Heat Transfer - 2

A long copper wire is used to carry an electric current and has an electrical resistance per unit length (*R'el*) of 0.001 ohm per meter. The wire is to be tested to determine the thermal properties for a lumped capacity model. The electric resistance causes the wire to heat up from current flow from an external electric source. The wire is covered by a thin layer of electrical insulation and is suspended in air at *Tamb* = 40 ^{0}C. The maximum allowable insulation temperature is 90 ^{0}C.

a) (**15 points**) Draw a diagram, label all of the symbols used, and formulate a steady state energy balance when internal heat generation is caused by the electric current flow. Find the heat generation per unit length in the wire when the current is 50 A.

b) (**15 points**) Find the product of the area per unit length and overall heat transfer coefficient, *UA/L* in W/^{o}C-m, for air cooling the wire from the measured steady state temperature of *Twire* = 50 ^{o}C when the current flow is 50 A.

c) (**15 points**) The wire is then heated to *Twire* = 90 ^{o}C using a higher steady state current flow. Find the internal heat generation and current flow for this condition. This is the steady state current rating of the wire.

d) (**20 points**) The current is then shut off and the wire begins to cool down. Test data shows that the wire temperature cools from 90 ^{o}C back to 50 ^{o}C in 425 seconds. From this cool down time, find the wire thermal time constant, τ, and then the wire lumped thermal heat capacity per unit length *MC/L* in kJ/^{o}C-m. If you know the form for the transient lumped capacity model, you can write it down, otherwise derive it. Be sure to use the three temperatures *Tinit, Tamb* and *Twire* in the correct order. State any assumptions you make.

e) (**20 points**) The short-term peak current rating of the wire is to be determined using a conservative estimate. Assuming the heat loss to the ambient air is small relative to internal heat generation for high peak current, formulate a transient energy balance for the wire for a constant current flow, and an initial temperature *Tinit*. Draw a large detailed diagram that includes ***all*** of the symbols used in the solution. Estimate the time for the wire to reach 90 ^{o}C when a current of 300 A is applied, starting from an initial temperature of 50 ^{o}C. State any assumptions you make.

f) (**15 points**) Beginning from the steady state condition in b), sketch the time history of the wire temperature for a steady current of 50 A for 30 seconds, a peak current of 300 A until the wire reaches 90 ^{o}C, and then the cool down period back to 50 ^{o}C when the current flow is zero. Show the correct relative time for each phase in the sketch.

After completing a) thru f), revisit e) and check that you put ***all*** symbols used in your solution on your diagram; redraw it if you started too small and can't fit all of the symbols legibly. Be sure to ***clearly*** indicate your answer to each part.