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Experimental and Numerical Investigation to Visualizing Gas Standing Waves of Air and Propane and the Effect on Smaller and Bigger Diameter Tube with Acoustic Propagator

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Experimental and Numerical Investigation to Visualizing Gas Standing Waves of Air and Propane and the Effect on Smaller and Bigger Diameter Tube with Acoustic Propagator

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any degree.

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ABSTRACT

The proposed study aims to demonstrate a standing wave with acoustic propagator. It demonstrates the link between sound pressure and sound waves. A review of literature on sound waves works with Ruben's Tube and benefit gain from learning sound analysis showed that this topic is continuously gaining its momentum. Nevertheless, application of acoustic from the study science and vibration can bring a lot benefit to the technology for human being such as application of horn antenna. Apart from that, a study on the different type of gas show how each type of gases reacts with the standing waves produced by speaker. Besides, using different size of tube diameter for acoustic propagator shows the effect to the standing wave output pattern. The most interesting in this experiment is to make Ruben's Tube into integrated system, where the tube would connect to laptop and used software Audacity for data analysis and data collection. All the program is created using the software where the change of frequency, amplitude and speed of gases automatically. Therefore, it would no longer used amplifier to find the suitable frequency to show the best standing wave pattern. Furthermore, the difference result analysis for air and propane gas show that air has higher speed of sound in both size tube diameter than propane. Also, the larger tube diameter makes the flame accelerates faster hence, when the flame touches the tube walls it would generate stronger pressure waves.

Keywords: Ruben's tube, standing wave, acoustic propagator.

P*enyiasatan Eksperimental dan Berangka Untuk Menggambarkan Gelombang Berdiri Gas Udara dan Propana dan Kesan pada Tiub Garis Pusat Kecil dan Besar dengan Penyebaran Akustik*

ABSTRAK

Kajian yang dicadangkan bertujuan untuk menunjukkan gelombang berdiri dengan penyebaran akustik. Ia menunjukkan hubungan antara tekanan bunyi dengan gelombang bunyi. Tinjauan kesusasteraan pada gelombang bunyi berfungsi dengan tiub Ruben's dan mendapat keuntungan dari analisis bunyi pembelajaran menunjukkan bahawa topik ini terus mendapat momentumnya. Walau bagaimanapun, aplikasi akustik dari sains kajian dan getaran boleh membawa banyak manfaat kepada teknologi untuk manusia seperti penggunaan antena tanduk. Selain itu, kajian mengenai jenis gas yang berbeza menunjukkan bagaimana setiap jenis gas bertindak balas dengan gelombang berdiri yang dihasilkan oleh pembesar suara. Di samping itu, menggunakan saiz garis pusat tiub yang berbeza untuk penyebaran akustik menunjukkan kesan kepada corak output gelombang berdiri. Yang paling menarik dalam eksperimen ini ialah membuat Ruben's Tiub menjadi sistem bersepadu, di mana tiub akan menyambung ke komputer riba dan menggunakan perisian Audacity untuk analisis data dan pengumpulan data. Semua program dibuat menggunakan perisian di mana perubahan kekerapan, amplitud dan kelajuan gas secara automatik. Oleh itu, ia tidak lagi digunakan penguat untuk mencari frekuensi yang sesuai untuk menunjukkan pola gelombang berdiri terbaik. Selain itu, analisis hasil perbezaan untuk udara dan gas propana menunjukkan bahawa udara mempunyai kelajuan bunyi yang lebih baik dalam garis pusat tiub berbanding dari gas propana. Garis pusat yang lebih besar juga membuat api bergerak lebih cepat dengan itu, apabila api menyentuh dinding tiub itu akan menghasilkan gelombang tekanan yang lebih kuat.

Kata kunci: *Tiub Ruben, gelombang berdiri, penyebar akustik.*

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LIST OF ABBREVIATIONS

AN	Anti-Nodes
GUI	Graphical User Interface
N	Nodes

CHAPTER 1

INTRODUCTION

1.1 Introduction

Sound propagates through air in the form of pressure waves (Gardner et al., 2009). However, it is difficult to watch standing waves with naked eye. Therefore, it can be visualized using the Ruben's Tube.

By passing flammable gas through a long metal tube with a small hole drilled on top, it is possible to create a line of individual flames. The height of each flame is related to the gas flow rate through the hole beneath it, which can be altered by modifying the gas pressure inside the tube (Gee, 2009). If this is done by a suitable choice of sound waves, standing waves can be established inside the tube, resulting in flame pattern. These can then be examined to establish relationships between the sound waves and the gas in which they travel.

1.1.1 Characteristics of Sound Waves

Characteristic of the sound waves come from the back and forth vibration of the particles of the medium through which the sound wave is moving. If a sound wave is moving from left to right through air, then particles of air will be displaced both rightwards and leftwards as the energy of the sound wave passes through it (Budak, 2009). This is what makes sound wave a longitudinal wave.

Air particles makes longitudinal motion therefore two kinds of regions are created according to the compression of particles as compressed together or as spread apart. When there is high pressure on a region than it is called compression however when there is a medium of low air pressure than it is called rarefaction (Amrita, 2013). A sound wave is formed of high and low-pressure regions therefore it is referred as a pressure wave.

The fluctuations in pressure as detected by a detector occur at periodic and regular time intervals. In fact, a plot of pressure versus time would appear as a sine curve. The peak points of the sine curve correspond to the compressions; the low points correspond to rarefactions; and the "zero points" correspond to the pressure which the air would have if there were no disturbance moving through it (Amrita, 2013). Example of pressure wave of sine curve shown in Figure 1.1.

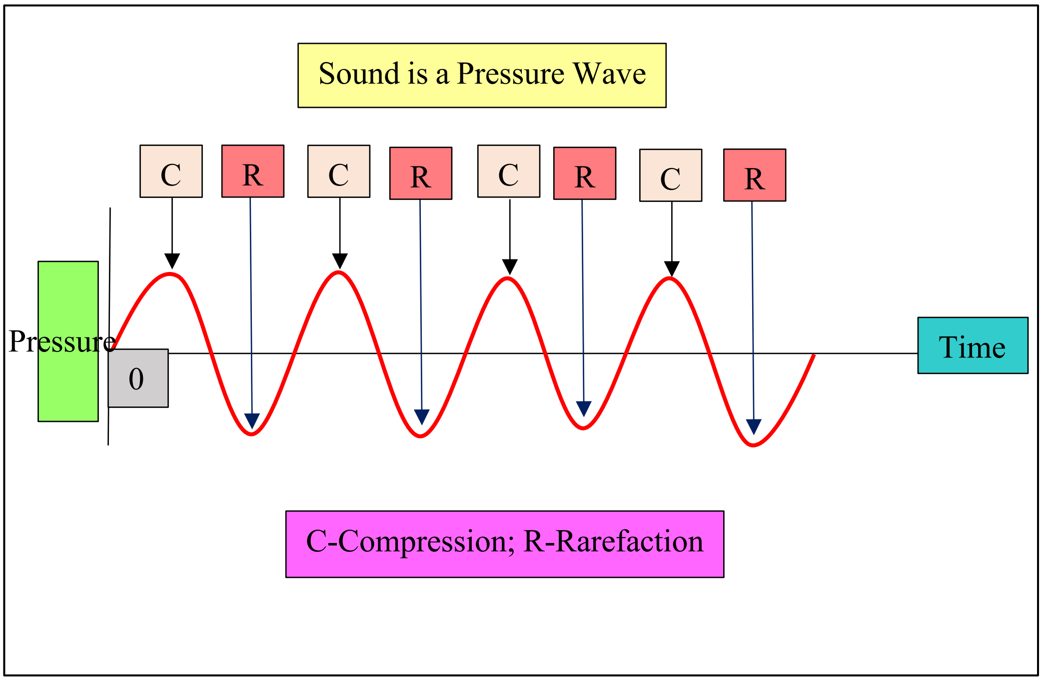

Figure 1.1: Sound is a Pressure Wave of Sine Curve

(Source: Salim et al., 2018)

Standing waves produced in Ruben's tube are open at one end and closed on the other. Therefore, the wave will start with a node and end with an antinode. According to Budak (2009), the reason for such behavior of the waves are the air pressure oscillation at the closed end since it has the greatest amplitude and forms an antinode.

1.1.2 Background of Ruben's Tube

Ruben's tube was invented by German physicists, Heinrich Rubens and Otto Krigar-Menzel. In 1905, Heinrich Rubens took a 4-metre-long tube and with 2-centimeter intervals and he drilled 200 small holes on the surface of the tube. Then he filled it with a flammable gas. When the gas was lighted, realized the rose of equal heighted flames escaping from the holes (Budak, 2009). This experiment revealed the acoustic standing wave behaviors.

After several trials, it concludes that when a sound is produced at the end of tube, it creates a standing wave which is equivalent to the wavelength of the sound given into the tube (Budak, 2009). The idea of Ruben's tube is coming from the demonstration of a standing wave by placing cork dust in a tube which was experimented in 1866 (Gee, 2009). In this experiment when a sound was made in the tube, the dust lined up as nodes and antinodes with the fluctuation of the sound wave in order to create a standing wave (Gee, 2009).

1.2 Problem Statement and Research Questions

Current system of Ruben's Tube is not rigid and it is not integrated which mean it needs to manually change the frequency, amplitude and speed of gas of the system during the experiment. Therefore, it is tedious and time consuming. Apart from that, different type of gas such as air and propane have different density and molar mass. Hence, it affects the pattern of flame and speed of sound inside the tube (Anderson et al., 2015). Besides, different size of tube diameter effects the flame pattern above the tube. Small and Big diameter tube has different effect on the flame propagation velocity inside the tube (Almarcha et al., 2015). Therefore, the primary research questions the researcher is trying to solve are:

i. How to make Ruben's Tube into instrumentation system by using numerical software?
ii. How does different type of gases effect the flow of gas vibration in Ruben's Tube?
iii. How do different size of diameter tube effect the flame propagation velocity?

1.3 Hypothesis

The integrated system of Ruben's Tube is easier to change the frequency and speed of gas rather than using the frequency generator by manually. The pattern of standing waves output also change with difference types of gases and difference size of diameter tube.

1.4 Research Objectives

The objectives of this study are:

i. To develop instrument system of Ruben's Tube through software Audacity for standing wave output with acoustic propagator.

ii. To establish relationships between the speed of gas into different types of gases that is air and propane.

iii. To investigate the effect on difference larger and smaller diameter tube with flame propagation velocity.

1.5 Scope of Research

This research explains the behavior of standing waves and sound pressure. A perfectly constructed Ruben's Tube would also show the property of the sound waves such as frequency, wavelength and speed. Besides, this research only used two types of gas that is air and propane due to limitation on money expenses. Apart from that, the researcher also wants to make Ruben's Tube into an integrated system where this experiment will use numerical software to change the speed of gases and frequency in it. Therefore, Ruben's Tube can be used as demonstrator in physic classes in many universities and engineering schools.

1.6 Research Novelty

There has been research on speed of gases using Ruben's Tube. However, that experiment only make comparison between air and propane by manually using frequency generator (Anderson et al., 2015). Therefore, this gives the idea to make comparison using numerical software which has higher accuracy than the manual set up.

1.7 Outline of Chapters

This section explains briefly what to expect in each chapter for this study.

Chapter 1- This chapter explains the history of Ruben's Tube and introduction of standing wave. It also explains the characteristic of sound waves inside the tube. This chapter also consist of problem statement and objective for this research study.

Chapter 2- This chapter provides a review on Ruben's Tube and some related work that has been done by others. Also, it consists theory in calculation that will be used in Chapter 4.

Chapter 3- This chapter explains the procedures and the methods using to complete this study. It provides the method of conducting this study and serve as a planning stage for data collection and result analysis.

Chapter 4- This chapter consists of result analysis for this research study. It will be in the form of table and graph. Also, it explains the finding of this study based on the objective of this experiment.

Chapter 5- This chapter concludes the research finding for this research study. It consists the recommendation for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This section provides a review of literature which evolves within the context of the topic. This is based on the engineering and social science literatures. It also involves some related work about sound waves that has been done by others.

2.2 Theory in Calculation

This research used two type of gas that are air and propane to measure the effect of frequency on standing waves. This experiment compared the difference between the calculated and actual data for the experiment. The wavelength is calculated for different frequencies using the following equation.

$$f = \frac{v}{\lambda} \qquad \text{Equation (1)}$$

The frequency and wavelength are inversely proportional. Where f is frequency, v is for speed of sound and λ is wavelength (Mahtani, 2012). For this experiment the velocity of sound in gas is calculated using:

$$v = \left(\frac{K}{\rho}\right)^{\frac{1}{2}} \qquad \text{Equation (2)}$$

Where K is the modulus of bulk while ρ is density of the gas. Modulus of bulk is used to measure how compressible the substance to resistance.

$$K = \gamma . p$$ Equation (3)

Where γ is specific ratio of the gas; air is 1.4 and propane is 1.127, ρ is pressure of gas in Ruben's tube. Then, solve for ρ using ideal gas law.

$$\rho v = nRT$$ Equation (4)

$$p = \frac{nRT}{v}$$ Equation (5)

Substitute: $\rho = \frac{nM}{v}$ and $p = \frac{nRT}{v}$

$$v = (\frac{K}{\rho})^{\frac{1}{2}}$$ Equation (6)

$$v = (\gamma . \frac{p}{\rho})^{\frac{1}{2}}$$ Equation (7)

$$v = (\frac{\gamma . nRT/v}{nM/v})^{\frac{1}{2}}$$ Equation (8)

$$v = (\frac{\gamma . R . T}{M})^{\frac{1}{2}}$$ Equation (9)

Where γ is specific ratio of gas, R is universal gas constant 8.314 J/mol.K, T is absolute temperature in Kelvin, and M is molecular mass. Finally, after the calculation, the velocity found for dry air at 20°C is 343.20 m/s and for propane at the same temperature is 249.51 m/s (Mahtani, 2012).

In this experiment, the frequency would increase. However, the number of nodes and antinodes would increase where more standing waves are produced. Wavelength can be calculated using:

$$\lambda = \frac{4L}{n}$$ Equation (10)

Where λ is wavelength, L is length of tube which is for this experiment will be 1.30 m.

2.3 Nodes and Antinodes

In this experiment, the tube is closed at one end. The number of nodes and antinodes produced are same (Bakar, 2007). It starts with nodes and ends it with antinodes. It stated that the maxima could occur at nodes or antinodes (Bakar, 2007).

Many years later, myriad of experiment has been done to prove the statement. It was claimed that the maxima of flame would be occur at antinodes (Gee, 2009). Under normal condition, at nodes the flame is yellow and tall, while at antinodes the flame is blue and short. Hence, it concludes that flame maxima occur at pressure nodes. However, under high sound intensities (140-150 dB) and variation of pressure occur inside the tube could make the maxima of flame reverse (Gee, 2009).

Besides, static gas pressure was important factor to decide the maxima of flame arise. Under normal static gas pressure, the flame maxima occur at pressure nodes and low static pressure maxima could happen at pressure antinodes (Salim et al., 2018). Therefore, the flame maxima could occur at pressure nodes and minima at pressure antinodes. However, the factor of sound intensity and static gas pressure can influence the location of flame maxima occur (Gee, 2009).

Bernoulli equation are used to make a simple model where can be used to check the mass flow rate inside the tube (Gardner et al., 2009). Under normal condition, the maxima occur at pressure nodes based on time-averaged mass flow rate. Nevertheless, increasing the sound level and decreasing the static pressure will reverse the effect in flame height which is flame maxima at the antinodes and flame minima at the pressure nodes (Gardner et al., 2009). Figure 2.1 shows the nodes and antinodes produce during the experiment.

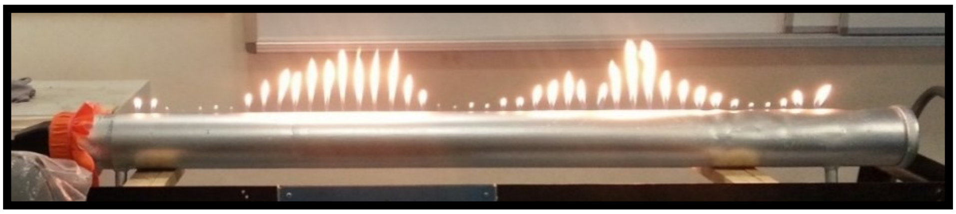

Figure 2.1: Nodes and Antinodes Produces During the Experiment

2.4 Related Work

Journals are reviewed to have better understanding about Ruben's tube. It focusing on using numerical software to make tube as integrated system, used difference type of gas to check speed of gas and frequency inside the tube and using difference diameter size of the tube to check the flame propagation which has strongly affect the occurrence of vortex flow inside the tube.

2.4.1 Ruben's Tube as Integrated System

Ruben's tube can be used altogether to make it as integrated system. For example, it can prove by investigation on the effect of frequency change on standing waves proves the sound wave is also pressure wave by vibration occur inside the tube (Budak, 2009). This experiment used same type of gas for entire experiment: propane gas. Distance between the tube and the speaker diaphragm does not change or not move to prevent the error during the experiment. After several data and calculation has been made, it shown that wavelength and the frequency generated are directly proportional. As the frequency increase, the number of antinodes and nodes increases and wavelength decrease shown the inverse relationship between wavelength and frequency.