California State University, Long Beach

Department of Mechanical and Aerospace Engineering

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Lab Report by:

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Heat Transfer Final Project

Course Number: MAE 431

Section Number: Sec 03

Professor Navdeep Singh Dhillon

Objective

Conduct heat transfer analysis and optimize the conditions for our imaginary commute to school on a road bike in the months of January, June, and October.

Abstract

The purpose of this project was to research and design appropriate clothing for a bike commute in Long Beach in the months of January, June, and October. We started off our design by making some general assumptions that would make the heat transfer analysis more simplistic. We then researched the weather conditions at Long Beach for the given months, and from this were able to get the fluid properties of air in each month. We used these properties to first calculate the rate of heat transfer due to conduction. Next, we researched different materials and their properties. We settled with cotton, polyester, and nylon and then found the rate of heat transfer due to conduction with each fabric at various thicknesses. Lasty, we researched the solar radiation in Long Beach for each month and were able to find the total rate of heat transfer due to radiation in each month. Bringing all of our findings together, we were able to conclude that the best attire in January is nylon with a thickness of 0.5 mm. June and October have the same attire with polyester at 0.25 mm.

Background

The distance that we must travel from home to school is about 12 miles, with an average bike speed of about 15 miles/hour. The exertion from the bike ride will lead to burning calories, thus generating heat inside the body. Further, our bodies will absorb a considerable amount of heat from the sun on a hot day. To compensate, our bodies will lose heat from various parts, including the head. The convection heat transfer coefficient increases with flow speed, so the faster we go, the more the fast air flow around the body will aid in heat loss. Conversely, if the air temperature is low, our body may lose too much heat. We should be dressed appropriately based on our physiology, biking speed, and the weather conditions. We will design appropriate clothing for our bike commute in the months of January, June, and October.

Methods

In order to perform heat transfer analysis, we must make some assumptions. Our body, 180 lbs, is to be modeled as a cylinder whose length is equal to our height, 65 inches, and whose diameter is equal to our average diameter at the waist, 38 inches. We will assume that the air is blowing purely perpendicular to our body. The clothing is to cover all parts of the body, except the face and head. We will assume our average skin temperature is approximately 36 ℃. Our clothing is to be a single layer of an appropriate material, covering the body. Finally we will assume that the sun's rays are also striking perpendicular to the body. We will also convert all forms of measurement into metric for the calculations.

At a rate of 15 mph, we will travel the distance of 12 miles in 48 minutes. Based on our assumptions, we can find that the surface area for the body is 6.47 m^2. Our research for weather conditions in Long Beach for January, June, and October gave us an average temperature and rate of heat transfer due to radiation (kW/m^2) of 27.72 ℃ & 3.3 , 30.5 ℃ & 8.3, and 30.5 ℃ & 4.9 respectively. We can calculate the film temperature of the three months by summing the average temperature and the skin temperature, and then dividing by two. This gives us a film temperature of 300.87 K for January, 303.65 K for June, and 303.65 K for October. Using table A-15 from the textbook and the film temperatures calculated, we are able to find the properties of the air which are given in Table 1.

	January	June	October
Density (kg/m^3)	1.1732	1.1621	1.1621
Thermal Conductivity (k)	0.0257098	0.025917	0.025917
Dynamic Viscosity (μ)	0.0000186142	0.000018743	0.000018743
Kinematic Viscosity ($\mathcal{V}$)	0.0000158684	0.000016127	0.000016127
Prandtl Number	0.728844	0.72806	0.72806

Table 1: Air Properties at Calculated Film Temperatures

Results

Sample Calculations for Conduction in January:

$$Re = \frac{VD}{\nu} = \frac{(6.705)(0.9652)}{0.00001587} = 4.079 \text{ x } 10^5$$

$$Nu = 0.3 \frac{0.62Re^{1/2}Pr^{1/3}}{[1+(0.4/Pr)^{2/3}\}^{1/4}} [1 + (\frac{Re}{282,000})^{5/8}]^{4/5} = 166.92$$

$$h = \frac{Nuk}{D} = 4.446$$

$$Q_{cond} = hA_s(T_s - T_\infty) = 476.23 \text{ W}$$

Reynolds Number	$4.079 \text{ x } 10^5$	$4.013 \text{ x } 10^5$	$4.013 \text{ x } 10^5$
Nu Number	166.921	143.967	143.967
Heat Transfer Coefficient	4.446	3.866	3.866
Heat Transfer	476.23	275.109	275.109

Sample Calculation for Convection in January with Cotton of thickness of 0.25 mm:

$$Q_{conv} = \frac{2\pi kL}{ln(r_1/r)} = 21554.8779 \text{ W}$$

	January		
Fabric	Cotton	Polyester	Nylon
Thickness 1 (mm)	21554.8779	126013.1323	43109.75579
Thickness 2 (mm)	10780.229	63022.87724	21560.458
Thickness 3 (mm)	7188.679049	42026.12367	14377.3581

	June		
Fabric	Cotton	Polyester	Nylon
Thickness 1 (mm)	14321.69739	83726.84631	28643.39476
Thickness 2 (mm)	7162.702491	41874.26072	14325.40498
Thickness 3 (mm)	4776.370644	27923.39761	9552.741287
	October		
Fabric	Cotton	Polyester	Nylon
Thickness 1 (mm)	14321.69739	83726.84631	28643.39476
Thickness 2 (mm)	7162.702491	41874.26072	14325.40498
Thickness 3 (mm)	4776.370644	27923.39761	9552.741287

Sample Calculation for Radiation in January:

$$q_{rad} = \varepsilon\sigma(T_{skin}^4 - T_{avg}^4) = 100.297\, W$$

$$q_{solar} = irradiance \cdot b$$

$$q_{solar} = (3.18) \cdot (0.6) = 1908\, W$$

$$Q_{rad,total} = q_{rad} + q_{solar} = 2008.3\, W$$

	January
Avg Temp (K)	292.5944444
Radiation Heat Transfer	100.2969619
Solar Irradiance (W/m^2)	3.18
Solar Heat Transfer	1908
Total Radiation Heat Transfer	2008.296962

Conclusion

In this project, we were tasked with analyzing the thermal properties of three different types of clothing fabrics in three different thicknesses for a casual biker to wear. In this process, we analyzed the thermal environment of Long Beach, California in the months of January, June, and October. In running calculations for Conduction heat transfer in those months, it was found that January has the highest heat transfer at 476.2 watts. This means that during that month, the body will lose the most heat as the person rides their bike. With this in mind, we moved onto the convection heat transfer calculations. For this mode of heat transfer, we ran calculations for the months of January, June, and October with our materials being cotton, polyester, and nylon. Each of these materials were analyzed at thicknesses of 0.25, 0.50, and 0.75 millimeters. Using these we were able to find out the ideal heat transfer transfer properties for each month. With this data, we recommend using a Nylon blend of 0.5 millimeter thickness for the month of January and a Polyester blend of thickness 0.25 millimeters during the months of June and October. Nylon is ideal for the colder month of January since a person would need to retain heat, meaning the lower convection heat transfer rate is beneficial. Additionally, Polyester is ideal for the warmer and more moderate months of June and October since a person would need to release heat, meaning that an increased convection heat transfer rate is beneficial.

References

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Appendix

Given Data

Distance (miles)	12	Distance (m)	19312.128
Velocity (mph)	15	Velocity (m/s)	6.70540903
Height (inches)	65	Height (m)	1.651003302
Diameter (inches)	38	Diameter (m)	0.9652019304
Time (minutes)	48	Time (secs)	2880
Weight (lbs)	180	Mass (kg)	81.63265306
Skin Temp (C)	36	Skin Temp (K)	309.15
Calories Burned	686	Surface Area (m^2)	6.469666972

Table Data

	January	June	October
[Avg Temp (F)]	67	77	77
Avg Temp (K)	292.5944444	298.15	298.15
Film Temp (K)	**300.8722222**	**303.65**	**303.65**
Film Temp (C)	27.72222222	30.5	30.5
[Radiation (kW/m^2)]	3.3	8.3	4.9
Density (kg/m^3)	1.1732	1.1621	1.1621
Thermal Conductivity, k	0.0257098	0.025917	0.025917
Dynamic Viscosity, u	0.0000186142	0.000018743	0.000018743
Kinematic Viscosity, v	0.0000158684	0.000016127	0.000016127
Prandtl Number, Pr	0.728844	0.72806	0.72806

Conduction (watts)

	January	June	October
Reynolds Number	407859.2511	401319.1381	401319.1381
Nu Number	166.9212684	143.9674604	143.9674604
Heat Transfer Coefficient	4.446232743	3.865724418	3.865724418
Heat Transfer	476.2312359	275.1094455	275.1094455

Researched Data

Shirt Fabric	Cotton	Polyester	Nylon
Thermal Conductivity, k	0.065	0.38	0.13
Emissivity of Skin	0.98	Thickness 1 (mm)	0.25
Absorptivity, b	0.6	Thickness 2 (mm)	0.5
Stefan Constant	0.0000000567	Thickness 3 (mm)	0.75

Convection (watts)

	January		
Fabric	Cotton	Polyester	Nylon
Thickness 1 (mm)	21554.8779	126013.1323	43109.75579
Thickness 2 (mm)	10780.229	63022.87724	21560.458
Thickness 3 (mm)	7188.679049	42026.12367	14377.3581
	June		
Fabric	Cotton	Polyester	Nylon
Thickness 1 (mm)	14321.69739	83726.84631	28643.39479
Thickness 2 (mm)	7162.702491	41874.26072	14325.40498
Thickness 3 (mm)	4776.370644	27923.39761	9552.741287
	October		
Fabric	Cotton	Polyester	Nylon
Thickness 1 (mm)	14321.69739	83726.84631	28643.39479
Thickness 2 (mm)	7162.702491	41874.26072	14325.40498
Thickness 3 (mm)	4776.370644	27923.39761	9552.741287

Radiation (watts)

	January	June	October
Avg Temp (K)	292.5944444	298.15	298.15
Radiation Heat Transfer	100.2969619	68.47375224	68.47375224
Solar Irradiance (W/m^2)	3.18	6.7	4.29
Solar Heat Transfer	1908	4020	2574
Total Radiation Heat Transfer	2008.296962	4088.473752	2642.473752

Radius Calculations

Radius (m)	0.4826009652
Thickness 1 (m)	0.00025
Thickness 2 (m)	0.0005
Thickness 3 (m)	0.00075
Radius 1 (m)	0.4828509652
Radius 2 (m)	0.4831009652
Radius 3 (m)	0.4833509652

Calories burned	686	cal
Calories burned	0.797284	w