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Experimental Study of Thermo-Acoustic Phenomena in Rijke Tube

Harpreet Singh[1], Gaurav Sachdeva[2], Anil Dadwal[3]

[1]M.TECH, Department of Mechanical Engineering, Continental Institute of Engineering & Technology, Fatehgarh Sahib, Punjab, India

[2]Assistant Professor, Department of Mechanical Engineering, Continental Institute of Engineering & Technology, Fatehgarh Sahib, Punjab, India

[3]Head of Department, Department of Mechanical Engineering, Continental Institute of Engineering & Technology, Fatehgarh Sahib, Punjab, India

Abstract: **Thermo-acoustic is concerned with the interactions between heat and pressure oscillations. Rijke Tube is an open-ended tube with a properly placed heat source inside it. To study thermo-acoustic phenomena in Rijke tube, Experimental setup was build up. Experiments were done by changing voltage, changing current, changing air temperature, variation of position of heating element inside the Rijke tube etc. This research paper basically deals with understanding thermo-acoustic effects in Rijke tube.**

Keywords: **Acoustic Oscillations, Rayleigh's Criterion, Rijke Tube, Sound Power, Thermo-acoustic effects.**

I. INTRODUCTION

There has been lot of interest in the study of thermo-acoustic instabilities in past many years. In many practical systems like industrial burners, aerospace motors, rocket motors etc. thermo-acoustic instabilities may develop due to thermo-acoustic transformation of supplied heat energy. Due to high sound amplitudes, system failure can exist. That is why these instabilities should be minimized or eliminated. In 1859, P. L. Rijke discovered a way of using heat to sustain a sound in cylindrical tube open at both ends. That is why Rijke tube bears the name of its discoverer, P. L. Rijke. It is a straight tube through which air flows and becomes hot after contacting heating gauze. Due to position and temperature of heating gauze, Rijke tube produces sound. The sound produces by Rijke tube is self-excited thermo-acoustic oscillations generated by interactions between flow, acoustics and the heat introduced at the heating element. The tube is held vertically and heating source is placed inside it at different locations. Sound production by Rijke tube is a classic example of thermo-acoustic phenomena.

Sound wave consists of compression and rarefaction. At the area of compression, a temperature rise occurs and at the area of rarefaction, a temperature drop occurs. These temperature waves accompany the pressure waves and they combine to produce thermo-acoustic effect. This paper discusses the typical structure of Rijke tube and explains thermo-acoustic phenomena behind it and Rayleigh's Criterion with experimental results and discussions. This can lead to better understanding of thermo-acoustics.

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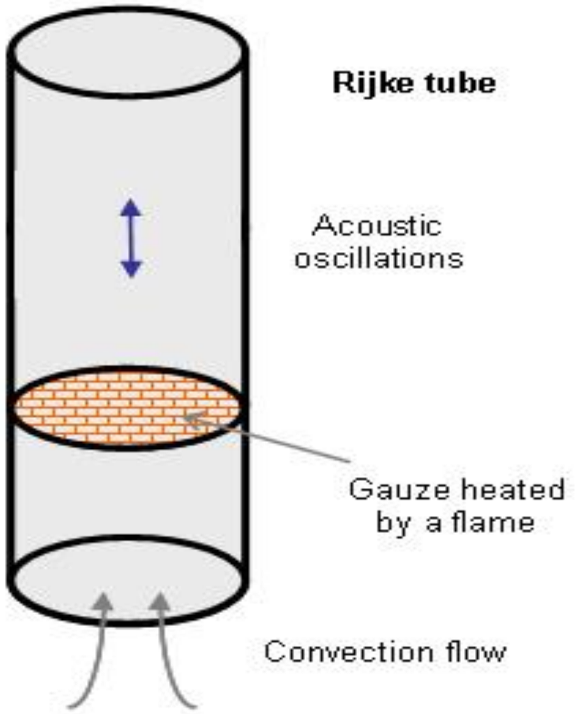

Fig. 1: Rijke Tube

II. RIJKE SOUND MECHANISM

The earliest explanation for the sounding mechanism was provided by P. L. Rijke himself. He suggested that the hot gauze transferred heat to the air in the tube, which then expanded, became less dense, and started rising up the tube, thus setting up a mean upward flow of air in the tube. The rising air coming in contact with cooler walls of the upper half of the tube contracted and became more dense, thereby setting up a variation in density along the length of the tube. According to Rijke, the resulting variation in pressure was such that, fluid elements in the lower half of the tube always experienced expansion while those in the upper part of the tube always experienced compression. Unfortunately, Rijke's argument was quite simplistic, and as we shall see in a moment, does not quite explain the sounding phenomenon. It is well known today that the sounding of an open-open tube, like the Rijke tube, is a result of a stationary acoustic wave being set up in the tube. As a result, fluid elements at any point in the tube experience alternate compression and expansion (in contrast to Rijke's understanding), and all the fluid elements in the tube oscillate in phase. Stationary acoustic waves in tubes can be easily set up by any source of energy, e.g., by using an oscillating tuning fork or by blowing at one of the ends of the tube. However, once the source of energy is discontinued, the acoustic waves usually damp out due to friction within the tube, and due to energy being lost at the open ends of the tube. Thus, the role of the energy source in a sounding Rijke tube is not merely to excite acoustic waves in the tube but also to build up and sustain the already excited acoustic waves. It appears that Rijke did not appreciate this distinction and, as a result, his explanation of the sounding phenomenon tried to focus only on how a heat source would excite acoustic waves in the tube.

III. RAYLEIGH'S CRITERION

In fact, by 1878, Lord Rayleigh had formulated a criterion to explain how acoustic waves could be excited and sustained by heat addition. Rayleigh's criterion (in Lord Rayleigh's words) can be stated as follows:

"If heat be communicated to, and abstracted from, a mass of air vibrating (for example) in a cylinder bounded by a piston, the effect produced will depend upon the phase of the vibration at which the transfer of heat takes place. If heat be given to the air at the moment of greatest condensation, or be taken from it at the moment of greatest rarefaction, the vibration is encouraged. On the other hand, if heat be given at the moment of greatest rarefaction, or abstracted at the moment of greatest condensation, the vibration is discouraged."

IV. EXPERIMENTAL SETUP & PROCEDURE

1. A cylindrical tube made of quartz open at both ends, of 400 mm, I.D 35 mm and O.D 45 mm was used.

2. Electrical heating was used for heating purpose. Voltmeter was used to check voltage variations, Multi-meter was used to check current variations, Decibel meter was used to check sound variations, K-type thermocouple was used to check temperature variations.

3. A transformer was used to increase and decrease the voltage according to the requirements during experimental procedure.

4. A means of localizing the heat transfer within the Rijke Tube was required. This was done by inserting a heating element (Heat Gun Element) inside the Rijke Tube by changing its position. The heating element was heated with A.C current which then transferred the heat to the acoustic waves.

5. After the setup was built, the sound power, temperature of air and heater was measured for different input current and thus different power. Then sound power output was measured by using decibel meter.

Fig -2: Complete Setup

V. RESULTS AND DISCUSSIONS

Using the setup built some experiments were performed by varying a number of parameters to observe the change in the generated sound level. A quartz tube having 400 mm length, internal diameter 35 mm, outer diameter 45 mm was used in whole the experimental procedure. The heating element was at the optimum position (one quarter of the length from the bottom) which satisfied the Rayleigh's Criterion.

(a) Variation of air temperature with Varying current:

From Chart 3 and Table 4, it was observed that the air temperature had increased with increase in current.

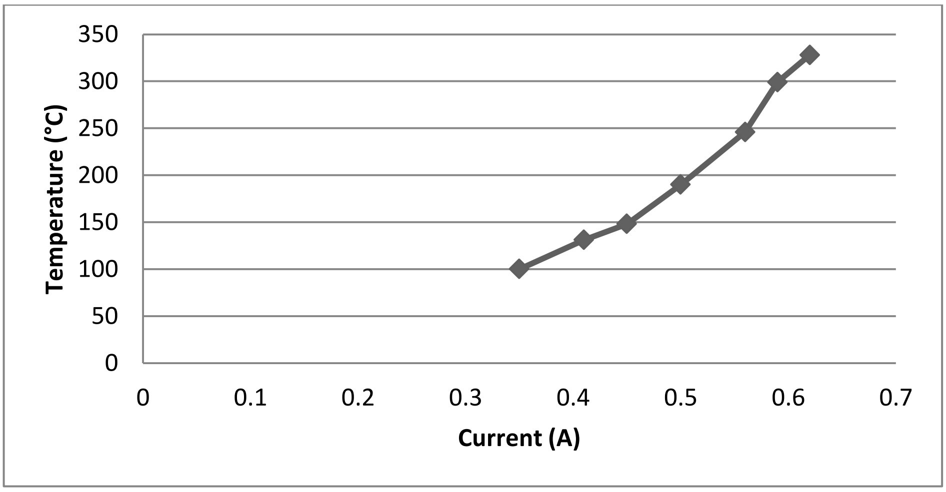

Chart -3: Variation of Air Temperature with Varying Current

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Table -4: Variation of Air Temperature with Varying Current

S.No.	Current (A)	Temperature (°C)
1.	0.35	100
2.	0.41	131
3.	0.45	148
4.	0.50	190
5.	0.56	246
6.	0.59	299
7.	0.62	328

(b) Variation of Sound Level with Varying Current:

From Chart 5 and Table 6, it was observed that Sound level was increased with variation in current up to some point after that it remains constant. This satisfies the Rayleigh's Criterion.

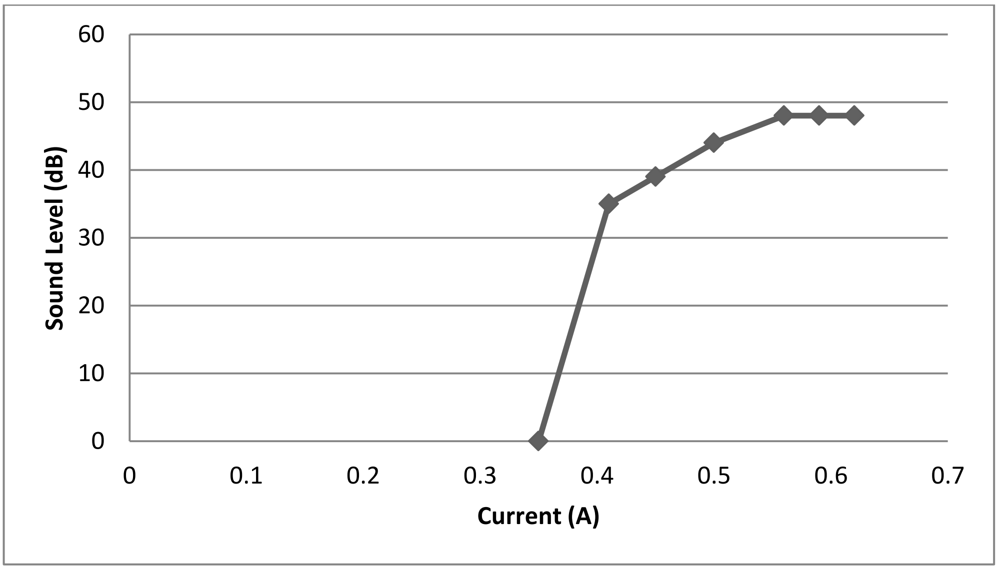

Fig -5: Variation of Sound Level with Varying Current

Table 6: Variation of Sound Level with Varying Current

S.No.	Current (Ampere)	Sound Level (dB)
1.	0.35	0
2.	0.41	35.1
3.	0.45	38.9
4.	0.50	44.6
5.	0.56	48.2
6.	0.59	48.2
7.	0.62	48.2

(c) Variation of Sound Level with Varying Input Power:

Figure 7 and Table 8 shows that sound level was increased with increasing input power up to some point after that it remained constant which again satisfied Rayleigh's Criterion.

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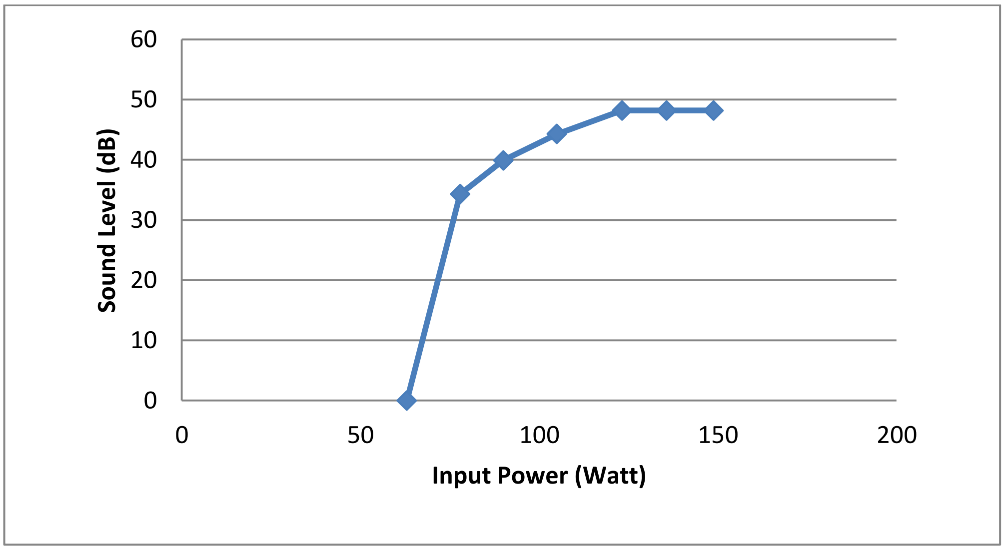

Fig. 7: Variation of Sound Level with Varying Input Power

Table 8: Variation of Sound Level with Varying Input Power

S.No.	Current (Ampere)	Voltage (Volt)	Sound Level (dB)	Input Power (Watt) P=V×I
1.	0.35	180	0	63
2.	0.41	190	34.3	77.9
3.	0.45	200	39.9	90
4.	0.50	210	44.3	105
5.	0.56	220	48.2	123.2
6.	0.59	230	48.2	135.7
7.	0.62	240	48.2	148.8

(d) Variation of Sound Level with Varying Tube Length:

Figure 9 and Table 10 shows that sound level was increased up to some length with varying tube length after that it decreased. It was observed that sound level is maximum at 100 mm length of tube (i.e. L/4 of total tube).

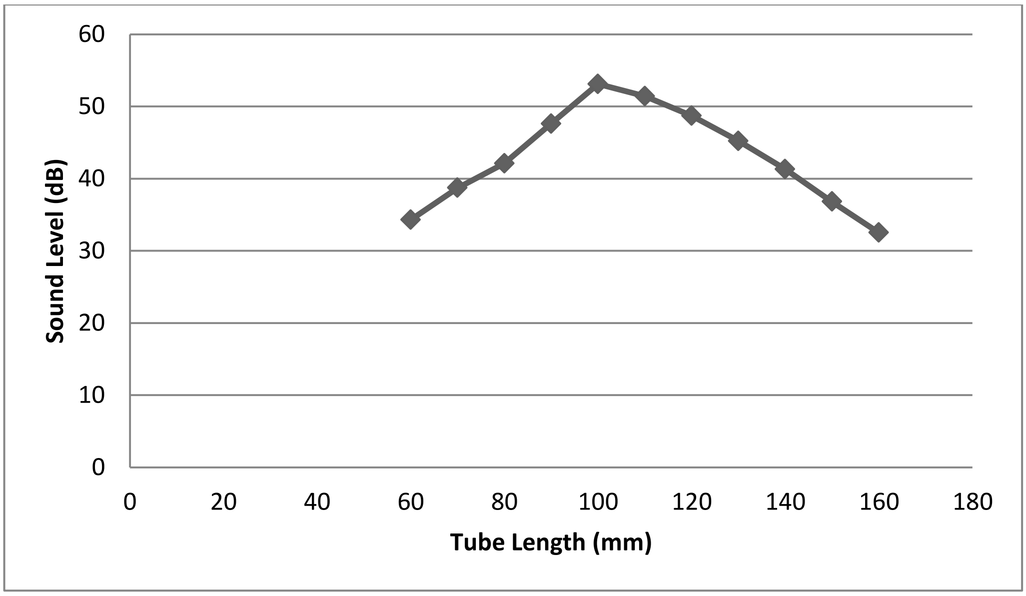

Fig -9: Variation of Sound Level with Varying Tube Length

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Table 10: Variation of Sound Level with Varying Tube Length

S.No.	Tube Length (mm)	Level of Sound (dB)
1.	60	34.3
2.	70	38.7
3.	80	42.1
4.	90	47.6
5.	100	53.1
6.	110	51.4
7.	120	48.7
8.	130	45.2
9.	140	41.3
10.	150	33.8
11.	160	32.5

VI. CONCLUSION

The Rijke Tube was built for controlling the main system parameters (e.g. heating element location, heating power released) in wide ranges. The performance of the designed apparatus was evaluated and compared with Rayleigh's estimation for better understanding of the thermo-acoustic effect occurring within the Rijke tube setup. The Setup was capable of producing sound at a level of 53.1 dB. The experiment yielded that high heating and hence high temperature resulted in sound with more intensity.

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