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Low efficiency of string passing through the ice – regelation phenomenon

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Abstract

The pressure-volume cycle for the regelation phenomenon is proposed, and it is shown to be a poorly competent phenomenon consistent with the slow movements of glaciers.

Introduction

Pirooz Mohazzabi [1] has described the phenomenon of regelation that initiates the passing of a string under load (Figure 1) through the ice without cutting it in half. According to him, “A simple explanation of this effect is that the pressure caused by the string makes the ice melt just below the string, the string slides down, and the water freezes again just above the string.” This so happens, as the melting point of ice falls under higher pressures [2, 3], resulting in the melting of ice below the string, and thereby the string falls under gravity. The melted water once again experiences one atmospheric normal pressure, and it freezes again by conducting heat to its neighbors; this process continues till the string reaches the end point of the ice.

Pressure-volume cycle

The process so described can be depicted through the pressure P and volume V cycle [4] in Figure 2. The curve AB, which corresponds to a straight line, represents the melting of the ice block under the constant load pressure $P_{LOAD}\ N/m^2$ exerted through the string having length $L\ m$, diameter $D\ m$, area $A = L \times D\ m^2$ and the weight suspended at both ends $M = 2\ kg$; the value of load pressure comes out to be

$$P_{LOAD} = \frac{F}{A} = \frac{2M \times g}{L \times D} = \frac{2(2)(9.81)}{0.05(3.048 \times 10^{-4})} = 2.575 \times 10^6\ \frac{N}{m^2} \qquad (1)$$

Its value in atmospheric units would be

$$P_{LOAD} = \frac{P_{LOAD}}{P_{ATMOSPHERE}} = \frac{2.575\times 10^6}{1.013\times 10^5} = 25.413\ atm \qquad (2)$$

The starting point A is the block of ice having extreme volume and mass, respectively, as

$$V_{ice} = L \times D \times dy = 0.05(3.048 \times 10^{-4}) \times dy\ m^3 \qquad (3a)$$

$$m = V_{ice} \times \rho_{ice}\ kg;\ density\ of\ ice\ \rho_{ice} = \ 916.8\ \ kg/m^3 \qquad (3b)$$

$$dy = 0.001\ m; height\ of\ the\ melting\ block, say \qquad (3c)$$

This block of ice having a tiny height, say, $dy\ m$ begins melting; the pressure $P_{LOAD} = 25.413\ atm$ causes the melting temperature to drop by, $\Delta T = -0.18\ K$ in view of the well-known fact that it falls by $1\ K$ under the atmospheric pressure $133\ atm = 1.35 \times 10^7\ \ N/m^2$, a simple arithmetic. It absorbs latent heat at temperature $273.15 - \Delta T$ from the neighbors at temperature $273.15\ K$. It melts; its volume decreases till it reaches the point B, where it has totally liquid water having minimum volume

$$V_{water} = \frac{m}{\rho_{water}}\ m^3; density\ of\ water\ \rho_{water} = \ 999.8\ \ kg/m^3 \quad (4)$$

The status of point B is totally liquid water, a transition point, shifting to point C, having normal atmospheric pressure $P_{ATMOSPHERE}$. The line CD represents the conversion of water to ice having higher volume by releasing heat to its neighbors; the point D signifies total ice, which is again under load pressure through the string, which is the point A.

The work W performed by regelation in the above-described process can be found [3] from the graph, it’s equal to the area outlined by the cycle:

$$W = (P_{LOAD} - P_{ATMOSPHERE})(V_{ice} - V_{water})\ J$$

$$= (2.575 \times 10^6 - 1.013 \times 10^5)\left(\frac{m}{\rho_{ice}} - \frac{m}{\rho_{water}}\right)\ J \qquad (5)$$

The efficiency η of the regelation phenomenon would be given by

$$\eta_{REGElATION} = \frac{W}{Q} \quad (6)$$

The input heat Q absorbed by melting ice under load pressure $2.575 \times 10^6 \frac{N}{m^2}$ and temperature $273.15 - \Delta T$ would be $m \times \ell\ J$; ℓ is the latent heat of fusion of ice at temperature $273.15 - \Delta T$. As the latent heat values are not sensitive [3], its value at temperature $273.15\ K$ would be adapted, that is, $333.5 \times 10^3\ J/kg$. Thus, the efficiency

$$\eta_{REGELATION} = \frac{W}{Q} = \frac{(P_{LOAD} - P_{ATMOSPHERE})(V_{ice} - V_{water})\ J}{m \times \ell\ J}$$

$$= \frac{2.474 \times 10^6 \times 1.265 \times 10^{-9}\ J}{1.397 \times 10^{-5} \times 333.5 \times 10^3 J} = 6.7 \times 10^{-2}\% \quad (7)$$

The regelation efficiency turns out to be poorly competent, a well-known fact visible from the recorded slow movement of related phenomena such as motion of glaciers [5, 6].

References

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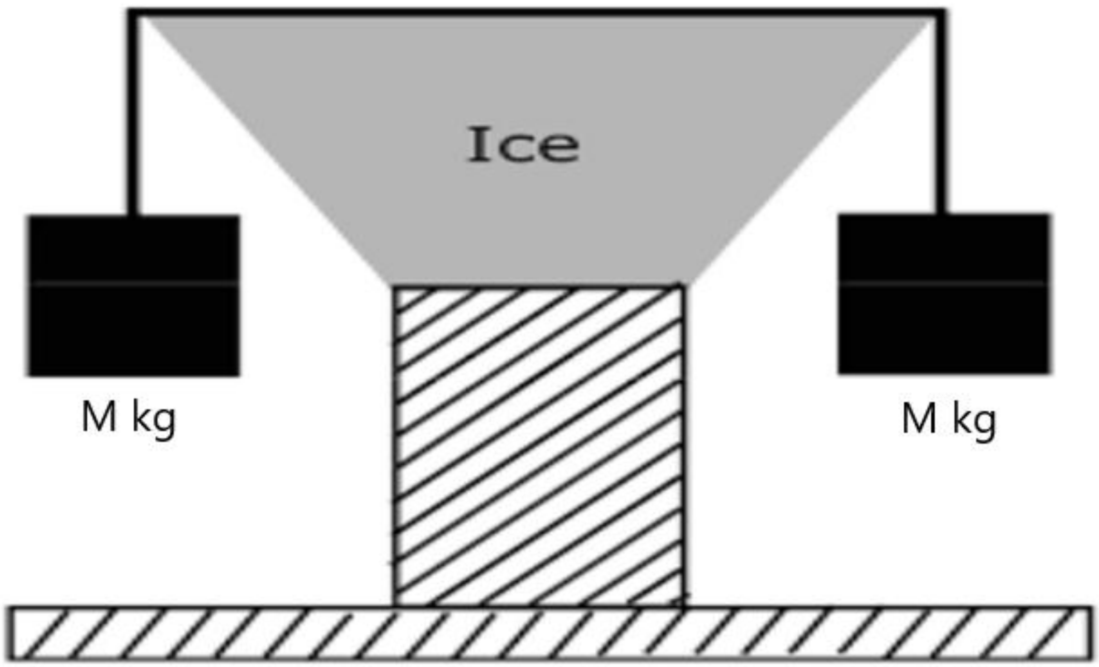

Figure 1: Pressure is applied to a block of ice by a string supporting two hanging masses. The string eventually passes through the ice without cutting it in half [1].

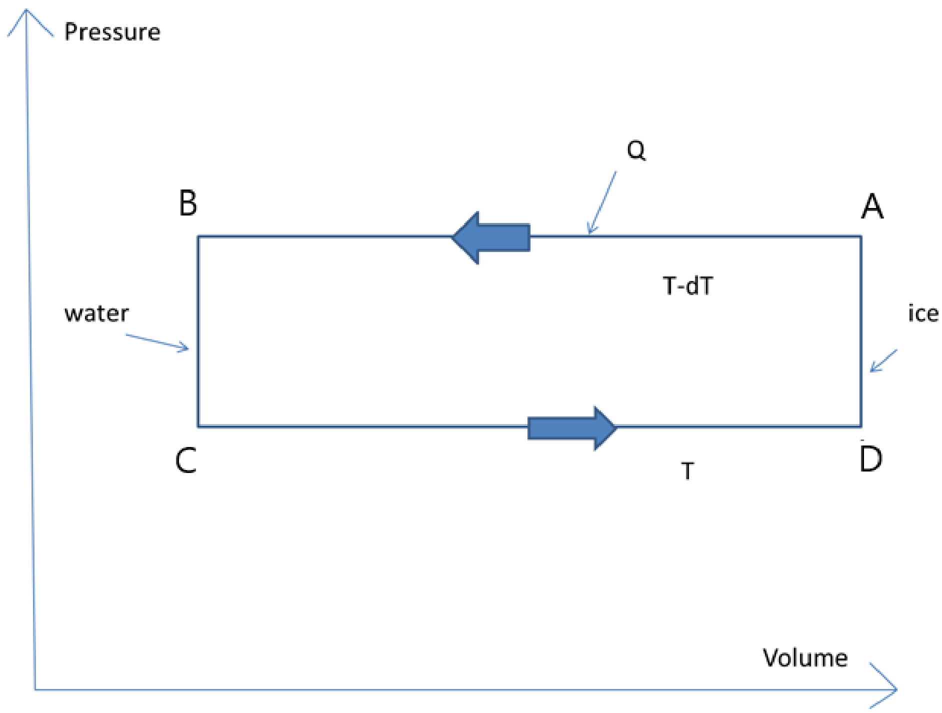

Figure 2: Pressure-volume diagram for the regelation phenomenon. The path AB describes the melting of ice under the loaded string, the path BC is water shifting to normal one atmospheric pressure, and the path CD describes the release of latent heat at normal atmospheric pressure to freeze once again. The last path, DA, represents a transition path of ice to load pressure. The values of T and dT are, respectively, 273.15 K and 0.18 K.