THERMOACOUSTIC EFFECT - RESONANT TUBES

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Abstract.

We present to undergraduate students a simple description of thermoacoustic effects found in resonant tubes. Are briefly analyzed the main mechanisms responsible for intense sound waves emitted in adiabatic compressions of heated air in cylindrical tubes.

Key words*: acoustic resonant frequencies in pipes; heating of air; adiabatic sound waves in pipes; thermoacoustic effects.*

(I)Introduction.

Is presented a simple analyzes of the thermoacoustic effect in resonant tubes.[1,2] It is assumed that these tubes are filled with an ideal gas (air). In **Section 1** are shown the resonant frequencies of acoustic waves in cylindrical tubes (*pipes*). In **Section 2** are shown thermoacustic effects observed in two kinds of resonant tubes. In **Section 3** are described mechanisms responsible by these thermoacoustic effects. In **Appendix** is shown how to determine experimentally the resonant frequencies.

(1) Resonant Frequencies in Pipes with a Tuning Fork.

According to basic physics courses,[3,4] in cylindrical tubes (pipes), filled with air (*ideal gas*) and length L, there are **n** longitudinal resonant sound waves (*acoustic waves*) with frequencies f_n (n =1,2,...). When in one end of the tube there is a **tuning fork** (**Figure (1.1)**) and the other end is **open** the resonant frequencies f_n are given by [3,4]

$$f_n = c/\lambda_n = nc/2L \qquad \textbf{(1.1)},$$

where c is the sound velocity and $\lambda_n = 2L/n$ are the resonant wavelengths where n = 1,2,3,...

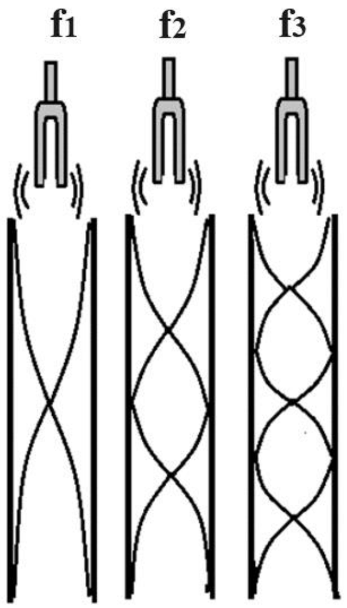

Figure (1.1). Resonant wavelengths λ_n with **opened** ends (n =1,2 and 3).[3,4]

When one end of the pipe is **closed** the resonant frequencies f_n^* are

$$f_n^* = c/\lambda_n^* = nc/4L \qquad \textbf{(1.2)},$$

where $\lambda_n^* = 4L/n$ with n = 1,2,3,...(**Figure (1.2)**).

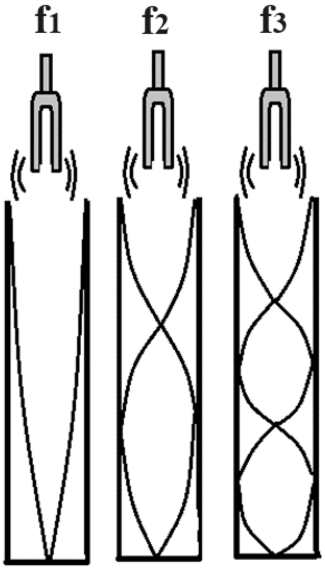

Figure (1.2). Resonant wavelengths λ_n with **closed** end (n =1, 2 and 3).[3,4]

It is important to remember that the acoustic waves[3,4] analyzed above are (adiabatic)**compression waves** and that a given **n-th** resonant frequency is created by the **n-th** tuning fork frequency vibration. When the tuning fork is vibrating with many frequencies and amplitudes the resulting acoustic wave is given by linear superposition of many individual compressions. In **Appendix** are seen measurements of these n-resonant frequencies.

In our laboratory we have vertical tubes with one closed end with different lengths L. Using a tuning fork with frequency f, one can detect 2 or more resonances (**Figure 1.3**).

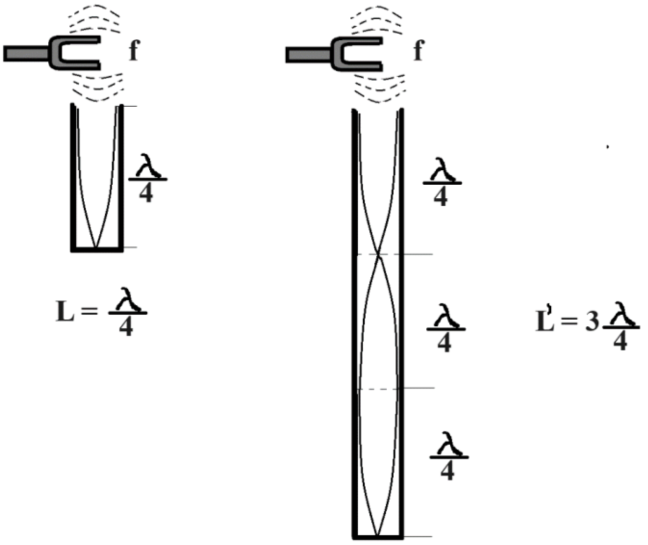

Figure (1.3a). Tuning fork with 2 vibrating frequencies $f_1^* = c/\lambda_n^* = nc/4L$.

A simple way to change the length L is to remember the hydrostatic principle of communicating vessels **(Figure 1.3b).** When resonance occurs, the sound inside the tube is significantly amplified.

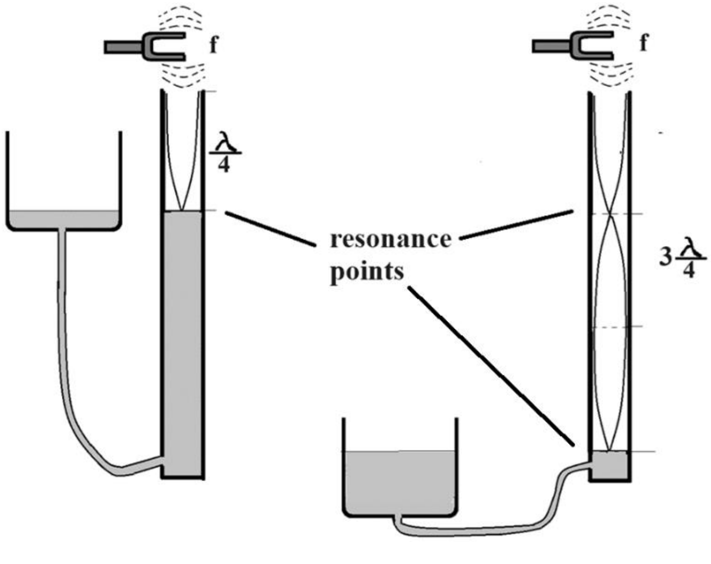

Figure (1.3b). Changing the liquid column height at left, we change the height at right.

(2)Thermoacoustic effect.

Thermoacoustic effect occurs when thermal energy is converted into sound energy or vice versa. In our laboratory there are two kinds of thermoacoustic resonators: Vertical tube (**Rijke Tube)** and Horizontal Tube.

(A) Rijke Tube - Vertical tube open at both ends.

In this tube (**Figure (2.A))** the sound waves have resonant frequencies $f_n = c/\lambda_n = nc/2L$ (**see Eq.(1.1)**). There is an upward air motion (*convection current*) due to the heated air and due the vertical sound waves created by the heated wire mash.

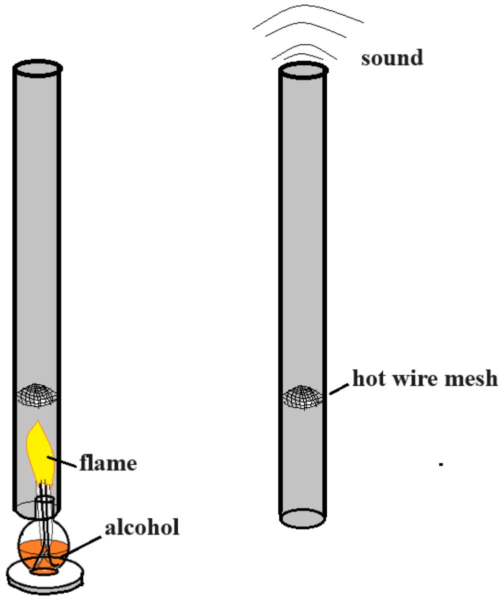

Figure (2.A). Vertical (**Rijke)** tube with the inside wire mesh heated by the alcohol flame. After heating, the tube begins to emit sound with a frequency $f_o = c/2L$.

Inside the vertical tube there is a *wire mesh* and a heat source (*alcohol flame*). After heating the wire mesh the vertical tube starts to emit sound. If the tube changes to the horizontal position, it stops to emit sound, because the air convection stops.

(B) Horizontal tube closed at one end.

It is shown in **Figure (2.B)**. Inside the tube there is an *iron gurze* and outside there is a humid ring cloth involving half part of the iron gauze which is heated an alcohol flame. In this tube, one end is closed and another is opened. In this case, the tube works at the horizontal because it does not require air convection motion.

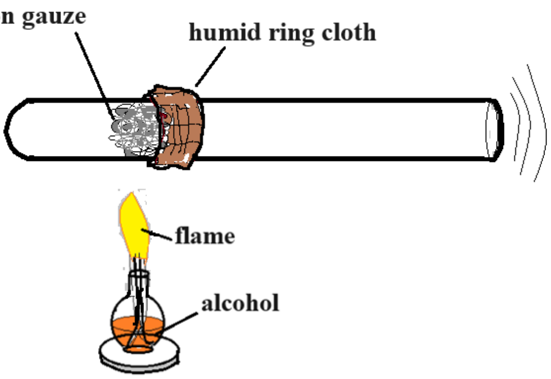

Figure (2.B). Horizontal tube with the inside gauze involved by an external humid cloth ring and the alcohol flame.

(3) Mechanisms Responsible by the Thermoacustic Effect.

As one can verify[2] that complex and intricate approaches are necessary to explain the thermoacoustic effect observed in resonator tubes. Here are presented only simple explanations.

The friction with walls of the tubes are sufficient to keep the iron gauze and iron mesh fixed in their positions. Both are heated until glowing red with T~ 460 °K. In the horizontal tube there is also fixed a humid ring cloth which remains at the ambient temperature T ~300° K.

(3.A) Rijke Tube -Vertical tube.

The **iron mesh,** in this case, having peculiar structural properties and submitted to convective motion of the heated in the tube, is responsible by back and forth vertical air motion in the tube. It would be responsible by the standing sonic waves in the tube.

Figure (3A) shows a 60 cm Rijke glass tube with $L = 60$ cm. After heating the wire mesh, the tube emits sound with $f \sim 300$ Hz, that is, with $\lambda \sim 2L$ measured on a frequency meter.

Figure (3A). Vertical tube with wire mesh and alcohol flame.

Only half part of the gauze is heated by the flame which remains at $T \sim 460^o$ K. The other half part, covered by a humid cloth ring is at the ambient temperature $T \sim 300^o$ K. So, a small portion Δm of air heated by the flame passing through the hot wire mesh, in a small time interval Δt, increases the air pressure inside the cold mesh. So, the pressure increases becoming $P(t + \Delta t) = P_{atm} + \Delta P$. This pressure pushes the air along the tube by a distance Δh. This heated air, entering in contact with cold region of the iron gauze, is cooled and its pressure decreases. Consequently, as it is submitted to a higher external P_{atm} it is pushed back. In this way, there are very quick back and forth motions of the air along the tube. These would be responsible by sonic waves similarly to those produced by vibrating forks. In stationary conditions these standing waves are essentially composed by low wavelengths.[1] They are air adiabatic expansions and compressions with a fundamental standing wave $\lambda \sim 4L$. The sound is rather loud and can be heard very far from the laboratory. With the heat being continuously being supplied, the sound is continuous and loud.

In figure (**3B.1**) is seen a container with alcohol and horizontal tube with $L \sim 19$ cm, closed at the left end. Inside there is, at left, an iron gauze and a humid cloth at right.

Figure (3B.1). Alcohol container, glass tube with iron gauze and humid cloth.

Figure (3B.2) below shows the alcohol flame heating the left side of the iron gauze, while the other half side remains at room temperature because of the humid cloth. .

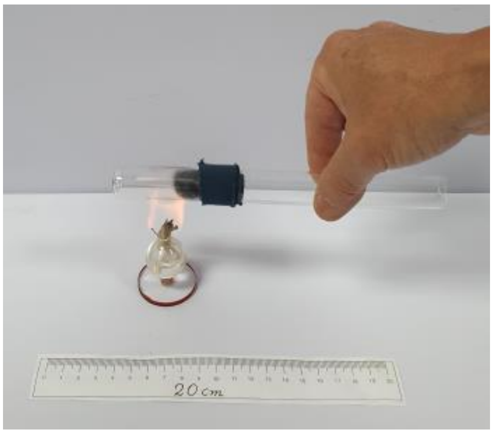

Figure (3B.2). Alcohol flame heating half of the iron gauze.

As long as the cloth remains damp and the flame continues to heat, the tube emits a sound with f ~ 456 Hz, that is, with $\lambda \sim 4L$.

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