Homework: COMSOL Project 1

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Description

One person is swimming outside in winter. The water temperature is assumed the same as that of the ambient (about 5℃. Estimate the body temperature distribution with respect to time.

Geometry

The person, as shown in Fig.1 and Fig.2, is represented by a sphere head, a cubic neck, a cylinder body, two cylindrical arms, and two cylindrical legs. Besides, there's a spine, two arm bones and two leg bones inside. The sizes of these parts are shown in Table1. Detailed parameters could be seen in COMSOL project "men_in_water_3.mph".

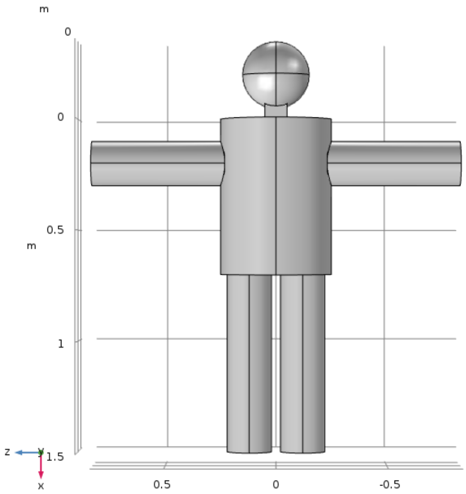


Fig.1 Mesh of person geometry

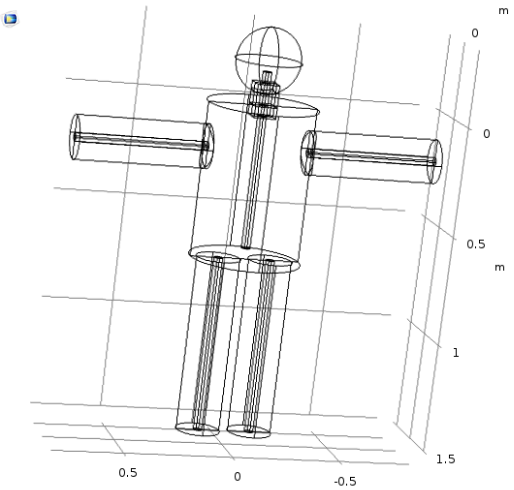


Fig.2 Transparent structure of person geometry

Body part	**Radius/m**	**Height/m**	**Body part**	**Radius/m**	**Height/m**
Body	0.25	0.7	Right leg	0.1	0.8
Head(sphere)	0.15	-	Spine	0.02	0.8
Neck(cubic)	0.1*0.1	0.15	Left arm bone	0.02	0.6
Left arm	0.1	0.6	Right arm bone	0.02	0.6
Right arm	0.1	0.6	Left leg bone	0.02	0.8
Left leg	0.1	0.8	Right leg bone	0.02	0.8

Table.1 Body parts and their size

Material

There're totally three kinds of material, muscle, skin, and bone. In this model, the five bones are made of bone material. Other parts except bones are made of muscle material. The skin surface, which is the boundary of the whole body, is made of skin material. All these material can be found in material library Bioheat. The material properties are listed in Table2.

Material	**Heat capacity at constant pressure/J/(kg*K)**	**Density/kg/m^3**	**Thermal conductivity/W/(m*K)**
Muscle	3421	1090	0.49

Skin	3391	1109	0.37
Bone	1313	1908	0.32

Table.2 Material properties

Bioheat Transfer

①Bioheat.

The problem can be thought as a Bioheat transfer problem and we can use Bioheat equation suggested by Pennes[1].

$$\rho c \frac{\partial T}{\partial t} = \nabla \cdot k \nabla T + Q_{\mathrm{hs}} - h_{\mathrm{bl}}(T - T_{\mathrm{bl}}) + Q_m$$

$$h_{\mathrm{bl}} = \rho_{\mathrm{bl}} c_{\mathrm{bl}} w_{\mathrm{bl}}$$

where ρ is the density (kg/m^3), c is the heat capacity (J /kg K), k is the thermal conductivity (W/m K),Q_{hs} is the heat source (W/m^3), Q_m is the metabolic heat source (W/m^3), T_{bl} is the temperature of blood (assumed to be 37°C), c_{bl} is the specific heat of blood (J /kg K), w_{bl} is the blood perfusion (s^{-1}), and h_{bl} is the connective heat transfer coefficient.

Parameters:

Artery blood temperature = 37 degC

Specific heat capacity = 4180 J/(kg•K)

Blood perfusion rate = 0.00641 1/s

Density of blood = 1050 kg/m^3

Metabolic rate = 60 W/m^2

②Initial value = 37 degC

③Constant temperature. Force those bones are always in 37 degC temperature since they are in the core and the person is healthy.

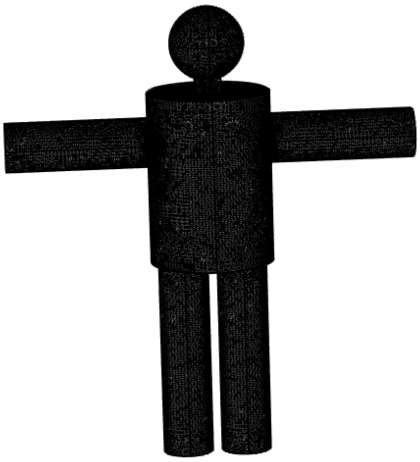
④Convection heat flux. On the surface, heat transfers by convection.

$$q_0 = h \cdot (T_{ext} - T)$$

On the air-body surface, the convection coefficient is defined as $20\frac{\mathrm{W}}{m^2 \cdot K}$ while on the water-body surface, it's $500\frac{\mathrm{W}}{m^2 \cdot K}$.

Grid

I use grid consist of free tetrahedrons. The maximum unit size is set as 0.03m, while the minimum unit size is 0.005m, which is the 1/4 of the bone radius. Therefore, it's dense enough to represent the person. What's more, it's even denser near boundary, which is helpful to reduce potential bias.



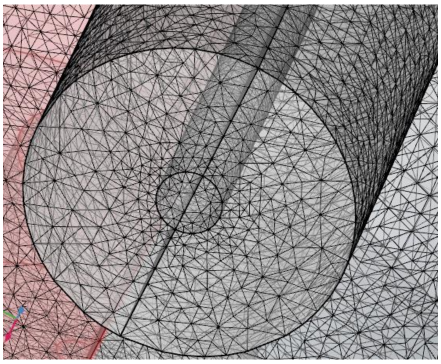


Fig.3 General mesh Fig.4 Local amplification

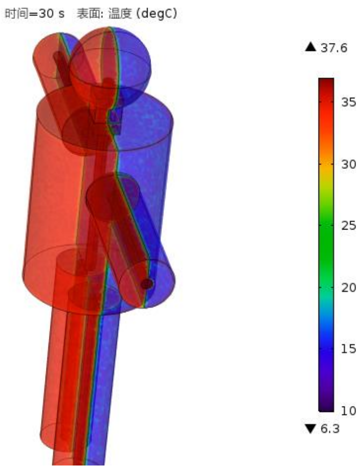
Research

I set the research as a transient problem with 0~30s range, 0.5s step.

Result & Discussion

①General temperature distribution

After 30s, the body-air surface temperature changes little, while the body-water surface temperature drops rapidly. The surface temperature distribution can be seen in Fig.5. Contour chart shows similar results.



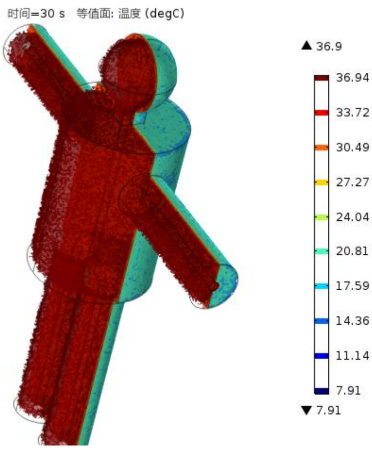


Fig.5 Surface temperature distribution in 30s Fig.6. Contour chart in 30s

②Temperature distribution shown in cross section

Temperature distribution in cross section shows better results. Temperature of inner body maintains temperature close to 37 degC while temperature near the skin drops greatly. In the body-air surface, the skin temperature doesn't change much. However, in the body-water surface, the skin temperature drops dramatically to a very low point.

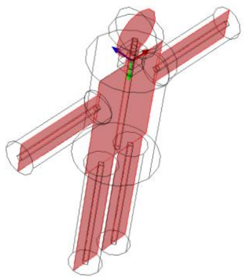


Fig.7 Central Y-Z plane

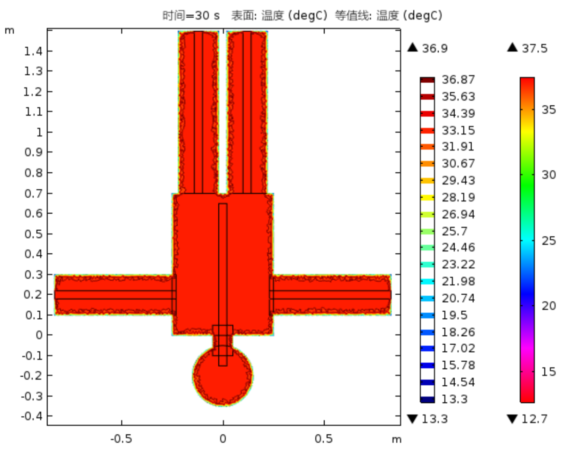


Fig.8 Central Y-Z plane temperature distribution

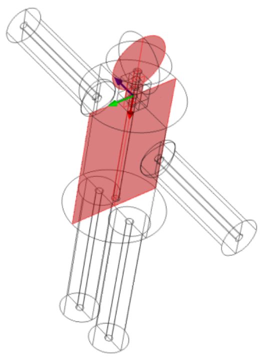


Fig.9 Central X-Y plane

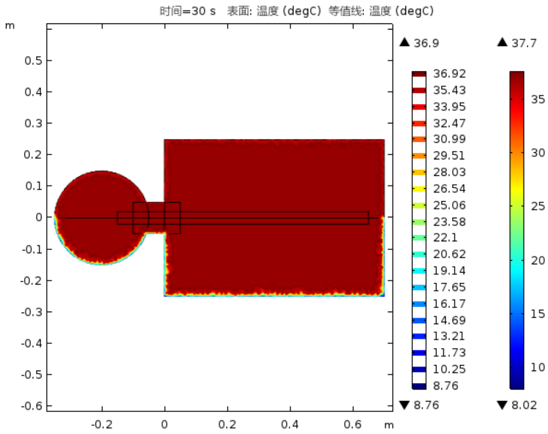
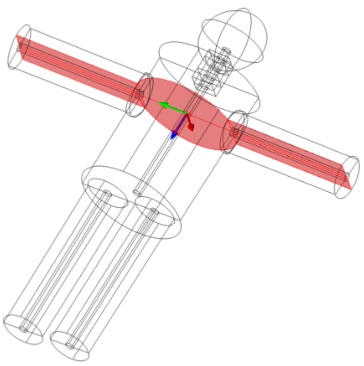


Fig.10 Central X-Y plane temperature distribution

These results show that in core part of body, temperature changes little, while on the skin surface, especially body-water surface, skin temperature drops rapidly.

We can see three more cross-overs to validate this conclusion.



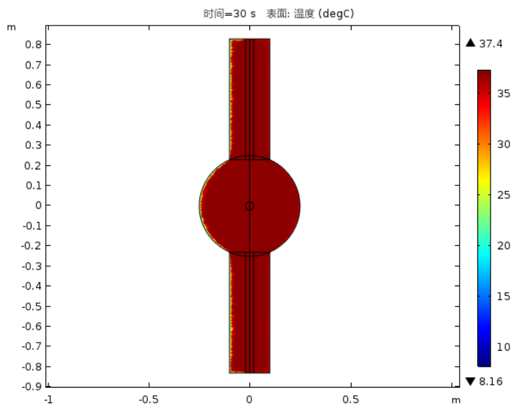
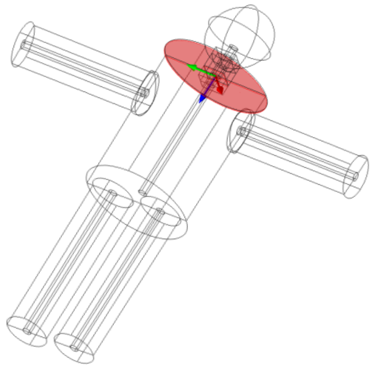


Fig.11 X-Z plane with 0.2m distance to upper surface Fig.12 Temperature distribution of the plane



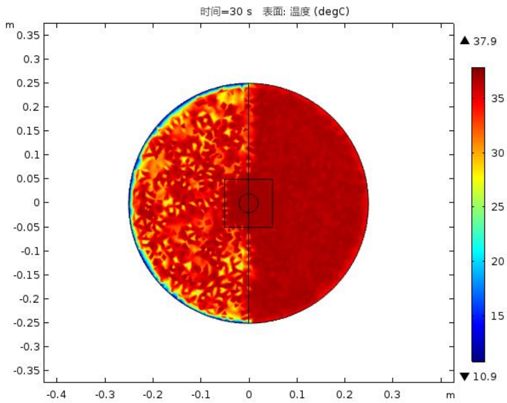
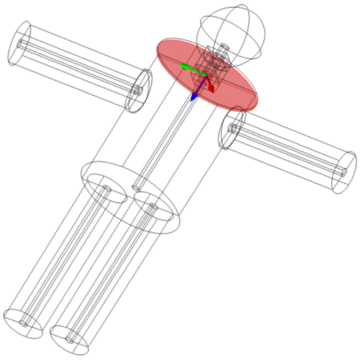


Fig.13 X-Z plane with 0.01m distance to upper surface Fig.14 Temperature distribution of the plane



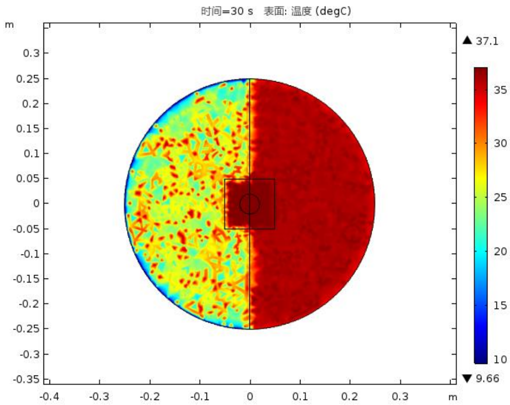


Fig.11 X-Z plane with 0.005m distance to upper surface Fig.12 Temperature distribution of the plane

From these figures, we find that the closer to the upper surface, the more obvious temperature dropping. On the central X-Z plane, only area very near to the skin has low temperature, while on the X-Z plane with closer distance, area of body-air half has a nearly 37 degC constant temperature, but area of body-water half has an obvious difference.

③1D Plot

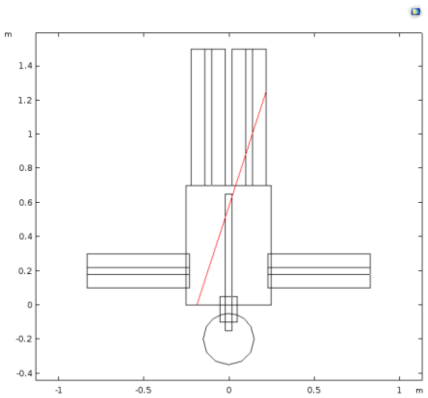


Fig.13 1-D line

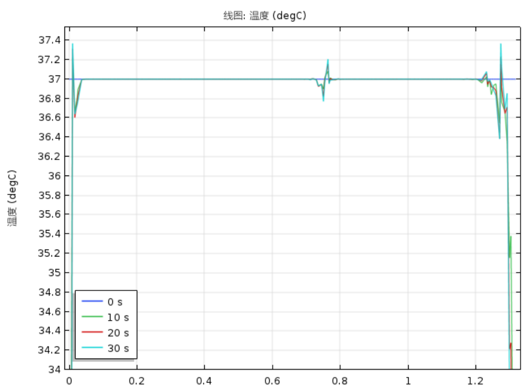


Fig.14 1-D line temperature distribution

Conclusion

1. In 30s, temperature of body near the air-body surface, whose convection coefficient is rather small, doesn’t change much, while the other surface drops dramatically.
2. In core part of body, temperature changes little, while on the skin surface, especially body-water

surface, skin temperature drops rapidly.

[1] H. H. Pennes, "Analysis of Tissue and Arterial Blood Temperatures in the Resting Human Forearm," *Journal of Applied Physiology,* vol. 1, pp. 93-122, 1948/08/01 1948.