Problem Set 3: Specific Heat Capacity

3.1 No, as they have different specific heat capacities.

3.2 [a] Convection losses from the surface of each cup should be the same, however the thinner, more delicate cup would lose heat more quickly and cool down quicker
[b] Brass has a higher specific heat capacity than pewter so the brass urn will take more heat away from the olive oil resulting in the oil in the pewter urn being hotter after thirty seconds.

3.3 $m = 153\ kg, c = 4180\ J\ kg^{-1}\ K^{-1}, \Delta T = 75°C - 15°C = 60°C$
$Q = mc\Delta T = 153\ kg \times 4180\ J\ kg^{-1}\ K^{-1} \times 60°C = 3.84\times10^{7}\ J = 38.4\ MJ$

3.4 $m = 0.782\ kg, c = 445\ J\ kg^{-1}\ K^{-1}, \Delta T = 445°C - 20°C = 425°C$
$Q = mc\Delta T = 0.782\ kg \times 445\ J\ kg^{-1}\ K^{-1} \times 425°C = 1.48\times10^{5}\ J = 148\ kJ$

3.5 $Q = 1.54\ MJ = 1.54\times10^{6}, m = 72.6\ kg, c = 1000\ J\ kg^{-1}\ K^{-1}$
$$\Delta T = \frac{Q}{mc} = \frac{1.54\times10^{6} J}{72.6\ kg \times 1000\ J\ kg^{-1}\ K^{-1}} = 21.2°C$$

3.6 Electrical energy supplied = heat gained by kettle + heat gained by water
$m_{kettle} = 0.355\ kg, c_{kettle} = 445\ J\ kg^{-1} K^{-1}, \Delta T_{kettle} = 100°C - 15°C = 85°C$
$m_{water} = 0.85\ kg, c_{water} = 4180\ J\ kg^{-1} K^{-1}, \Delta T_{water} = 100°C - 15°C = 85°C$
$Q = m_{kettle} c_{kettle} \Delta T_{kettle} + m_{water} c_{water} \Delta T_{water}$
$Q = 0.355 kg \times 445\ J\ kg^{-1} K^{-1} \times 85°C + 0.85\ kg \times 4180\ J\ kg^{-1} K^{-1} \times 85°C$
$Q = 3.15\times10^{5}\ J = 315\ kJ$

3.7 $Q = 55.3\ MJ = 5.53\times10^{7} J, m = 286\ kg, \Delta T = 452°C - 22°C = 430°C$
$$c = \frac{Q}{m\Delta T} = \frac{5.53\times10^{7}\ J}{286\ kg \times 430°C} = 450\ J\ kg^{-1} K^{-1}$$

3.8 $Q = 2.84\times10^{5}\ J, m = 2.75\ kg, c = 4.13\times10^{3}\ \ J\ kg^{-1}\ K^{-1}$
$$\Delta T = \frac{Q}{mc} = \frac{2.84\times10^{5} J}{2.75\ kg \times 4.13\times10^{3}\ J\ kg^{-1}\ K^{-1}} = 25°C$$

3.9 $m = 0.865\ kg, c = 900\ J\ kg^{-1}\ K^{-1}, \Delta T = 120°C - 55°C = 65°C$
$Q = mc\Delta T = 0.865\ kg \times 900\ J\ kg^{-1}\ K^{-1} \times 65°C = 5.06\times10^{4}\ J = 50.6\ kJ$

3.10 $Q = 118\ kJ = 1.18\times10^{5}\ J, m = 0.385\ kg, \Delta T = 98.6°C - 18°C = 80.6°C$
$$c_{ave} = \frac{Q}{m\Delta T} = \frac{1.18\times10^{5}\ J}{0.385\ kg \times 80.6°C} = 3800\ J\ kg^{-1} K^{-1} = 3.80\times10^{3}\ J\ kg^{-1}\ K^{-1}$$

3.11 The crust of the pie has a lower specific heat capacity than the filling and thus has less heat energy to transfer to your mouth resulting in there being less energy to raise the temperature of your mouth and burn you. A minor effect may be that the liquid filling may be a better conductor of heat to your mouth.

3.12 Heat a measured mass, M, of the alloy to a known temperature, T, and put into a well-insulated and measured mass, m, of water at known temperature, t. The measured final temperature, T_f of the mixture can be related to the specific heat capacity of the alloy
Heat lost by alloy + heat gained by water = 0
$$M\, c_{alloy}\left(T_f - T\right) + m\, c_{water}\left(T_f - t\right) = 0$$
Hence c_{alloy} can be calculated.

3.13 [a] Time to heat is inversely proportional to specific heat capacity. Ethylene glycol has a lower specific heat capacity than water and will reach 100°C faster by a factor of:
$$\frac{c_{water}}{c_{glycol}} = \frac{4180\, J\, kg^{-1}K^{-1}}{2400\, J\, kg^{-1}K^{-1}} = 1.74$$
So, it takes 1.74 times longer to heat the water.

[b] Water has a significantly higher specific heat capacity than ethylene glycol. Other factors, such as boiling point and corrosive effects are important. In terms of its ability to absorb heat energy without a significant rise in temperature, water is more efficient. However, even under pressure water will boil at about 120°C. If a designer wants to run an engine at a higher temperature, which is potentially more efficient, then a liquid with a higher boiling point is needed. Ethylene glycol boils at 198°C and is also less corrosive to metal parts than water. Often a mixture of both liquids is used as a coolant.
[c] If a bigger mass of coolant was used, or the rate at which it is pumped through the system is increased, cooling could be improved.

3.14 The storage system must be fully enclosed and very well lagged to prevent heat escaping through its walls and its upper and lower surfaces. It should have a low coefficient of expansion so there is very little increase in size and less chance of fracturing due to expansion. It should have a high melting point. Its inner walls should be silvery or shiny to prevent heat escaping by radiation.

3.15 $Q = 2.93\, MJ = 2.93 \times 10^6\, J, c = 4180\, J\, kg^{-1}K^{-1}, \Delta T = 100°C - 20°C = 80°C$
$$m = \frac{Q}{c\Delta T} = \frac{2.93 \times 10^6\, J}{4180\, J\, kg^{-1}K^{-1} \times 80°C} = 8.76\, kg$$
Therefore, 8.76 kg of water is needed (or just a little more in order to prevent the coolant water from boiling).

3.16 Energy required by the water:
$m = 245\, kg, c = 4180\, J\, kg^{-1}K^{-1}, \Delta T = 68°C - 12°C = 56°C$
$Q = mc\Delta T = 245\, kg \times 4180\, J\, kg^{-1}K^{-1} \times 56°C = 5.735 \times 10^7\, J$
At 62% efficiency the oil would have to supply:
$$\frac{5.735 \times 10^7 J}{0.62} = 9.25 \times 10^7 J$$
Therefore, the mass of oil required:
$$m = \frac{Q}{Q_{per\ kg}} = \frac{9.25 \times 10^7\, J}{4.15 \times 10^7\, J\, kg^{-1}} = 2.23\, kg$$

3.17 The longer the hot bathwater remains in the bath tub the more heat energy it will transfer to the colder air around it as it attempts to reach thermal equilibrium with the room. Effectively, it would warm up the room.

3.18 Water has a higher specific heat capacity than and. Hence the same heat input from the sun shall raise the temperature of the land by much more than that for an equivalent amount of water.

3.19 Microwave energy supplied = heat gained by glass + heat gained by water
$m_{glass} = 0.215\ kg, c_{glass} = 670\ J\ kg^{-1}K^{-1}, \Delta T_{glass} = 98.5°C - 18.5°C = 80°C$
$m_{water} = 0.145\ kg, c_{water} = 4180\ J\ kg^{-1}K^{-1}, \Delta T_{water} = 98.5°C - 18.5°C = 80°C$
$Q = m_{glass}c_{glass}\Delta T_{glass} + m_{water}c_{water}\Delta T_{water}$
$Q = 0.215\ kg \times 670\ J\ kg^{-1}K^{-1} \times 80°C + 0.145\ kg \times 4180\ J\ kg^{-1}K^{-1} \times 80°C$
$Q = 6.00 \times 10^4\ J = 60kJ$

3.20 Final temperature of the soup = final temperature of the bowl = 97°C
Heat lost by soup = heat gained by bowl = 0
$m_{soup} = 0.8\ kg, \Delta T_{soup} = 97°C - 98°C = -1°C$
$m_{bowl} = 0.1\ kg, c_{bowl} = 320\ J\ kg^{-1}K^{-1}, \Delta T_{bowl} = 97°C - 10°C = 87°C$
$m_{soup}c_{soup}\Delta T_{soup} + m_{bowl}c_{bowl}\Delta T_{bowl} = 0$
$0.8\ kg \times c_{soup} \times (-1°C) + 0.1\ kg \times 320\ J\ kg^{-1}K^{-1} \times 87°C = 0$
$c_{soup} = 3.48 \times 10^3\ J\ kg^{-1}K^{-1}$

3.21 Heat lost by tea + heat gained by water = 0
$m_{tea} = 0.185\ kg, c_{tea} = 4180\ J\ kg^{-1}K^{-1}, \Delta T_{tea} = \left(T_f - 85.5°C\right)$
$m_{water} = 0.035\ kg, c_{water} = 4180\ J\ kg^{-1}K^{-1}, \Delta T_{water} = \left(T_f - 18°C\right)$
$m_{tea}c_{tea}\Delta T_{tea} + m_{water}c_{water}\Delta T_{water} = 0$
$0.185\ kg \times 4180\ J\ kg^{-1}K^{-1} \times \left(T_f - 85.5°C\right) + 0.035\ kg \times 4180\ J\ kg^{-1}K^{-1} \times (T_f - 18°C = 0$
Solving for T_f gives $T_f = 74.8°C$

3.22 Each hour, mass of water flowing, $m = 1300\ kg\ min^{-1} \times 60 = 7.8 \times 10^4 kg\ h^{-1}$
Each hour, energy transferred to water by pump = $10000\ J\ s^{-1} \times 3600 = 3.6 \times 10^7 J\ h^{-1}$
35% of this energy is transferred as heat, $Q = 0.35 \times 3.6 \times 10^7 J\ h^{-1} = 1.26 \times 10^7 J\ h^{-1}$
So during the hour:
$$\Delta T = \frac{Q}{mc} = \frac{1.26 \times 10^7 J\ h^{-1}}{7.8 \times 10^4\ kg\ h^{-1} \times 4180\ J\ kg^{-1}K^{-1}} = 0.0386°C = 3.86 \times 10^{-2}°C$$

3.23 Electrical energy input = $\frac{heat\ gained\ by\ kettle + heat\ gained\ by\ water}{0.65}$ as it is 65% efficient
$m_{kettle} = 5.25\ kg, c_{kettle} = 445\ J\ kg^{-1}K^{-1}, \Delta T_{kettle} = 96°C - 12°C = 84°C$
$m_{water} = 1.55\ kg, c_{water} = 4180\ J\ kg^{-1}K^{-1}, \Delta T_{water} = 96°C - 12°C = 84°C$
$$Q = \frac{m_{kettle}c_{kettle}\Delta T_{kettle} + m_{water}c_{water}\Delta T_{water}}{0.65}$$
$$Q = \frac{5.25\ kg \times 445\ J\ kg^{-1}K^{-1} \times 84°C + 1.55\ kg \times 4180\ J\ kg^{-1}K^{-1} \times 84°C}{0.65}$$
$Q = 1.14 \times 10^6\ J = 1.14MJ$

3.24 85% of the heat lost by hot water + heat gained by cold water = 0 (since bath & surroundings absorb 15%)
$c_{hot} = 4180\ J\ kg^{-1}K^{-1}, \Delta T_{hot} = 75.3°C - 45°C = 30.3°C$
$m_{cold} = 40\ kg, c_{cold} = 4180\ J\ kg^{-1}K^{-1}, \Delta T_{cold} = 45°C - 16.5°C = 28.5°C$
$0.85 \times m_{hot}c_{hot}\Delta T_{hot} + m_{cold}c_{cold}\Delta T_{cold} = 0$
$0.85 \times m_{hot} \times 4180\ J\ kg^{-1}K^{-1} \times 30.3°C + 40\ kg \times 4180\ J\ kg^{-1}K^{-1} \times 28.5°C = 0$
Solving for m_{hot} gives $m_{hot} = 44.3\ kg$

3.25 Heat gained by glycol + (heat lost by radiator + heat lost by water) = 0

$m_{glycol} = 0.655\ kg, c_{glycol} = 2400\ J\ kg^{-1}K^{-1}, \Delta T_{glycol} = T_f - 22°C$

$m_{radiator} = 4.5\ kg, c_{radiator} = 390\ J\ kg^{-1}K^{-1}, \Delta T_{radiator} = T_f - 92°C$

$m_{water} = 6.75\ kg, c_{water} = 4180\ J\ kg^{-1}K^{-1}, \Delta T_{water} = T_f - 92°C$

$m_{glycol}c_{glycol}\Delta T_{glycol} + m_{radiator}c_{radiator}\Delta T_{radiator} + m_{water}c_{water}\Delta T_{water} = 0$

$$0.655\ kg \times 2400\ J\ kg^{-1}K^{-1} \times (T_f - 22°C) + 4.5\ kg \times 390\ J\ kg^{-1}K^{-1} \times (T_f - 92°C) + 6.75\ kg \times 4180\ J\ kg^{-1}K^{-1} \times (T_f - 92°C) = 0$$

Solving for T_f gives $T_f = 88.5°C$