁, i.e. the length of air column) [4].

Speed of sound can be determined using the equation,

\[ v = \lambda f \] (1)
Where $f$ is fundamental frequency and $\lambda$ is the wavelength, $\lambda = 4L_1$, where $L_1$ is the length of the air column in first harmonic.

An end correction factor must be added to the length because the antinode forms above the top of the tube. Based on theory, it is found that correction factor $e$ is equal to $0.4d$ for closed-tube [4], where $d$ is the inner diameter of the tube. Hence,

\begin{align}
\lambda &= 4(L_1 + e) \\
v &= 4f(L_1 + 0.4d)
\end{align}

In closed-tube, the length of an air column for second harmonic is $L_2 = \frac{3}{4}\lambda$ [5,6]. So that, end correction can be calculated by substituting equation (2) into $L_2 + e = \frac{3}{4}\lambda$ because there is an end correction factor for second harmonic. Therefore,

$$e = \frac{L_2 + 3L_1}{2}$$

Sound wave propagates in the air depend on ambient temperature [1]. In air $0^\circ$C and 1 atm, sound travels at speed $331$ ms$^{-1}$. If $v_0$ refers to the speed of sound in the air at $0^\circ$C and $T_c$ to the medium temperature in degrees Celcius, then the speed of sound in any temperature is given the following formula [7,8],

$$v = v_0 + (0.6T_c)$$

2. Method

The research design is by using quantitative descriptive method. The sample is taken from freshmen in Universitas Negeri Surabaya, Indonesia. The research subjects are 19 experiment groups in physics laboratory. Each of the groups is consist of two or three members.

![Flowchart of the research methods](image)

Data is obtained from the result of the senior student’s experiment and freshmen’s experiment report. Both of them used similar instrument, namely resonance tube with apparatus. It is conducted by
using loudspeaker as a sound source and set amplifier for particular frequency. Piston movement in a tube make different tone from the source. At the time of recording it, the scale of loudest tone is a length of air column that resonance occurs. It is observed to get first and second harmonic. Senior experiment activity is selected five frequencies in the audible range, 311-395 Hz. Every frequency is repeated three times for getting accurate data. The data of waves are calculated to determine the speed of sound from that experiment. Afterwards, it is compared to the speed of sound in theory. Difference result both of the speed of sound in experiment and theory are analysed to figure out the correction factors.

One of parts in freshmen’s experiment report is discussion part. They write their prediction and discussion about the factors that affect to their experiment result on it. Then it will be analysed to find the precise reason. The correction factors of them are presented in percentage form in a table.

3. Results and Discussion
Explanation of the result will be showed in two parts. Experimental data by the senior student is explained first in the table 1. The speed of sound is calculated with adding end correction factor.

Table 1. Experimental data performed by the senior students.

| No. | Frequency (Hz) | L₁ (x 10⁻² m) | L₂ (x 10⁻² m) | Speed of sound (ms⁻¹) |
|-----|----------------|---------------|---------------|-----------------------|
| 1   | 311.4          | 29.97         | 83.17         | 331.33                |
| 2   | 338.0          | 28.90         | 77.90         | 331.24                |
| 3   | 354.6          | 26.47         | 73.17         | 331.20                |
| 4   | 375.9          | 22.47         | 67.33         | 337.31                |
| 5   | 394.5          | 21.57         | 64.13         | 335.85                |
|     | Speed of sound average |            |               | 333.38                |

Determining speed of sound that indicated by the senior student is 333.38 ms⁻¹ at room temperature. It has deviation to the theory about 3.98%. Then the data is represented in a graph to get speed of sound using the gradient of graph in figure 1.

![Figure 1](image-url)  
**Figure 1.** Plotting of 1/\(\lambda\) as a function of \(f\) to determine \(v\), indicated by the senior student.
Based on the graph shown in Fig. 1, the speed of sound in the air can be obtained as follows:

\[
v = \frac{1}{m} = \frac{1}{0.003} = 333.33 \text{ m/s}^{-1}
\]

The speed of sound that indicated by freshmen is categorised in three parts: accurate, middle and lower. It base on the difference between the speed of sound in the air that indicated by freshmen and theory. For dry air condition with 1 atm pressure, the speed of sound that calculated by using equation (5) at room temperature 27°C is 347.2 m/s and at 20°C is 343 m/s. Some previous research found different values of speed of sound such as: (343±3) m/s at 25.5 °C [10], 342.96 m/s at 23°C [6], (344±3) m/s at 23°C [11], and the average speed of sound value of (336±4) m/s at various temperature from 19.1°C to 26.8°C [9]. The categories are presented in the table 2.

**Table 2.** The speed of sound categories in air indicated by freshmen.

| No. | Speed of Sound Range (m/s) | Categories | Percentage (%) |
|-----|-----------------------------|------------|---------------|
| 1   | 343 – 359                   | accurate   | 52.63         |
| 2   | 298 – 337                   | middle     | 31.58         |
| 3   | 117 – 125                   | lower      | 15.79         |

The largest percentage is in the accurate category where the value is approximate to the speed of sound in theory. Meanwhile, there is still a speed of sound in the lower category. The result in other categories is caused by factors as a correction of the experimental results. The correction factors that mentioned freshmen are presented in the table 3.

**Table 3.** Correction factors based on freshmen’s experiment report.

| No. | Correction Factors                        | Percentage (%) |
|-----|------------------------------------------|----------------|
| 1   | Error in determining first and second harmonic | 21.28          |
| 2   | Temperature                               | 19.15          |
| 3   | Noisy                                     | 17.02          |
| 4   | Pressure                                  | 12.77          |
| 5   | Too low frequency                         | 10.64          |
| 6   | Density                                   | 6.38           |
| 7   | End-correction of tube diameter           | 6.38           |
| 8   | Uncertainty of measure tool               | 4.26           |
| 9   | Moving air condition                      | 2.13           |

A correction factor about 4.5 ms⁻¹°C⁻¹, can be used as a scale between temperature and speed of sound in cold water. The important role to respect the speed of sound in water is temperature and salinity [12]. The speed of sound depends on temperature and does not depend on pressure in the air [13]. The speed of sound is increase as the equation (5). The increase of density is affected by the increasing of pressure. There is no speed of sound change caused by pressure. But it is true if the temperature remain constant. Density change is caused by temperature change. It does not affect pressure. Pressure changes may affect density but do not vice versa [13]. Other studies have suggested that temporal or spatial variations in pressure (e.g., atmospheric influences) have a small effect on the speed of sound so that the pressure attenuation can be ignored [12].

Another factor that affects the density is humidity. Dry air is more dense than moist air (not particularly visible). This causes an increase in the speed of sound. The decrease of specific-heat ratio is caused by moisture, which cause speed of sound to decrease. However, increasing moisture will
increase the speed of sound because the decrease in the density is dominant [13]. Sound waves have a strong influence on temperature and relative humidity [14] because it affects the amount of absorption by the atmosphere. It also deals with the frequency which is the high frequencies will be absorbed more than low frequencies [14,15].

The end correction of tube diameter is one of the reasons for the difference between the speed of sound and theory. It should be calculated based on the equation (4). While the instrument that is used to measure the length of air column has uncertainty about 0.05 cm.

Moving air or wind conditions have an effect on the speed of the sound. If the medium moves, the sound will be transported further [15,16]. The high horizontal wind speed will produce sound refraction because it causes the average speed of sound to vary [17]. However, in determining speed of sound was not done in outdoor so no moving air factors that affect.

There are many predictions of correction factors that have been determined by freshmen. The percentage of error when determining the first and second harmonic is the greatest of all. One of the reasons expressed by the freshmen is when pulling the piston is not slowly. Longitudinal waves located in the compressed area by the piston move at a certain velocity v, but the piston does not move with velocity v because the speed of sound is greater than the speed of the piston [3]. The error of determining the first and second harmonic affects to the length of the air column so give different wavelength as the results. It has a major effect on the speed of sound, especially in the lower category.

According to table 2, the correction factors corresponding to the experiments are error in determining first and second harmonic, uncertainty of the instrument, end correction of tube diameter and environmental factors such as temperature, humidity, density, and pressure.

From the experiment result and explanation above, some suggestion to the freshmen is doing experiment in the noiseless place so that the sound coming out can be heard clearly. It will reduce the error of obtaining the first and second harmonic. Experimental report, especially in discussion part should be analysed deeply for determining correction factors precisely. Analyse ability will give benefit for student to get one of skills in 21 century and improve conception of learning physics [18].

4. Conclusion
Speed of sound indicated by freshmen is different. They are categorized into three groups: accurate (52.63%), middle (31.58%) and lower (15.79%). The most results are accurate, the value approximate to theoretical. Speed of sound indicated by senior students is 333.38 ms⁻¹ with a deviation to the theory about 3.98 %. The correction factors are suggested: error of determining first and second harmonic, uncertainty of the measuring instrument, end correction of the tube diameter, and environmental factors such as temperature, humidity, density, and pressure.

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