Iced Bio-Bandage Design for Skin Burns

Arar Alkhader1, Junling Hu2, Akinwumi Akinkunmi1, Prabir Patra1, Xingguo Xiong3
1 Department of Biomedical Engineering, University of Bridgeprot, Bridgeport, CT, USA
2 Department of Mechanical Engineering, University of Bridgeprot, Bridgeport, CT, USA
3 Department of Electrical Engineering and Computer Engineering, University of Bridgeprot, Bridgeport, CT, USA

Abstract

In this paper a new model for a burns biobandage is introduced not only as a protective means but also as a treatment technique by helping the tissue to rebuild itself as fast as possible. The main objective of this research is to develop a simple cryotherapeutic system to reduce the temperature of the burned tissues to normal temperature of the human body in order to facilitate the tissue healing and regeneration process. A biobandage is proposed to include an iced layer as a cooling source, a cotton layer and a water gel layer for comfort and temperature control, and a plastic layer to seal the ice layer. The optimal combination of these four layers physically work together to reduce inflammation, which in turn makes the heeling or recovery time shorter and reduces pain as a result of decreasing the nerve conductivity. The COMSOL Multiphysics was used to model the cooling process on burned tissue using the proposed iced-biobandage. A modeling analysis was performed to examine the changes of temperature over a predetermined time and to help in identifying the optimal period for ice cooling process.

Introduction

burns are one of the most common accidents which vary in types and depth. The type of accident refers to causes like electrical, chemical, etc., While depth of burns reflects the degree; it depends on the temperature and contact duration with the burning substance.

There are four major degrees of burns, first, second, third, and fourth degree burns. Greater degree means greater damaged tissue, and more complicated situation and treatment procedure. Ice is one of the simplest and cheapest cooling techniques; usually the person after any simple burn (first and second degree burns) tries to cool the burned part with cold water or ice to reduce pain and swelling. This method of cooling are considered as a type of cryotherapeutic treatment.

Figure 1: Skin Burn

Mathematical Statement

Choosing appropriate geometries is the first step toward the goal. The design is composed of four layers, the ice layer, thermoplastic layer, water gel layer and cotton layer. The thickness of each layer was chosen approximately, but after getting the results, it can be easily modified to get the desired cooling. Skin is also considered as a layer with similar width of the bandage as it is the actual area of interest, but it has a specific thickness.

Material properties are important issue, as these properties will directly affect the heat flow within the layers of the design, and overall heat exchanging as well. In this type of analysis, the main interest is with the thermal properties of the material, that's why choosing the materials is basically based on these properties, specially, thermal conductivity and specific heat capacity of the material. Density of the material is also important and should be taken into account in these calculations.

The initial and boundary conditions are also an important issues in any molding analysis, and they vary due to different cooling situations that requires assuming a correct values inputs to approximately reflect the real case.
A time-dependent heat transfer problem defined above was solved in a FEM software package COMSOL to study the 20 minutes cooling process of an iced bandage placed on a burn. A free triangular meshing as shown in Fig. 3 was used to mesh the computational domain. Finer meshes are generated near the interfaces between different layers. Mesh convergence study has taken to choose an appropriate set of mesh for further study.

material	Thermal Conductivity (k) W/m·K	Density (ρ) kg/m^3	Specific Heat Capacity (Cp) J/kg·K
Ice	1.88	920	2100
Thermoplastic	0.2	1200	1200
Hydrogel	0.258	1097	2360
Cotton	0.04	200	1340
Skin	0.37	1109	3391

Table 1: Physical and thermal properties of the materials [4]

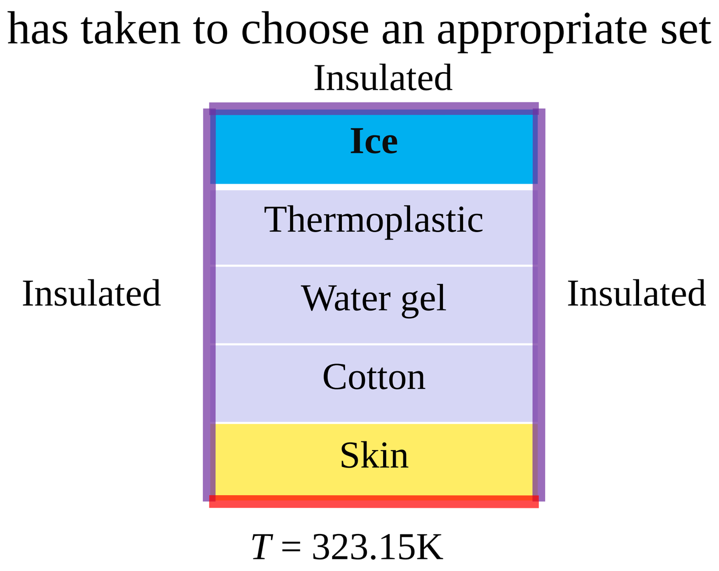

Figure 2: Initial and boundary conditions input for bandage model

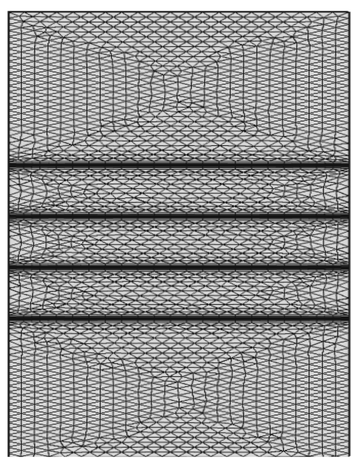

Figure 3: Mesh of the model

Results

Figure 4 shows the temperature field in the whole computational domain which includes the four layers in bandage and the skin layer at various time steps.
The detailed temperature response can be clearly seen in the temperature profiles along the thickness of the computational domain at various time steps as shown in Fig. 5.

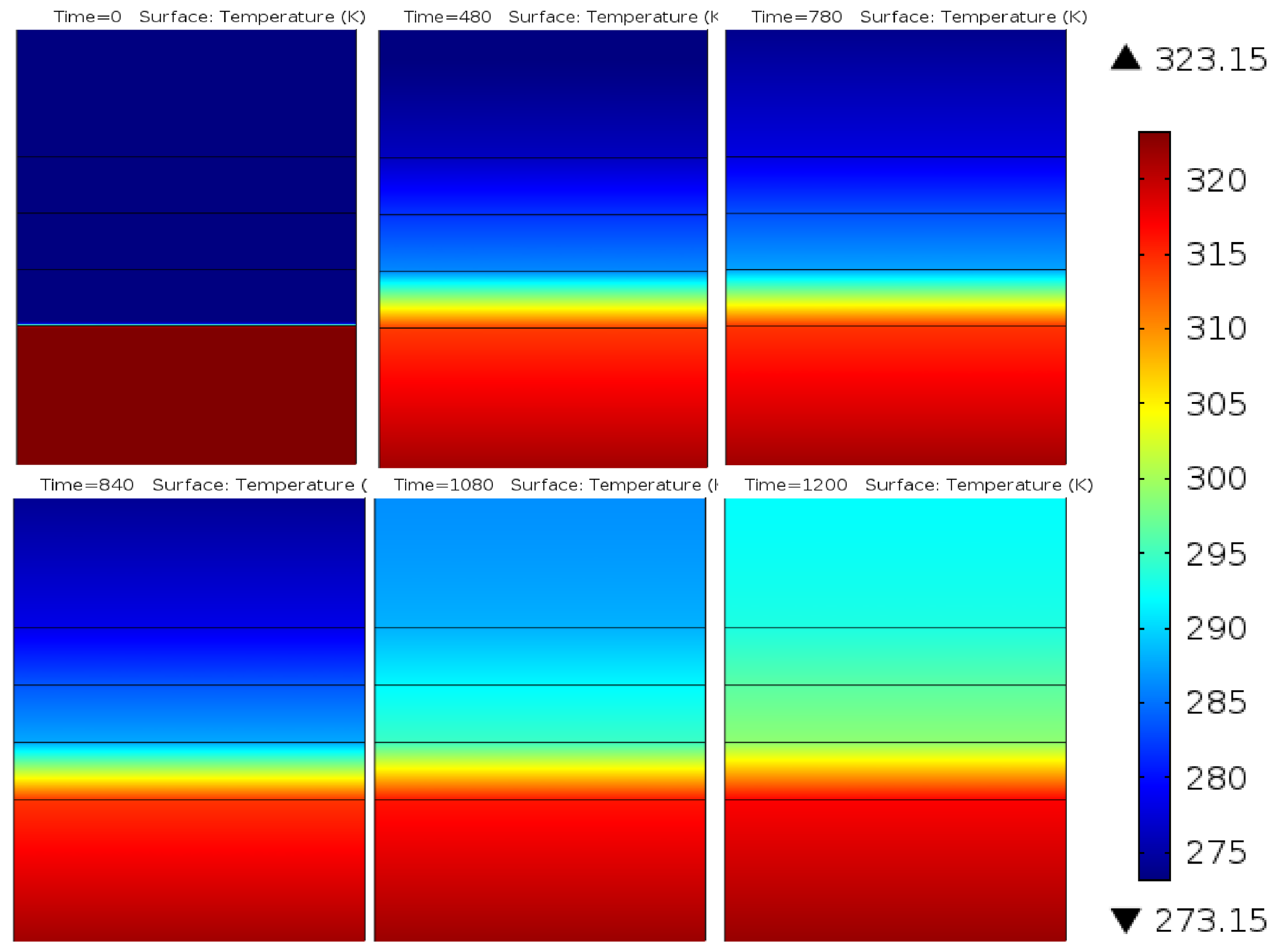

Figure 4 Temperature field in bandage and skin at various time steps.

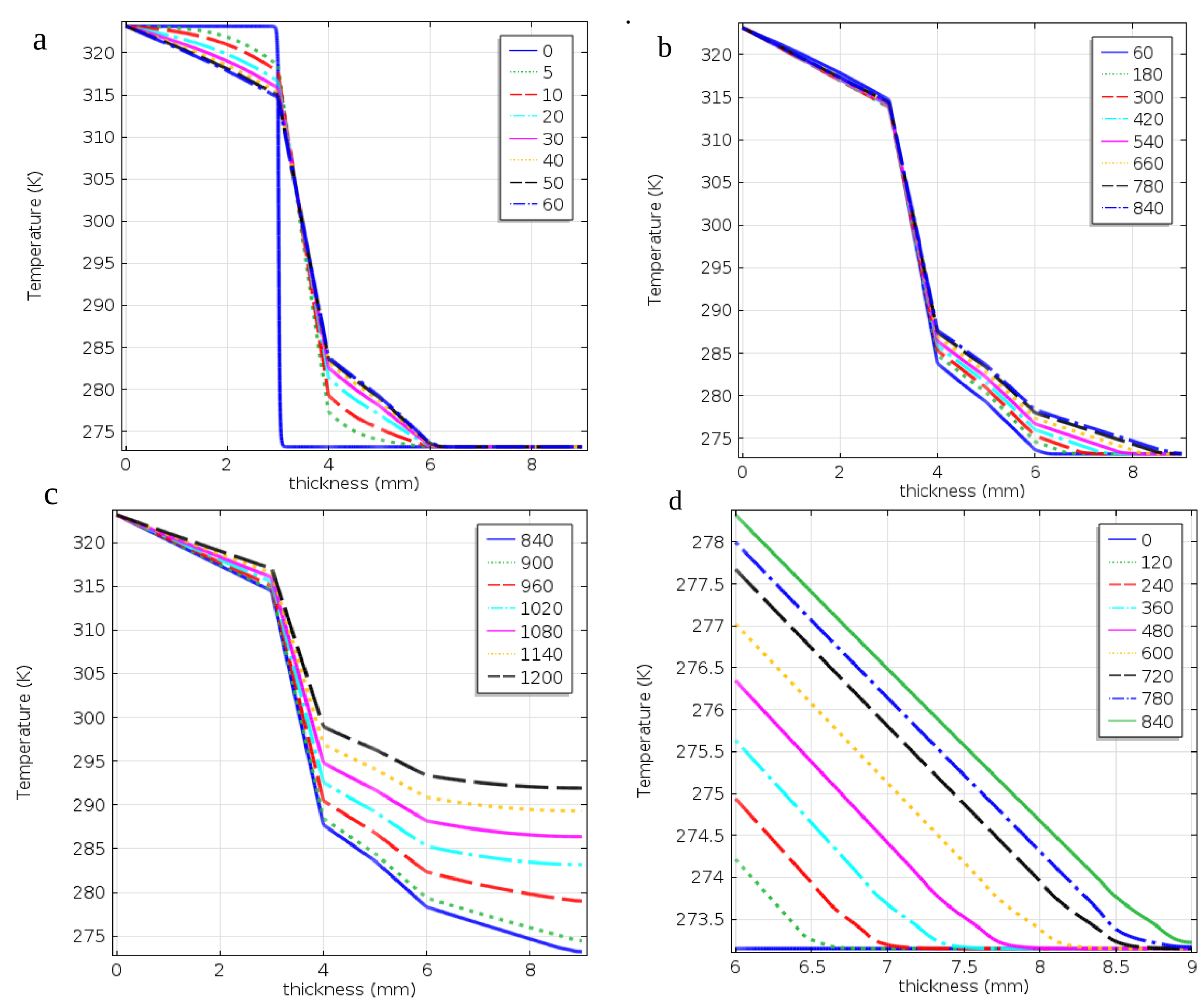

Figure 5: Temperature profiles along the thickness of the computational domain various time steps: (a) from 0s to 60s, (b) from 60s to 780s, and (c) from 780s to 1200s.
(d) Temperature profiles of ice from 0s to 840s.

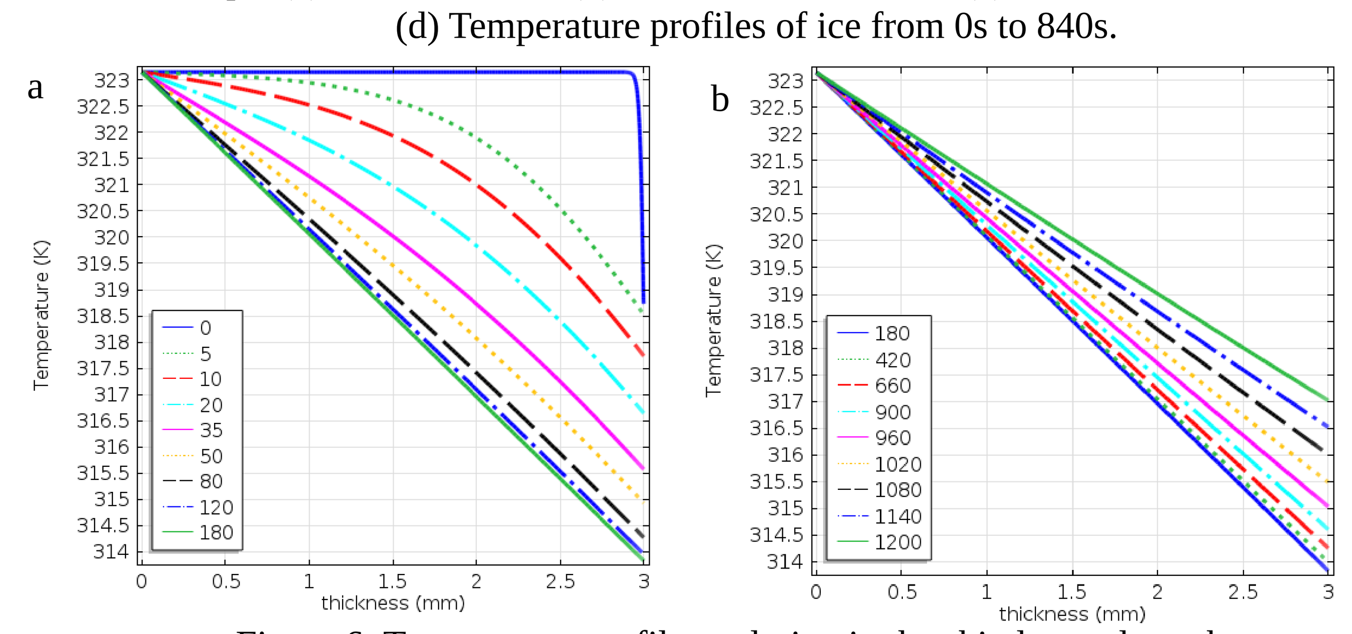

Figure 6: Temperature profile evolution in the skin layer along the depth: (a) from 0s to 180s and (b) from 180s to 1200 s

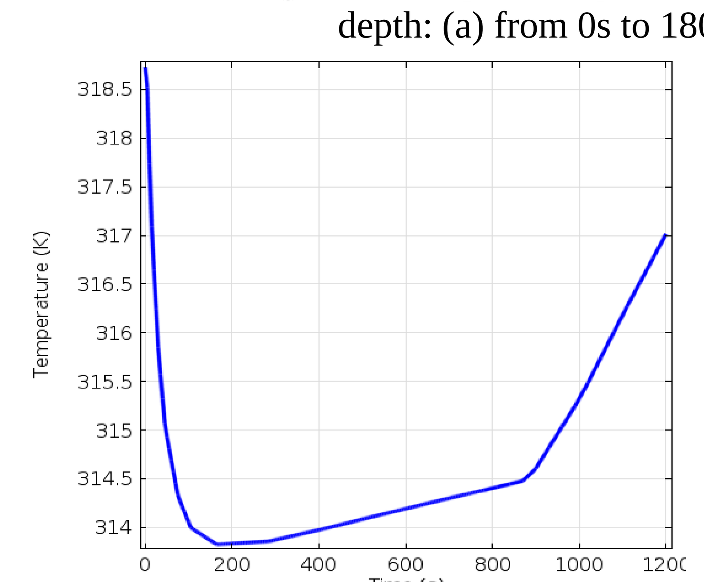

Figure 7: Temperature history at the skin surface

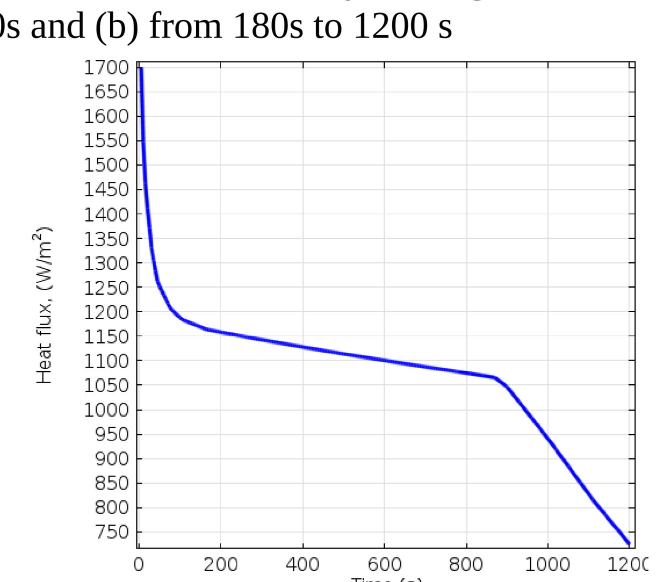

Figure 8: Heat flux history at the skin surface

As shown from the previous figures, we can recognize that the effective cooling process happened during the first 14 minutes as the temperature of the skin dropped from 323K to 314.5K (about 4.5 degrees of the normal body temperature) which is considered a highly beneficial change in the physiological system.

Future Work

- In the future researchers should carefully analyze the effect of the metabolic rate and blood perfusion on the mathematics of the governing equation.
- Remodel this idea for each degree of burns taking into account the specific thickness of the burned tissue and the size of the tissue damage.
- Using the water-gel layer in a more effective way, as it could be as effective as the ice layer
- Examine the intermitted protocol and make detailed comparisons between both protocols