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Supplementary Materials

Active Textile Glove for Cooling and Personal Protection

Xiaoda Hou [1,2], Travis Neuendorf [1], David Mast [3], Ashley Kubley [4], Vianessa Ng [1,2] and Mark Schulz [1,2,*]

[1] College of Engineering and Applied Sciences, University of Cincinnati, Cincinnati, OH 45221, USA; houxad@gmail.com (X.H.), neuendtc@mail.uc.edu (T.N.), ngva@mail.uc.edu (V.N.)
[2] Nanoworld Laboratories, University of Cincinnati, Cincinnati, OH 45221, USA
[3] Department of Physics, University of Cincinnati, Cincinnati, OH 45221, USA; mastdb@ucmail.uc.edu
[4] College of Design, Architecture, Art, and Planning, University of Cincinnati, Cincinnati, OH 45221, USA; kubleyay@ucmail.uc.edu
* Correspondence: schulzmk@ucmail.uc.edu

Supplementary Description of The Analysis Equations

Refer to Figure 1. In this heat transfer model system, the glove is simulated based on thermal conduction and convection. The glove is separated into two parts, one is the upper side, and another is the lower side. The equations and theory of heat transfer on both sides are the same. The heat transfer by conduction through the glove equals that of the CNT sheet layer, so:

$$q_{g1} = q_{CNT1} \quad (1)$$

The heat transfer rate by conduction of the upper layer of the glove is:

$$q_{g1} = P_g \times (T_1 - T_3) \quad (2)$$

where P_g is $\frac{KA}{L}$, and K is the thermal conductivity of the glove, A is the surface area of the glove, L is the thickness of the glove material. T1 is the environmental temperature and T3 is the temperature between the glove layer and the CNT sheet layer.

The heat transfer rate by conduction of the CNT fabric is:

$$q_{CNT1} = q_{ch1} + q_{cp1} \quad (3)$$

where q_{ch1} is the heat transfer rate by conduction of the CNT fabric to the hand and the direction is vertical (through the thickness), and q_{cp1} is the heat transfer rate by conduction of the CNT fabric to the convection area, whose direction is transferred in the plane of the fabric. The convection area has a specific temperature.

Here, P_{cp} is $\frac{KA_c}{L}$, and K is thermal conductivity of CNT fabric to convection area (thermal conductivity of CNT fabric in the plane of the fabric direction), A_c is the cross-sectional area of the CNT fabric, L is the length of the CNT sheet or fabric to convection area. Also, T7 is the temperature between the CNT sheet and convection model, and T5 is the temperature between the CNT sheet and hand.

The heat transfer rate by convection is:

$$q_{convection1} = P_{conv} \times (T_7 - T_9) \quad (4)$$

where P_{conv} is $\widetilde{hc} \times A$, and $\widetilde{hc}$ is the average convection heat transfer coefficient over the surface area A, and A is the area of convection model. T9 is the temperature at the end of the thermal convection model, which is set at 40 degrees Celsius.

Equation 5 represents the heat transfer rate by conduction from the CNT sheet or fabric to the convection area.

$$q_{cp1} = P_{cp} \times (T_7 - \frac{T_3+T_5}{2}) \quad (5)$$

The heat transfer rate by conduction from the CNT sheet layer to the hand is:

$$q_{ch1} = P_{ch} \times (T_3 - T_5) \quad (6)$$

where P_{ch} is $\frac{\mathrm{KA}}{\mathrm{L}}$, and K is the thermal conductivity of the CNT sheet to hthe and, A is the surface area of the CNT sheet, L is the length of the CNT sheet to the hand.

The heat transfer rate by conduction of the hand on the upper side is:

$$q_{h1} = P_h \times (T_5 - T_{11}) \quad (7)$$

where P_h is $\frac{\mathrm{KA}}{\mathrm{L}}$, and K is the thermal conductivity of the hand, A is the surface area of hand, L is half of the thickness of hand. T11 is temperature at the center of the hand.

The heat transfer rate based on conduction of the hand to the arm is:

$$q_{ha} = P_{ha} \times (T_{11} - T_{12}) \quad (8)$$

where P_{ha} is $\frac{\mathrm{KA_c}}{\mathrm{L}}$, and K is the thermal conductivity of the hand to the arm, A_c is the cross-sectional area of the hand, L is half of the length of hand. T12 is temperature between the hand and the arm.

The heat transfer rate based on conduction of the arm is:

$$q_a = P_a \times (T_{12} - T_{13}) \quad (9)$$

These are all the equations to model the upper side of the glove. Next are the equations to model the lower side of glove. The heat transfer based on conduction of glove equals that of the CNT sheet layer, so:

$$q_{g2} = q_{CNT2} \quad (10)$$

The heat transfer rate by conduction of the lower side of the glove is:

$$q_{g2} = P_g \times (T_2 - T_4) \quad (11)$$

where T2 is the environment temperature and T4 is the temperature between the glove layer and CNT sheet layer.

The heat transfer rate based on conduction of the CNT sheet is:

$$q_{CNT2} = q_{ch2} + q_{cp2} \quad (12)$$

where q_{ch2} is the heat transfer rate by conduction of the CNT sheet to the hand and the direction is vertical (through the thickness), and q_{cp2} is the heat transfer rate by conduction of CNT sheet to the convection model, whose direction is horizontal (in the plane of the fabric).

$$q_{cp2} = P_{cp} \times \left(T_8 - \frac{T_4+T_6}{2}\right) \quad (13)$$

where T8 is temperature between the CNT sheet and the convection area, and T6 is temperature between the CNT sheet and the hand.

The heat transfer rate based on convection is:

$$q_{convection2} = P_{conv} \times (T_8 - T_{10}) \quad (14)$$

Here T10 is the temperature at the end of the convection model, which is set at 40 Celsius degrees.

The heat transfer rate by conduction from the CNT sheet layer to the hand is:

$$q_{ch2} = P_{ch} \times (T_4 - T_6) \quad (15)$$

The heat transfer rate by conduction of the hand on the lower side is:

$$q_{h2} = P_h \times (T_6 - T_{11}) \quad (16)$$

The heat transfer rate by conduction of the hand to the arm also equals:

$$q_{ha} = q_{h1} + q_{h2} \quad (17)$$

$$q_{ha} = q_a \quad (18)$$

At the same time,

$$q_{h1} = q_{ch1} \quad (19)$$

$$q_{h2} = q_{ch2} \quad (20)$$

$$q_{cp1} = q_{conv1} \quad (21)$$

$$q_{cp2} = q_{conv2} \quad (22)$$

Then, the 22 equations can be transferred into a matrix, so that it can be solved simultaneously in MATLAB.

Parameter values used in the glove simulation model.

Parameter Name	Parameter Symbol	Parameter Value	Parameter Unit
Thermal conductivity of outer layer of glove	K_glove	0.05	W/(m·K)
Area of outer layer of glove	A_glove	0.03	m^2
Length of outer layer of glove	L_glove	0.01	m
Thermal conductivity of the CNT sheet from CNT sheet to convection model (in the plane direction)	K_cp_convection	200	W/(m·K)
Area of the place from CNT to convection model	A_cp_convection	0.003	m^2
Length from the CNT to convection model	L_cp_convection	0.15	m
Heat conductivity of the place from CNT to hand	K_ch_CNTtoHand	2	W/(m·K)
Area of CNT sheet from CNT to hand	A_ch_CNTtoHand	0.0225	m^2
Length from the CNT to hand	L_ch_CNTtoHand	0.001	m
Heat conductivity of the place from hand to arm	K_ha_HandtoArm	2	W/(m·K)
Area of the place from hand to arm	A_ha_HandtoArm	0.00225	m^2
Length from hand to arm	L_ha_HandtoArm	0.1	m
Heat conductivity of arm	K_a_Arm	2	W/(m·K)
Area of arm	A_a_Arm	0.004	m^2
Length of arm	L_a_Arm	0.03	m
Heat conductivity of hand	K_h_Hand	2	W/(m·K)
Area of hand	A_h_Hand	0.03	m^2
Length of hand	L_h_Hand	0.0075	m
Environment temperature	T1 and T2	Changing by cases	K
Temperature at the end of phase change material	T9	313.15	K
Temperature at the end of the arm	T13	310.15	K