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Thermodynamic Analysis of Massic Heat Capacity in Bovine Species

Giana Ibrahiem Khalifa

Department of Physical Sciences, College of Science, Jazan University, P.O. Box. 114, Jazan 45142, KSA

Abstract: ***This study investigates the specific heat capacity of femur, rib, and scapula bones from ox and camel under normal and decalcified conditions using Renault's apparatus, which operates on the principle of the method of mixtures. The results indicate a decrease in specific heat after decalcification, with variations observed among different bones and species. The study highlights the influence of calcium phosphate on the thermal properties of bones, providing insights into the thermal regulation mechanisms in living organisms. The method employed is described as simple, elegant, inexpensive, and accurate.***

Keywords: Specific heat, Femur, Rib, Scapula, Ox, Camel, Decalcification

1. Introduction

Bone is a dense, hard, and rigid tissue. Bone consists of 45% water, 30% protein, 15% bone salts and 10% lipids. The bony matrix forming the bony lamellae is partly organic and partly inorganic. Organic matrix forms 30 to 40% of the bone weight. It is made up of fibers of collagen proteins embedded in a mucopolysacha side protein complex. The organic matrix is referred to as the osteoid matrix. The cells of bone are called osteocytes. They are found in spaces or lacunae. Each cell has strands of its protoplasm connecting with other bone cells by fine channels. These link up with central haversian canals providing essential food and oxygen. The inorganic matrix forms 60 to 70% of the bone weight. The crystals of the inorganic matrix are tiny, about 20 nm long. The inorganic matrix is made up of calcium phosphate (85%), calcium carbonate (10%), and traces of calcium fluoride, magnesium chloride, etc. The study of thermal properties such as specific heat is important as most biological processes, in which biological tissues, cells, and molecules involved are temperature dependent. So the body temperature of an animal must be kept within a narrow range. Warm-blooded animals, such as birds and mammals, control their own temperature by regulating the heat loss from their bodies. By contrast, cold-blooded animals are dependent for their environment for the maintenance of their body temperature. For example, snakes are often found sunning themselves on sun-warmed rocks. Many insects must beat their wings before takeoff to raise the temperature of their flight muscles.

The source of body heat is the chemical metabolism of nutrients. Depending on the air temperature, the heat generated may be needed to overcome convective and radiative losses, or it may be a waste product to be disposed of by the body. A warm-blooded animal has a number of mechanisms to use in controlling its temperature. To raise its temperature, the body reduces blood flow through the capillaries nearest the skin surface. The flesh is a poor conductor of heat, so this is effective in reducing heat losses. Also, body hair can be fluffed up to increase insulation. Finally, heat production may be increased by shivering.

Hence, extensive studies have been made, in the past, on the thermal properties of biological macromolecules, cells, tissues, and organs to understand the specific heat of different living systems. Keshin et. al., [1] (1958) determined the specific heat of bound water of plants calorimetrically. Plant tissue contains at least three forms of water, firmly bound, loosely bound and free water. The ratio of firmly bound to loosely bound water in the seeds is 1:2. seed germination occurs only when free water appears. The maximum amount of firmly and loosely bound water is observed in the leaves of mesophyts and xerophytes and the minimum amount in hydrophytes and succulents. The specific heat of living leaves is minimum in xerophytes, rises in mesophytes and hydrophytes and reaches a maximum value in succulents. Poppendiek et. al., [2] measured thermal conductivity in a large number of normal and frozen samples of biological fluids and tissues using a special unidirectional heat flow apparatus. The thermal conductivities of all the biological fluids and tissues studied were also predicted using mathematical heat conduction models. Patrick [3] studied electrical resistivity and temperature coefficient of resistivity of some biomaterials such as zinc poly carboxylate cement, zinc phosphate cement, glass ionomer and children's tooth. The measurements were carried out using a sample holder fabricated in the laboratory. They reported that the electrical resistivity is of high order (order of 10^8) in the case of zinc poly carboxylate, low in case of zinc phosphate and glass ionomer (order of 10^8), when compared with that of milk tooth (order of 10^8). The temperature coefficient of resistivity is the same irrespective of the dental material studied. The author also studied the thermal properties of some biomaterials such as zinc poly-carboxylate, zinc phosphate, and glass ionomer, used as dental restorative materials. The specific heat of the material was determined using the method of mixtures. The thermal conductivity was determined by an apparatus devised in the laboratory, which is a modification of Lee's apparatus. They reported that the specific heat of glass ionomer is maximum, and the thermal conductivity of zinc poly-carboxylate is minimum. The thermal diffusivity of zinc polycarboxylate is comparable to glass ionomer. The study also reports the specific heat value of milk tooth. Patrick et al. [4] investigated certain physical properties viz. thermal conductivity, specific heat, vickers firmness and breaking intensity of glass ionomer cement. They determined the thermal conductivity and specific heat

using the principal method of mixtures and Lee's apparatus, respectively.

Liu et al. [5] evaluated the effects of various decalcifications on morphological and antigenicity preservation in SD rat femurs. Chukwuneke et al. [6] studied the evaluation of noticeable response of heat of bone cement in hip replacement and simulation was done using the steady state thermal structural analysis. Mei-ling Lau [7] investigated the condition of organic constituents of a bovine cortical bone by using thermal gravimetric analysis. Ok et al. [8] compared the properties of thermal conductivity of glass ionomer cements with various contents. Babu et al. [9] studied a commercially accessible dental glass ionomer cement by adjusting at room temperature (300 K) for understanding its thermal properties, dielectric, and DC electrical conductivity. Oikarinen [10] prepared decalcified bone matrix from cortical bones of rats. Abdul Rauf and Ahmad [11] used a uniform bending technique to study the energy-dissipated properties of normal and decalcified rib, femur, and scapula bones of camel and ox.

2. Material and Methods

The ox and camel were selected for the study of specific heat of their bones. Fresh samples of bones were collected from the local slaughterhouse. They were boiled for two hours after removing fresh material and then kept exposed to air for seven days. To determine the specific heat, the bones were cut into small pieces of irregular shapes suitable to heat in a steam generator (Renault's apparatus). The pieces were ground so that they can freely dropped into the calorimeter after sufficient heat treatment.

3. Experimental

The specific heat of the material was determined by the principle of the method of mixtures. In this method, bodies at different temperatures, which do not chemically react with one another, were brought into contact inside a calorimeter. As a consequence, heat flowed from the hot bodies to the cold bodies until all of them attained a common temperature under the condition that the calorimeter was thermally insulted.

Heat lost by the hot bodies = heat gained by the cold bodies

The sample pieces were heated to a steady temperature (θ_2) in a Renault apparatus (Fig.1). The weight of the copper calorimeter with a stirrer (w_1) was determined using a single pan balance. The calorimeter was filled with water just sufficient to immerse the bone samples in it. The weight of the calorimeter, stirrer, and water (w_2) was determined. The initial temperature (θ_1) of the calorimeter and water kept at room temperature was noted. The calorimeter was enclosed in a wooden box with wool to minimize loss of heat due to conduction and convection. Loss of heat due to radiation was minimized by polishing the outer surface of the calorimeter. The bone sample pieces, at temperature θ_2, were then dropped into the calorimeter containing water. The mixture was stirred well and the resultant temperature (θ_3) was measured. The weight (w_3) of the calorimeter with stirrer, water, and samples was determined. If S is the specific heat of the material of the calorimeter, the specific heat 'S' of the samples is given by

$$S = \frac{[(w_2 - w_1) + w_1 S](\theta_3 - \theta_1)}{(w_3 - w_2)(\theta_2 - \theta_3)}$$

Figure 1: Experimental Setup for the specific heat

4. Results

Table 1 provides the data on the specific heat of normal and decalcified bones – femur, rib, and scapula of the animals – ox and camel.

Observed parameters namely w_1, w_2, θ_1, θ_2 & θ_3 are presented. Specific heat decreased considerably after decalcification, slight variation in the specific heat of different bones of the same animal species was observed. Variation was observed among the specimens of the same bone of different animal species.

It is observed that the specific heat of the femur is less than that of rib and scapula. The data on the percentage change in the specific heat of bone specimens with respect to percentage change in decalcification is presented in Figure. 2 shows plots drawn between percentage of decalcification on x-axis and percentage change in specific heat on y-axis. Plots show linear trend.

Table 1.1: Data on % change in Specific heat S with respect to % change in mass due to decalcification for Ox Femur

Sample Code	% Decalcification	% change in S
OF35	26.70	21.71
OF36	19.76	10.63
OF37	32.51	28.29
OF38	31.55	27.95
OF39	32.79	30.30
OF40	19.77	12.30
OF41	22.29	18.52
OF42	24.37	21.15
OF43	23.43	20.94
OF44	24.98	26.66

Table 1.2: Data on % change in Specific heat S with respect to % change in mass due to decalcification for Camel Rib

Sample Code	% Decalcification	% change in S
CR35	13.59	21.18
CR36	07.80	15.16
CR37	21.59	32.21
CR38	23.32	30.95
CR39	29.02	39.93
CR40	23.07	34.53
CR41	28.13	36.29
CR42	14.22	26.49
CR43	16.44	28.86
CR44	17.04	28.27

Table 1.3: Data on % change in Specific heat S with respect to % change in mass due to decalcification for Ox Rib

Sample Code	% Decalcification	% change in S
OR35	18.95	22.61
OR36	35.06	33.12
OR37	13.91	21.85
OR38	13.38	19.23
OR39	36.59	33.62
OR40	40.23	35.29
OR41	24.49	26.04
OR42	50.95	44.52
OR43	35.96	33.46
OR44	45.13	40.36

Table 1.4: Data on % change in Specific heat S with respect to % change in mass due to decalcification for Ox Scapula

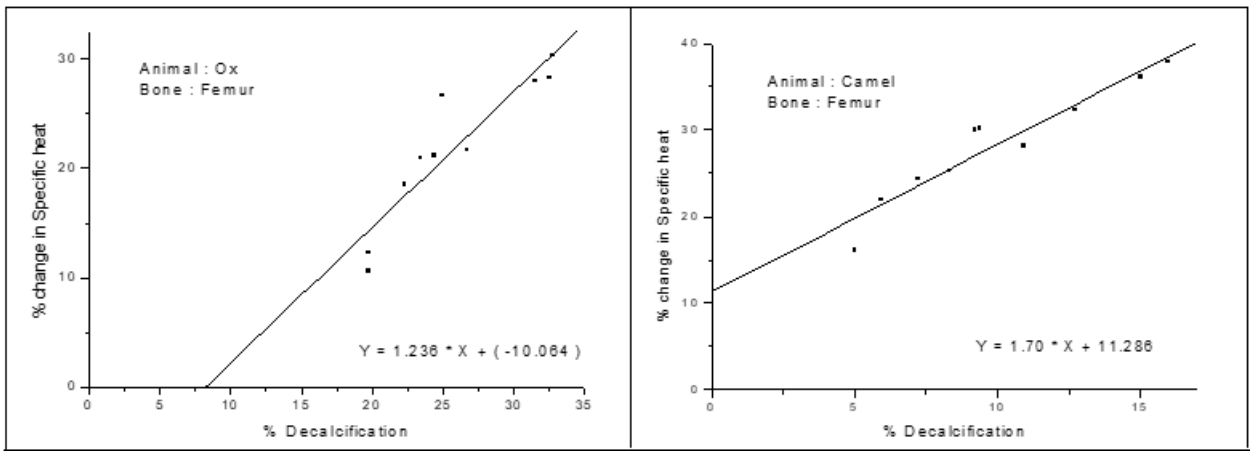
Sample Code	% Decalcification	% change in S
OS35	07.52	09.95
OS36	06.78	07.14
OS37	03.14	04.40
OS38	02.43	03.26
OS39	02.42	03.65
OS40	04.10	03.96
OS41	15.21	17.47
OS42	07.06	09.09
OS43	12.73	11.99
OS44	02.21	03.09

Table 1.5: Data on % change in Specific heat S with respect to % change in mass due to decalcification for Camel Femur.

Sample Code	% Decalcification	% change in S
CF35	09.21	30.00
CF36	05.92	21.90
CF37	12.72	32.36
CF38	10.92	28.17
CF39	08.31	25.24
CF40	15.00	36.09
CF41	07.24	24.37
CF42	09.38	30.18
CF43	15.96	37.83
CF44	05.00	16.12

Table 1.6: Data on % change in Specific heat S with respect to % change in mass due to decalcification for Camel Scapula

Sample Code	% Decalcification	% change in S
CS35	03.14	02.34
CS36	06.34	09.82
CS37	14.42	18.37
CS38	06.15	05.30
CS39	07.01	06.94
CS40	09.88	13.43
CS41	21.26	25.52
CS42	03.50	01.30
CS43	18.34	21.62
CS44	22.19	32.86



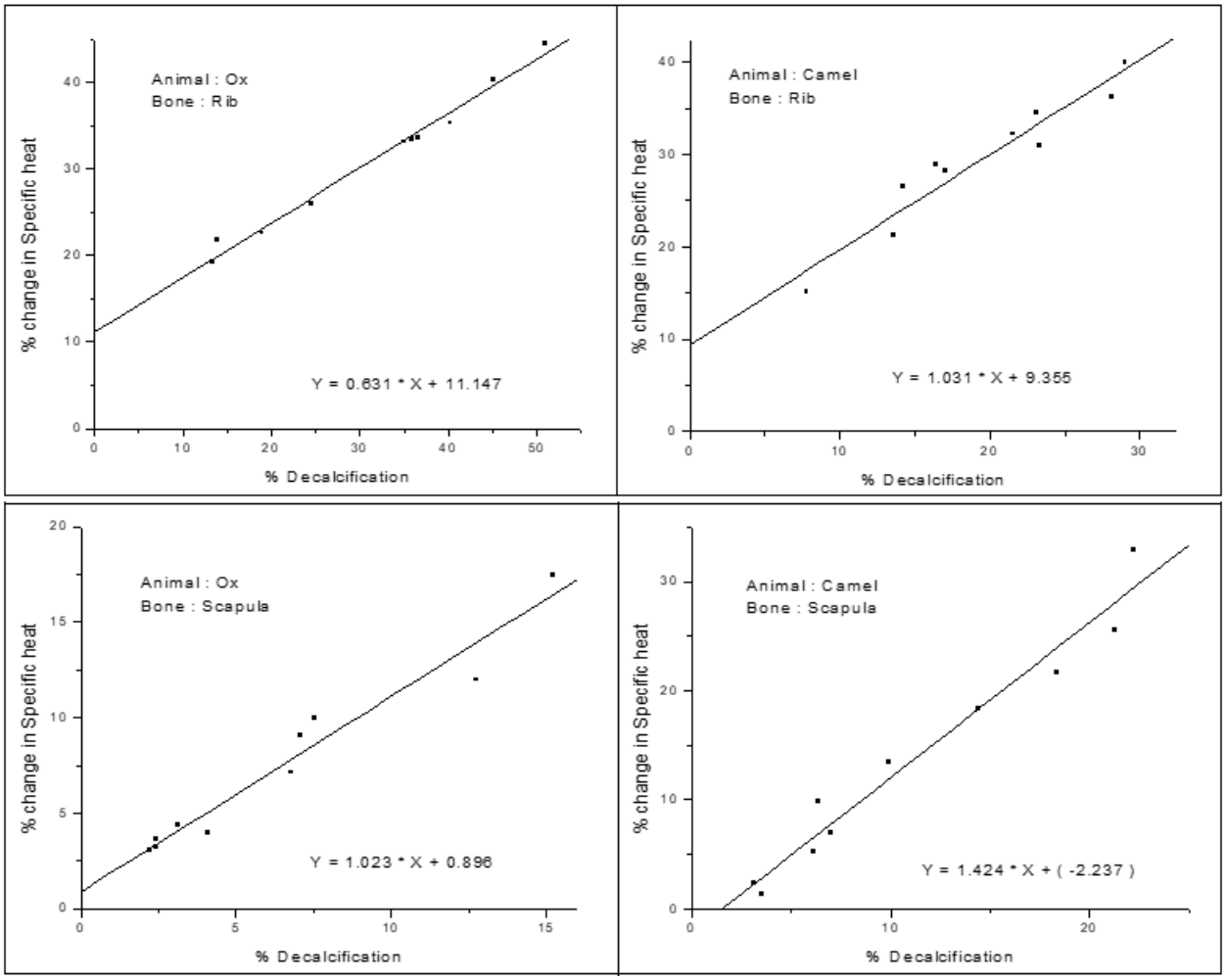


Figure 2: Percentage Variation of Specific heat with % Decalcification

Table 2: A Comparisons of average values of specific heat of normal & decalcified animal bone.

Animal	Bone	Specific heat (cal / gm°C)	
		Normal	Decalcified
OX	Femur	0.311 ± 0.055	0.276 ± 0.060
	Rib	0.291 ± 0.055	0.222 ± 0.035
	Scapula	0.312 ± 0.045	0.290 ± 0.042
Camel	Femur	0.243 ± 0.240	0.189 ± 0.023
	Rib	0.339 ± 0.028	0.620 ± 0.018
	Scapula	0.311 ± 0.055	0.276 ± 0.060

5. Conclusion

Heat exchange in living organisms, under natural conditions, is one of the most important processes where this process is under constant interaction with the external environment. In homoeothermic animals like mammals and birds the adaptations to environmental temperature are developed not on the lines of passive resistance to temperature reactions, but on maintaining the thermal homeostasis of the internal environment. Homoeothermic is a progressive form of heat exchange, in which due to the maintenance of relative constancy of internal environment of the organism, the biochemical and physiological processes always proceed under optimum temperature conditions. Thermos regulation in living organism, through the process of heat transfer, can be understood by the study of thermal capacity of macro molecular tissues, and fluids present in different systems which carry out life processes.

The present investigation on thermal properties of animal bones suggests that specific heat of femur, rib and scapula of the animals- ox and camel, are more or less constant irrespective of animal. The constancy in the values of specific heat for the femur, rib and scapula of different animals is because of identical composition of organic and inorganic materials. But when types of bones like femur, rib, and scapula are considered, a significant difference exists in specific heat. Specific heat is less in the femur than in the rib and scapula irrespective of animal. The significant differences in these thermal parameters may be due to calcium phosphate deposition and their structure. The variation in the specific heat of femur, rib and scapula is expected since their functions are of entirely different in nature. Depending upon their functions the structure is also different. The rib and scapula, known as spongy bones, are composed of two thin layers of compact tissue enclosing between them a variable quantity of cancellous tissue. While femur is a compact bone that consists of a dense, compact tissue of considerable thickness and is tough in nature. The calcium phosphate plays a vital role in thermal behavior, as is evident from the data on decalcified bones of ox and camel. It is evident from Figs. 2 that the graphs are linear, but do not pass through the origin. This is due to the fact that it is not possible to perform experiment on the same specimen of different percent of decalcification. Observations are made on different specimens of the same type of bone having different quantities of calcium phosphate. This is the limitation of experimentation.

However, the main aim is to find out how calcium phosphate influences the thermal properties like the specific heat of animal bone.

The present investigation on the thermal properties of decalcified animal bones suggests that the specific heat of bone after decalcification decreases as shown in Table 2. The difference in specific heat of calcified and decalcified bone of ox and camel are more or less constant irrespective of animals.

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