

Temperature and Energy Loss of a Bouncing Basketball

Pakapas Plangsiri

*International School Bangkok,
29/7 Samakee Rd, Pakkret,
Nonthaburi, 11120, Thailand
Email: reply.to.bung@gmail.com*

Abstract

A basketball ranging in temperature from 255 K to 323 K (-18 to 50°C) was released from a height of 1.92 m and tracked with a motion detector as it bounced to measure the effects on energy loss related to changes in the Young's modulus of the basketball wall. It was found that there is a linear relationship between the coefficient of restitution and the temperature of the basketball within the range tested. The effect of pressure change with changing temperature was factored out of the energy loss, and was also found to decrease linearly with increasing temperature.

Keywords: Basketball bounce, temperature, coefficient of restitution, Young's modulus

I. INTRODUCTION

Basketball is played around the globe, in all seasons. It is played in conditions ranging from winter in Hokkaido to summer in Abu Dhabi. The temperature will affect how a basketball bounces, so it is important to study this effect so that players can compensate for the effect of temperature on how the ball plays.

When a basketball bounces, some of its kinetic energy transforms into heat during the deformation and restitution processes, so the ball never bounces back to its original drop height.¹ The energy loss can be expressed in terms of the coefficient of restitution which is defined as the ratio of the post-impact velocity to the pre-impact velocity. For cases in which air resistance is negligible, the coefficient of restitution can be expressed as:

$$C_R = \sqrt{\frac{h_b}{h_i}} \quad (1)$$

where C_R is the coefficient of restitution, h_b is the maximum bounce height after the bounce and h_i is the initial drop height.²

Hysteresis is related to the energy dissipated as heat in an elastic material in one cycle of compression and extension.³ This occurs when an elastic

material doesn't obey Hooke's Law perfectly, as shown in Figure 1. The area under the blue curve indicates the energy used to compress the material while the area under the red curve represents the energy dissipated during the expansion. The net energy loss is represented by the area between the two curves, known as the hysteresis loop.³ The walls of a basketball experience energy loss due to hysteresis during a bounce.

There are two ways that the area between the loading and unloading curve can be affected. Firstly, when the pressure in the ball changes, whether from changes in temperature or the amount of air inside the ball, this will affect the extension of the curves. Higher pressure results in less compression of the walls, thus a smaller net area between the curves and a decrease in energy loss due to hysteresis. Secondly, a change

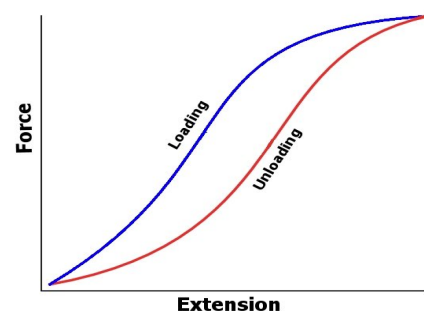


Figure 1. Idealized graph of elastic hysteresis loop for rubber.⁴

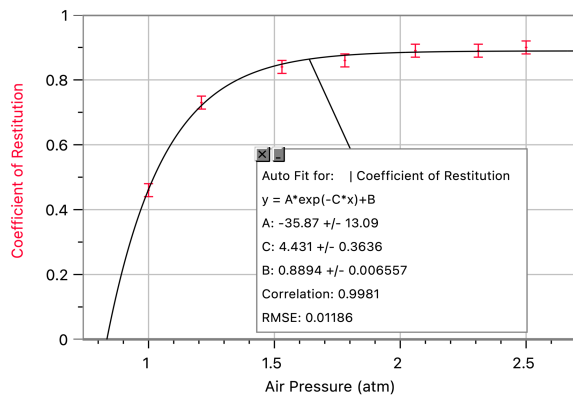


Figure 2. The effect of absolute pressure on the coefficient of restitution of a handball.²

in Young's modulus will affect the compression of the ball during the bounce. If Young's modulus increases, the wall of the ball becomes stiffer, less deformation during the impact will occur, and energy loss will decrease.

By changing the temperature of the ball, two main effects will occur. First, altering the temperature means that the pressure also changes according to the ideal gas law equation, where the temperature is directly proportional to pressure. With greater pressure, the deformation of the ball will be less. With less deformation of the ball, less energy is lost due to hysteresis, resulting in a greater coefficient of restitution. This effect can be seen from the results of Osman and Kim (Figure 2) investigating the effect of the pressure of a rubber handball on the coefficient of restitution. They found that there is an inverse exponential relationship between the two over the range tested.²

Second, changing the temperature of the basketball will also affect the characteristics of the walls of the ball. Young's modulus is the measure of the stiffness of an isotropic elastic material and is roughly proportional to temperature in rubber.³ At higher temperatures, the Young's modulus of the basketball wall is expected to increase which would result in a decrease in total energy dissipation, and an increase in the coefficient of restitution.

According to Tamiya, there is an inverse exponential relationship between the temperature of the polybutadiene superball bouncing on the floor and the coefficient of restitution, as shown in Figure 3.³ It is expected that this relationship would also apply to a basketball, as an important component of the wall of the basketball is rubber.

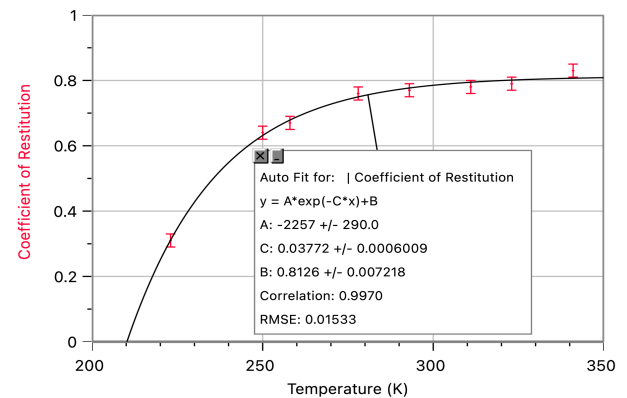


Figure 3. The effect of temperature on the coefficient of restitution of a solid polybutadiene ball.³

In order to isolate the effect of temperature on the energy loss of a basketball during a bounce, two factors were investigated: 1. Ball temperature and coefficient of restitution and 2. Ball pressure and coefficient of restitution. When the effect of each of these on the coefficient of restitution is known, the effects of the change in pressure can be factored out to obtain the effect of changing temperature alone on the energy loss.

II. METHODS

A size 7 basketball with a diameter of 23.9 ± 0.1 cm was released from a height of 1.92 ± 0.05 m. The position of the ball was tracked by a motion detector as it bounced on a wooden floor, as shown in Figure 4. The coefficient of restitution was calculated from the position data.

The ball was brought to five different temperatures ranging from 255K to 323K, and five trials were conducted for each temperature. The amount of air in the ball was kept constant for all temperatures. The

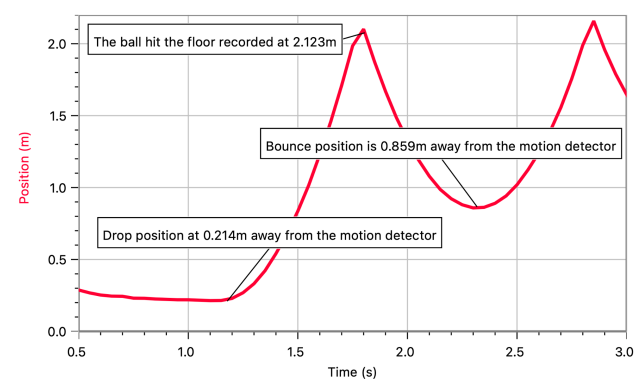


Figure 4. Sample position-time graph of a basketball when dropped.

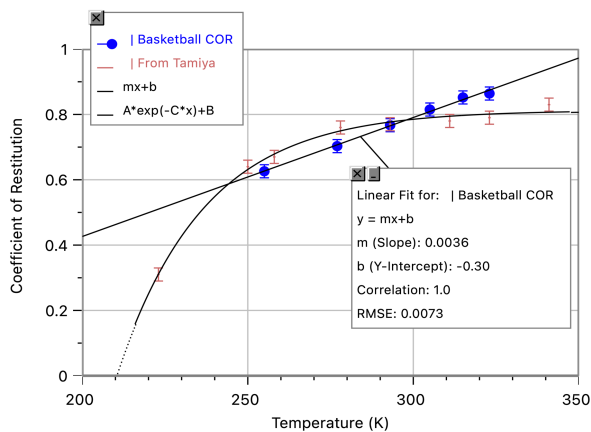


Figure 5. A linear relationship between the coefficient of restitution of a basketball and temperature is shown for the range tested here, compared to Tamiya's results.

ball was then pumped to five different gauge pressures ranging from 0.432 to 0.524 bar, calculated to match the pressure of the ball at each of the temperatures tested. Five drop trials were conducted for each pressure.

III. RESULTS AND DISCUSSION

The relationship between the temperature of a basketball and its coefficient of restitution is shown in Figure 5, with Tamiya's results underlaid. While Tamiya showed a non-linear relationship for a solid rubber ball over his larger temperature range, the basketball demonstrated a linear relationship between temperature and coefficient of restitution for the range tested here. It is possible that the fact that the pressure inside a basketball changes with changing temperature accounts for this difference. The following equation models this relationship for the basketball:

$$C_R = 0.0036 K^{-1} \times T - 0.3 \quad (2)$$

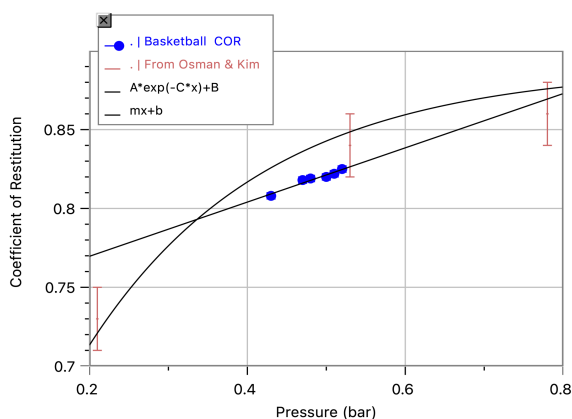


Figure 7. Data from Figure 6 shown with Osman & Kim's results.

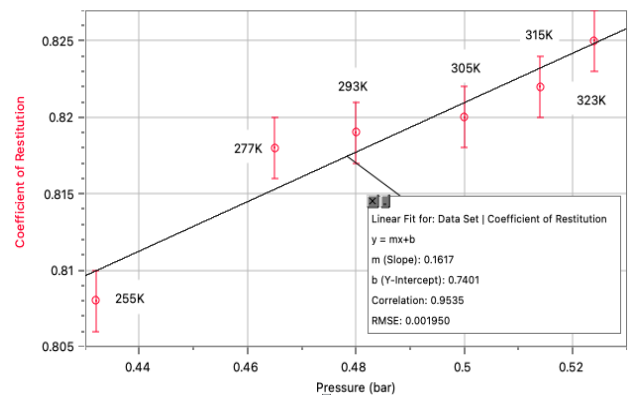


Figure 6. Coefficient of restitution as a function of gauge pressure, with the temperatures corresponding to those pressures indicated.

The basketball was pumped to the ball pressures that would have occurred at each of the temperatures tested, with the results shown in Figure 6. The change in pressure in the ball due to changing temperature has a relatively small effect on the coefficient of restitution compared to the effect of temperature shown in Figure 5.

Figure 7 shows the pressure data compared with a portion of Osman & Kim's results. It is clear from Figures 5 and 7 that the basketball behaves similarly to previously published results for other balls with respect to both temperature and pressure.

Combining the temperature data for the basketball from Figure 5 and the corresponding pressure data from Figure 6, Figure 8 shows the effects of both the temperature (in blue) and pressure (in red) on the relative energy loss during a bounce. This allows us to factor out the effect of the corresponding pressure changes that resulted for the tested temperatures shown in Figure 5. Comparing the two factors, it is clear that the effect of change in pressure on relative energy loss is very small compared to the effect of

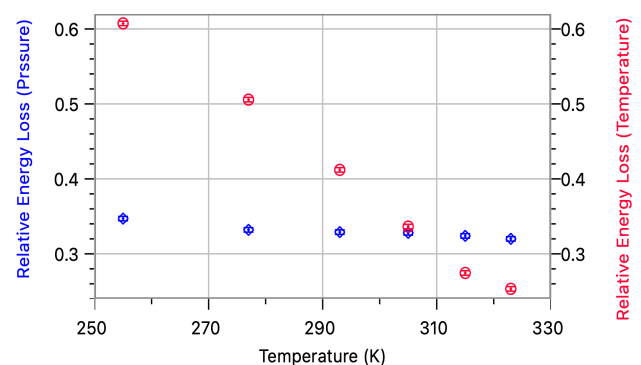


Figure 8. Comparison between the relative energy loss due to pressure change (blue) and temperature change due to temperature (red).

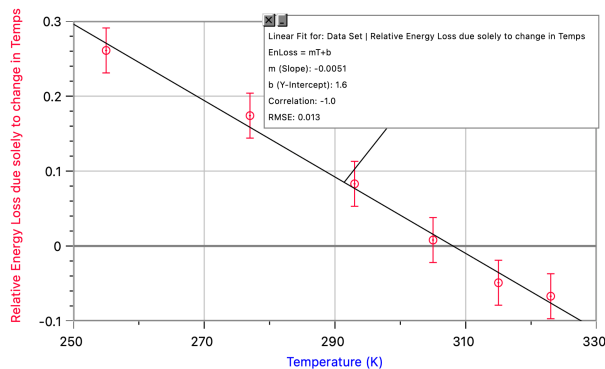


Figure 9. A negative linear relationship between the relative energy loss due exclusively to changes in temperature and temperature in Celsius.

temperature. Temperature is by far the more significant factor affecting the energy loss in the wall of the basketball.

In Figure 9, the effect due to only changing the pressure is factored out from the effect due to the change in both temperature and pressure. The normal outside temperature of 305 K (32°C) was the comparison point at which pressure and temperature were the same for both factors, leading to values for relative energy loss due exclusively to the effect of temperature being negative for temperatures above 305 K and positive for temperatures below 305 K.

There is a negative linear relationship between relative energy loss during a basketball bounce and the temperature of the basketball. This indicates that the Young's modulus of the basketball walls increases with decreasing temperature, as predicted by Tamiya. While the relationship between temperature and energy loss is linear within the range tested, the precise relationship between temperature and Young's modulus of the basketball

walls cannot be derived from the results. Further research in which the pressure of the ball is adjusted to a constant value at each temperature is suggested to confirm these findings. Research directly measuring the effect of temperature on Young's modulus of a basketball wall is also suggested.

IV. CONCLUSION

There is a linear relationship between the coefficient of restitution and the temperature of a basketball for the normal range of playing temperatures. When the effect of pressure is factored out, it is found that change in temperature is the dominant factor causing the change in the energy loss due to hysteresis effects in the wall of the basketball.

V. REFERENCES

1. *The influence of temperature on bouncing balls.* (2013). Queensland parliament. <https://documents.parliament.qld.gov.au/committees/EIC/2013/QldAssessment/tp-20Mar2013-Assignment.pdf>
2. Osman, K, & Kim, B. (2009). *Air Pressure and the Coefficient of Restitution of a Ball.* ISB Journal of Science, 2 (2).
3. Tamiya, Y. (2010). *Temperature Dependence of the Coefficient of Restitution for a Rubber Ball.* ISB Journal of Physics, 4 (1).
4. Urban, J. (2010). *An Introduction to the Theory of Stochastic Systems.* University of South Bohemia. http://www.auc.cz/ipb/vpk/doc/stochastika112010/stochastika_urban_prez.pdf