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Study on the Behavior of Helmholtz Resonance in Different Size Bottles

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Abstract

The resonance is the specific response of system which is capable to vibrate with certain frequency to an external force acting with the same frequency. When air is blown across the open mouth of different bottles then air vibrate in a neck at resonant frequency. In this study we consider 5-5 bottles of different five types bottles having different of length of neck, radius of port, cross-sectional area of port and same volume (250ml). Resonance in different bottles was studied to determine how the volume of air cavity of different bottle affects the resonance. From calculated and experimental data, we found that the Helmholtz resonance frequency decreases with increase in volume and vice versa in each case of different bottles. From graph we also found that the calculated and experimental model are about 100% and 99% variability of the response data around its mean. The practical range for these different bottles is from about 256 to 512 Hz. This is about an octave plus a musical fifth near the middle of the musical instrument, so most simple musical tunes can be produced with such bottles.

Key words: resonant frequency, resonator, cavity, volume, octave

Introduction

Resonance describes the phenomenon of increased in amplitude when the frequency of external periodic force is equal to natural frequency. So, the resonance is the specific response of system which is capable to vibrate with certain frequency to an external force acting with the same frequency. When air is blown across the open mouth of bottle then air vibrate in a neck at resonant frequency. The resonant cavities are enclosed structures that supports an electromagnetic oscillation which may be rectangular, cylindrical, or spherical in geometry. Helmholtz resonance is the phenomenon of air resonance in a cavity, such as when one blows across the top of an empty bottle (Helmholtz,1885). Helmholtz established the equation for describe resonant frequency of the cavity as

$$f_{resonance} = \frac{v}{2\pi}\sqrt{\frac{A}{VL_e}} \qquad \text{... (1)}$$

where; $f_{resonance}$ is the frequency of resonance (Hz), v is the velocity of sound in air, V be the volume of cavity, A is the cross-sectional area of the port and L_e is the effective length of the port which is $L+1.5r$, where L is the actual length and r is the circular port radius (Helmholtz ,1885; Gunnar,1970).

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Historical shows that the Greeks were aware of the Helmholtz resonator and exploited this very phenomenon in their theatre designs (Polychronopoulos et al., 2013). Which remains to this day, some of the most astounding structures in the world. Resonating vessels such as the one much later described by Helmholtz can also be found in literature from that time.
De Bedout et al. (1997) described a self - tuning adaptive passive Helmholtz resonator. Adaptive passive HR change the passive elements of Helmholtz resonator such as; volume, neck length and entrance area, to ensure robust performance for changing conditions. This is accomplished by pistons, moveable parts and embedded sensors that react to input.
Tang (2010) continued the investigation on the effects of a double chamber Helmholtz resonator towards its acoustic performance. The effect of having a dual chamber resonator through compartmenting was also investigated. The results indicate that the introduction of an additional chamber will produce two resonant peaks and the front cavity´s resonance has a more significant impact on the sound attenuation than the rear cavity of the coupled resonator. (Zhao, 2012) suggested a dual chamber Helmholtz resonator in a parallel coupled Helmholtz resonator network. The concept that two resonators are connected by means of a thin compliant membrane. The results demonstrated that the compliant membrane motion produced additional attenuation peaks at non resonant frequencies of the resonator.
Today, Helmholtz resonators are most notably used in engine noise suppression, in the form of mufflers, and in subwoofer design, in the form of bass reflexes, but their properties can also be seen exploited in instrument design, acoustic hall design, and acoustic treatment for studios (Gabriel, 2018).

Method

The cavity resonance frequencies of different 5-5 bottles having different shape of five different types but same volume 250ml as shown in table 1 were observed by blowing over the top of it with the help of different tuning forks having different frequencies 256, 288, 302 ,320, 341, 362, 384, 405, 413, 426.5 ,480, 512 Hz.

Table1. Measurement of length of neck, radius of port, cross-sectional area of port, effective length and volume of different bottles.

S. N	length of neck of bottle L in cm	Radius of port (r) in cm	Cross-sectional area of port (A) in	Effective length of neck = $L + 1.5r$ in cm	Volume of bottle (V) in ml
1	6.30	1.00	3.14	7.80	250
2	4.90	0.80	2.01	6.10	250
3	8.30	0.85	2.27	9.85	250
4	5.50	0.90	2.55	6.85	250
5	5.50	0.85	2.27	6.78	250

At first measuring bottle neck length, cross sectional area of port, effective neck length, empty space volume of bottle, velocity of sound in air at room temperature 16°C. Then determine resonance frequency of bottle with help of Helmholtz equation. Using these tuning forks, we calculate the different volumes. The main motive of our study is to identify maximum resonance and to minimize errors. We subject available tuning forks into bottles at calculated volume as like in air column method and listen their resonance.

Observation:

Table:2. Calculation and observation table for a bottle having cross-sectional area A= 3.14 cm^2 and effective length of neck L_e = 7.80 cm.

Calculation		Observation		SD of observed volume of air corresponding frequency	Correlation
Volume of air in bottle in ml	**Resonance frequency corresponding volume of air in bottle in Hz**	**Frequency of tuning fork in Hz**	**Volume of air in bottle corresponding frequency**		
250	218	256	181	5.62	0.85
225	229	288	143	4.23	
200	243	302	130	5.12	
175	260	320	115	3.21	
150	280	341	102	2.11	
125	307	362	89	2.24	
100	343	384	81	1.22	
75	394	405	73	0.09	
50	486	413	70	1.24	
25	688	426.5	65	3.44	
		480	51	3.58	
		512	45	3.65	

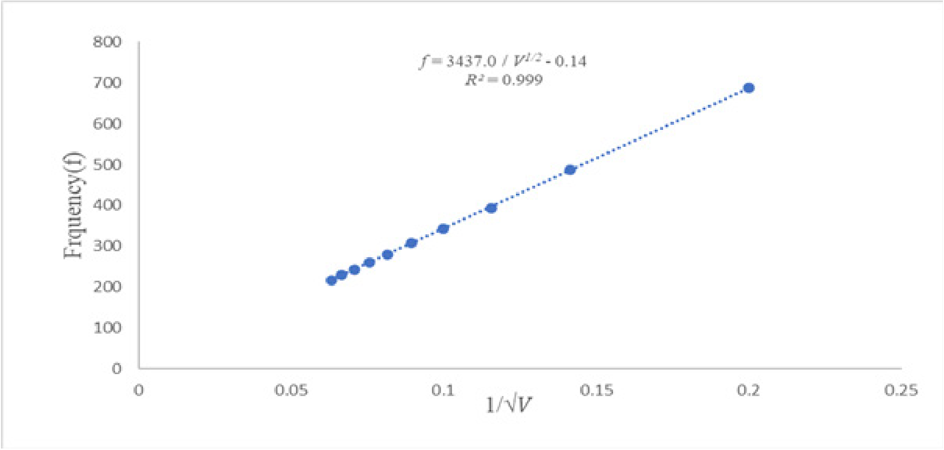

Fig.1 Graph between calculate resonance frequency and square root of volume of air cavity of bottle having cross-sectional area A = 3.14 cm^2 and effective length of neck L_e= 7.80 cm.

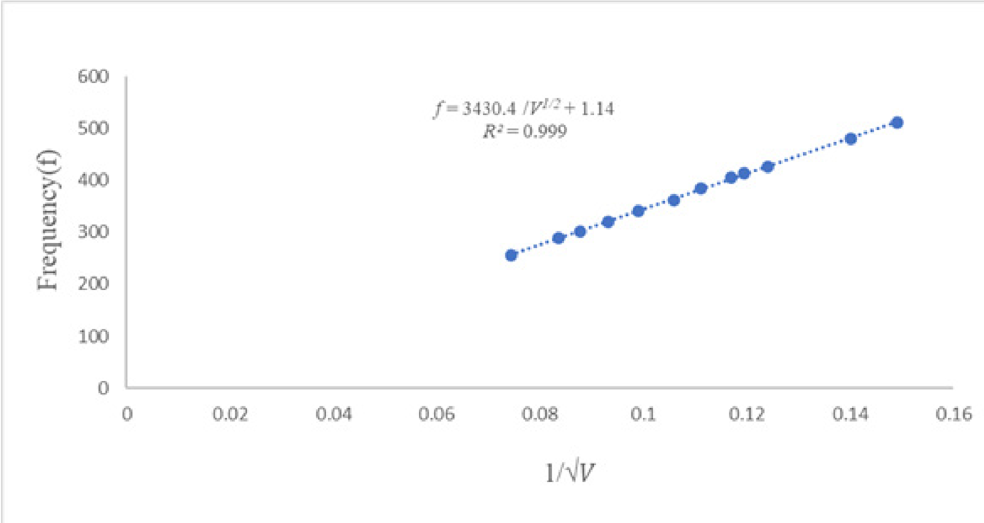

Fig. 2 Graph between observed resonance frequency and square root of volume of air cavity of bottle having cross-sectional area $A = 3.14$ cm^2 and effective length of neck $L_e = 7.80$ cm.

Table: 3. Table for calculation and observation value of a bottle having cross-sectional area $A = 2.01$ cm^2 and effective length of neck $L_e = 6.10$ cm.

Calculation		Observation		SD of observed volume of air corresponding frequency	Correlation
Volume of air in bottle in ml	Resonance frequency corresponding volume of air in bottle in Hz	Frequency of tuning fork in Hz	Volume of air in bottle corresponding frequency in ml		
250	198	256	145	6.22	0.85
225	207	288	119	5.33	
200	221	302	103	4.21	
175	236	320	96	3.21	
150	254	341	81	2.11	
125	275	365	75	1.24	
100	311	384	66	3.22	
75	359	405	61	0.59	
50	441	413	58	1.14	
25	621	426.5	54	1.04	
		480	43	3.51	
		512	38	1.23	

Fig. 3 Graph between calculate resonance frequency and square root of volume of air cavity of bottle having cross-sectional area $A = 2.01$ cm^2 and effective length of neck $L_e = 6.10$ cm.

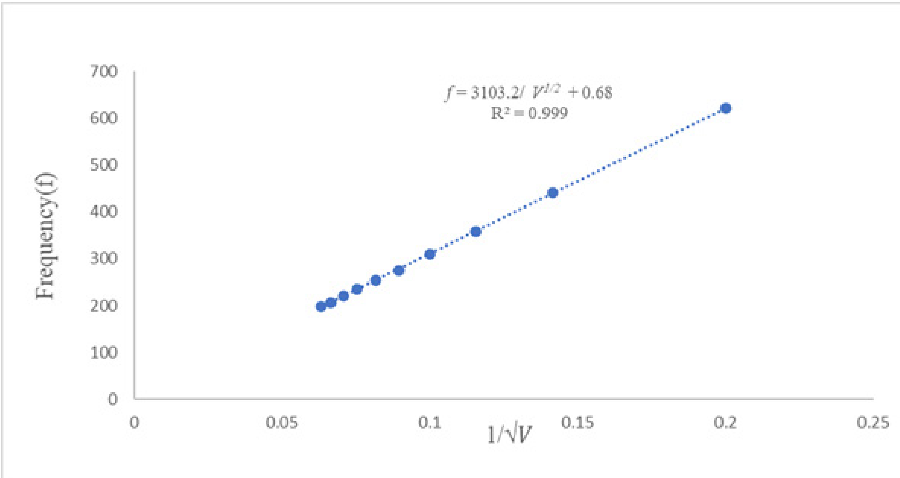

Fig. 4 Graph between observed resonance frequency and square root of volume of air cavity of bottle having cross-sectional area A = 2.01 cm^2 and effective length of neck L_e = 6.10 cm.

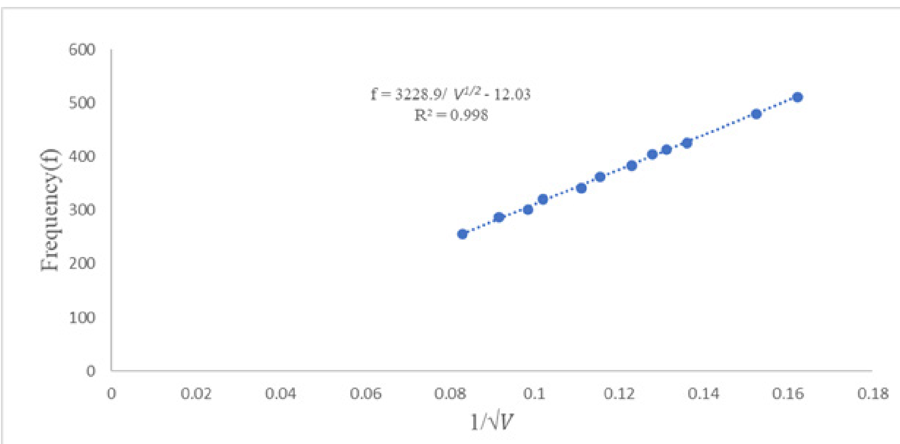

Table: 4. Calculation and observation for a bottle having cross-sectional area A = 2.27 cm^2 and effective length of neck L_e = 9.58 cm.

Calculation		**Observation**		**SD of observed volume of air corresponding frequency**	**Correlation**
Volume of air in bottle in ml	**Resonance frequency corresponding volume of air in bottle in Hz**	**Frequency of tuning fork in Hz**	**Volume of air in bottle corresponding frequency in ml**		
250	167	256	106	4.55	
225	176	288	85	3.44	
200	187	302	77	3.89	
175	200	320	68	2.54	
150	216	341	61	2.11	
125	236	362	53	1.14	

100	264	384	47	2.22	0.86
75	305	405	42	1..09	
50	373	413	40	0.99	
25	528	426.5	38	0.87	
		480	29	1.29	
		512	26	1.05	

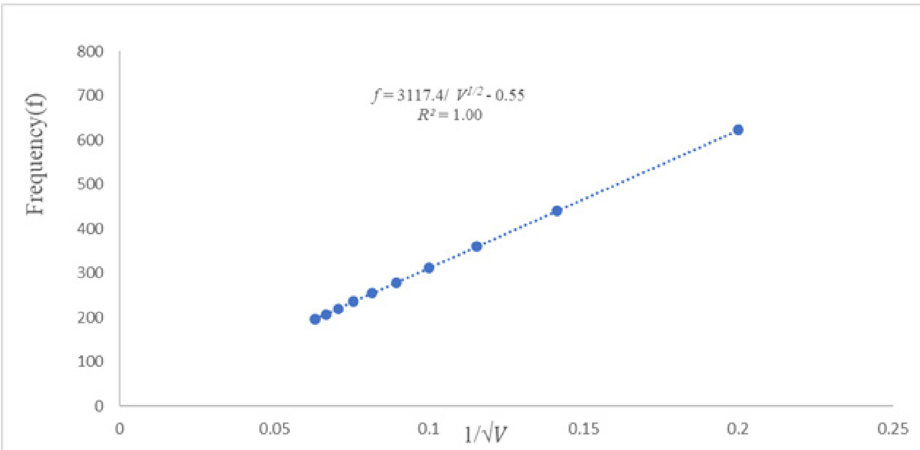

Fig. 5 Graph between calculate resonance frequency and square root of volume of air cavity of bottle having cross-sectional area A= 2.27 cm^2 and effective length of neck L_e = 9.58 cm.

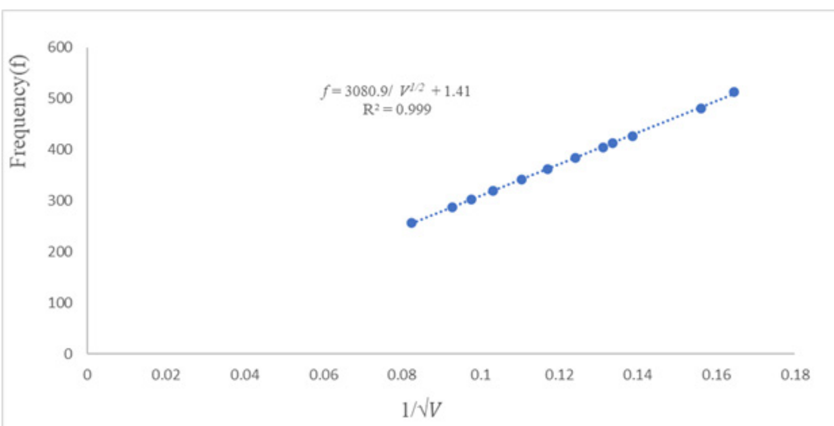

Fig. 6 Graph between observed resonance frequency and square root of volume of air cavity of bottle having cross-sectional area A= 2.27 cm^2 and effective length of neck L_e = 9.58 cm

Table: 5. Table for calculation and observation value of a bottle having cross-sectional area A = 2.55 cm^2 and effective length of neck L_e = 6.85 cm.

Calculation		Observation		SD of observed volume of air corresponding frequency	Correlation
Volume of air in bottle in ml	Resonance frequency corresponding volume of air in bottle in Hz	Frequency of tuning fork in Hz	Volume of air in bottle corresponding frequency in ml		
250	210	256	166	4.77	0.86
225	220	288	132	4.21	
200	234	302	120	5.11	
175	250	320	107	3.15	
150	270	341	95	2.54	
125	296	362	84	4.11	
100	331	384	74	3.87	
75	382	405	65	1.21	
50	468	413	63	0.97	
25	662	426.5	59	1.63	
		480	47	5.81	
		512	42	2.62	

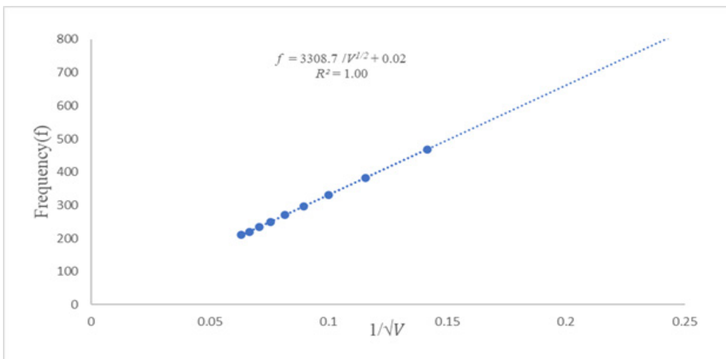

Fig.7 Graph between calculate resonance frequency and square root of volume of air cavity of bottle having cross-sectional area A= 2.55 cm^2 and effective length of neck L_e = 6.85 cm.

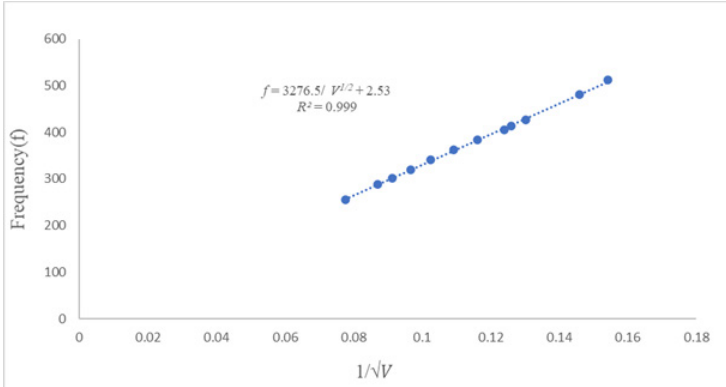

Fig. 8 Graph between observed resonance frequency and square root of volume of air cavity of bottle having cross-sectional area A = 2.55 cm^2 and effective length of neck L_e = 6.85 cm.

Table: 6. Calculation and observation value for a bottle having cross-sectional area A= 2.27 cm^2 and effective length of neck L_e = 6.78 cm.

Calculation		Observation		SD of observed volume of air corresponding frequency	Correlation
Volume of air in bottle in ml	Resonance frequency corresponding volume of air in bottle Hz	Frequency of tuning fork in Hz	Volume of air in bottle corresponding frequency in Hz		
250	199	256	152	6.21	0.86
225	210	288	118	5.94	
200	222	302	108	2.66	
175	237	320	95	3.91	
150	257	341	83	5.01	
125	281	362	75	4.78	
100	314	384	68	3.80	
75	363	405	61	2.61	
50	444	413	57	3.50	
25	628	426.5	53	0.78	
		480	43	2.67	
		512	38	2.21	

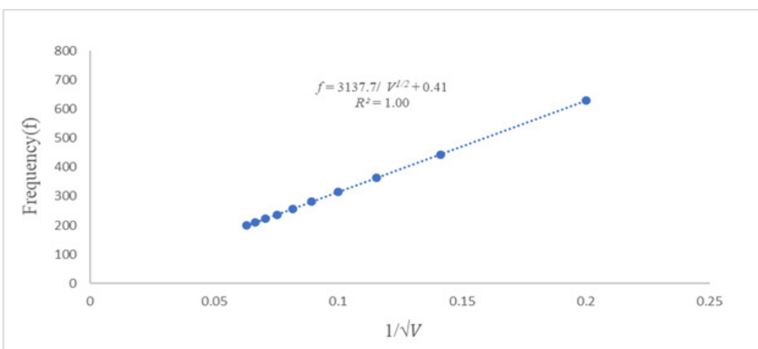

Fig. 9 Graph between calculate resonance frequency and square root of volume of air cavity of bottle having cross-sectional area A= 2.27 cm^2 and effective length of neck L_e = 6.78 cm.

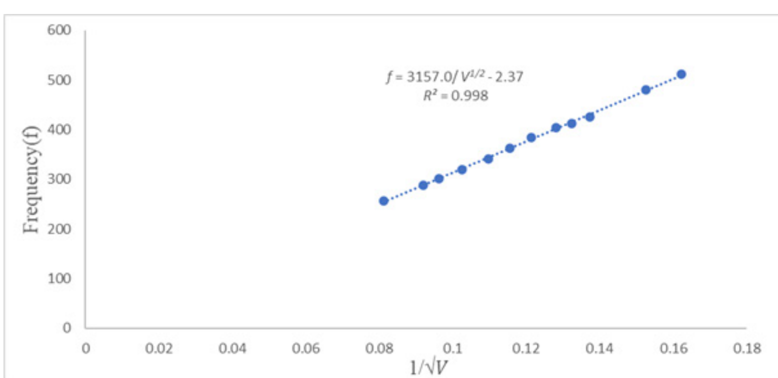

Fig. 10 Graph between observed resonance frequency and square root of volume of air cavity of bottle having cross-sectional area A = 2.27 cm^2 and effective length of neck L_e = 6.78 cm.

Results & Discussion

From above tables and graphs we observed that when the resonant frequency is plotted as a function of the inverse square root of the volume then a straight-line plot is obtained. This shows that the frequency is proportional to the inverse square root of volume.

The calculated frequency of a resonant cavity depends upon the speed of sound *v* and square roots of the area A of the opening, volume *V* of the cavity and the length *L* of the opening port.

The observation has verified the theoretical data calculation or Helmholtz resonance of cavity by demonstrating that resonance frequency of bottle decreases with increase in volume or vice versa and graph is linear in nature. The discrepancy between calculated trend line equation for each bottle can be analyzed as error that happen in the process of calculation and observation.

For a bottle having cross-sectional area $A = 3.14$ cm^2 and effective length of neck $Le =$ 7.80 cm. Variation of standard deviation (SD) of volume of air in bottle corresponding frequency is 0.09 to 5.62. The coefficient of correlation between calculated and observed value is 0.85. That means calculated and observed value are significantly corelated each other and same nature in graph. The series calculated trend line equation is $f = 3437.0 - 0.14$ ($R^2 = 0.999$) and series observed trend line equation is $f = 3430.4 + 1.14$ ($R^2 = 0.999$).

For a bottle having cross-sectional area $A = 2.01$ cm^2 and effective length of neck $L_e =$ 6.10 cm. Standard deviation (SD) of volume of air in bottle corresponding frequency is varies from 0.59 to 6.22. The value of coefficient of correlation 0.85 indicate that the calculated and observed value are significantly corelated each other and same nature in graph. The calculated and observed trend line equation are $f = 3103.2 + 0.68$ ($R^2 = 0.999$) and f = 3228.9 - 12.03 ($R^2 = 0.998$) respectively.

For a bottle having cross-sectional area $A = 2.27$ cm^2 and effective length of neck $L_e =$ 9.58 cm. Standard deviation (SD) of volume of air in bottle corresponding frequency is varies from 0.87 to 4.55. The value of coefficient of correlation 0.86 indicate that the calculated and observed value are significantly corelated each other and same nature in graph. From graph calculated and observed trend line equation are $f = 3117.4 - 0.55$ ($R^2 = 1.00$) and $f = 3080.9 + 1.41$ ($R^2 = 0.999$) respectively.

For a bottle having cross-sectional area $A = 2.55$ cm^2 and effective length of neck $L_e =$ 6.85 cm. Variation of standard deviation (SD) of volume of air in bottle corresponding frequency is 0.97 to 5.11. The coefficient of correlation between calculated and observed value is 0.86. That means calculated and observed value are significantly corelated each other and same nature in graph. The series calculated trend line equation is $f = 3308.7 + 0.02$ ($R^2 = 1.00$) and series observed trend line equation is $f = 3276.5 + 2.53$ ($R^2 = 0.999$).

For a bottle having cross-sectional area $A = 2.27$ cm^2 and effective length of neck $L_e = 6.78$ cm. The standard deviation (SD) of volume of air in bottle corresponding frequency is varies from 0.78 to 6.21. The coefficient of correlation between calculated and observed value is 0.86. That means calculated and observed value are significantly corelated each other and same nature in graph. From graph calculated and observed trend line equation are $f = 3137.7 + 0.41$ ($R^2 = 1.00$) and $f = 3157.0 - 2.37$ ($R^2 = 0.998$) respectively.

Calculated and observed trend line equation having approximately nearly same nature of positive slope having either positive or negative intercepts. From above equation we can conclude that the equation produce in observation is approximately fit in the theory.

Conclusion

The comparative study has been made between theoretical calculation and observation to reach a conclusion. This straight line calculated and experimental result are consistent with the cavity resonance formula. from graph we also found that the calculated and experimental model are about 100% and 99% variability of the response data around its mean.

The practical range for these different bottles is from about 256 to 512 Hz. This is about an octave plus a musical fifth near the middle of the musical instrument, so most simple musical tunes can be produced with such bottles.

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