PROBLEM 2.24

KNOWN: Five materials at 300 K.

FIND: Heat capacity, ρc_p. Which material has highest thermal energy storage per unit volume. Which has lowest cost per unit heat capacity.

ASSUMPTIONS: Constant properties.

PROPERTIES: *Table A.3*, Common brick (T = 300 K): ρ = 1920 kg/m^3, c_p = 835 J/kg·K. *Table A.1*, Plain carbon steel (T = 300 K): ρ = 7854 kg/m^3, c_p = 434 J/kg·K. *Table A.5*, Engine oil (T = 300 K): ρ = 884.1 kg/m^3, c_p = 1909 J/kg·K. *Table A.6*, Water (T = 300 K): $\rho = 1/v_f$ = 997 kg/m^3, c_p = 4179 J/kg·K. *Table A.3*, Soil (T = 300 K): ρ = 2050 kg/m^3, c_p = 1840 J/kg·K.

ANALYSIS: The values of heat capacity, ρc_p, are tabulated below.

Material	Common brick	Plain carbon steel	Engine oil	Water	Soil
Heat Capacity (kJ/m^3·K)	1603	3409	1688	4166	3772

<

Thermal energy storage refers to either sensible or latent energy. The change in sensible energy per unit volume due to a temperature change ΔT is equal to $\rho c_p \Delta T$. Thus, for a given temperature change, the heat capacity values in the table above indicate the relative amount of sensible energy that can be stored in the material.

Of the materials considered, water has the largest capacity for sensible energy storage. <

Various materials also have the potential for latent energy storage due to either a solid-liquid or liquid-vapor phase change. Taking water as an example, the latent heat of fusion is 333.7 kJ/kg. With a density of $\rho \approx$ 1000 kg/m^3 at 0°C, the latent energy per unit volume associated with the solid-liquid phase transition is 333,700 kJ/m^3. This corresponds to an 80°C temperature change in the liquid phase. The latent heat of vaporization for water is very large, 2257 kJ/kg, but it is generally inconvenient to use a liquid-vapor phase change for thermal energy storage because of the large volume change.

The two materials with the largest heat capacity are also inexpensive. The consumer price of soil is around $15 per cubic meter, or around $4 per MJ/K. The consumer price of water is around $0.40 per cubic meter, or around $0.10 per MJ/K. In a commercial application, soil could probably be obtained much more inexpensively.

Therefore we conclude that water has the lowest cost per unit heat capacity of the materials considered. <

COMMENTS: (1) Many materials used for latent thermal energy storage are characterized by relatively low thermal conductivities. Therefore, although the materials may be attractive from the thermodynamics point of view, it can be difficult to deliver energy to the solid-liquid or liquid-vapor interface because of the poor thermal conductivity of the material. Hence, many latent thermal energy storage applications are severely hampered by heat transfer limitations. (2) Most liquids and solids have a heat capacity which is in a fairly narrow range of around 1000 – 4000 kJ/m^3·K. Gases have heat capacities that are orders of magnitude smaller.