MATHEMATICAL MODEL OF HEAT TRANSFER IN LAYERED STRUCTURE OF HUMAN SKIN INFLUENCED BY HEATED UP TO HIGH TEMPERATURES PARTICLE

Alexandr A. Stuparenko[1, *], and *Andrey* S. Solodkin[2]

[1] National Research Tomsk Polytechnic University, 634050 Tomsk, Russian Federation
[2] National Research University "MPEI", 111250 Moscow, Russian Federation

Abstract. Numerical research results of heat transfer in layered system "air-heated particle-skin layer" presented. Skin structure includes epidermis, derma and hypodermis layers. Skin was influenced by heated up to high temperatures particle. The problem is solved in simple one-dimensional statement in Cartesian system of coordinates. The typical range of influence parameters of heated particle considered. Temperature distributions in different moments of time obtained. Condition of burn occurrence by heated particle is under consideration in this work.

1 Introduction

Skin is a natural external cover of a body. The area of skin surface approximately is equal to 1-2 m^2. The skin can carry out various functions for the person: sensitive, protective, secretory and thermoregulatory [1]. The protective role of skin is multipurpose. It can protect internal parts of body from mechanical damages, detain water evaporation, interfere with penetration of microorganisms, protect from ultra-violet beams. Skin receptors make interaction of organism with the environment. About 15-20 % of blood lump can be collected in hypodermic network of blood vessels. The skin consists of three layers: epidermis, derma and hypodermic fatty cellular tissue (hypodermis) [2].

Epidermis is external layer which is formed by multilayered epithelium. Top epithelium layers are formed by the dead keratinous cells. This layer is most grown in place, where the skin is exposed to mechanical influence (palms and soles) [2].

Derma is layer of dense fibrous connecting tissues which is after epidermis layer. This layer consists from sweat glands, receptors of skin sensitivity, hair bulbs, sebaceous glands, blood and lymphatic vessels. Cells of derma layer are capable to division. Distinctive ability of these cells consists that they can secrete a pigment. Skin cells are bound by elastic fibers which give to skin elasticity [2].

Hypodermis is formed by fatty tissue which carries out role of thermoinsulator which protects organism from cooling. Fat in integument plays role of reserve of nutrients and can be spent in starvation [2]. Hypodermis comprises sweat glands and large blood vessels which allow to skin to adapt to local thermal influences in certain limits of temperatures [3].

---

[*] Corresponding author: firedanger@tpu.ru

Thermal burns occur as a result of high temperature source action on human skin [4]. Majority of such damages depend on source temperature and influence time. Heated up to high temperatures particles of metals and nonmetals are probable sources of high temperature at natural and technogenic fires [5-8].

The purpose of the present work is mathematical simulation of heat transfer in layered structure of human skin at influence of heated up to high temperatures particle.

2 Physical and Mathematical Statements

The human skin is rather difficult structure and one have a various texture in different parts of a body. It is possible to separate out three basic layers: epidermis, derma and hypodermic (fig. 1) [2].
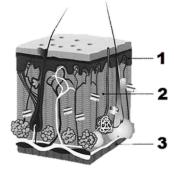

Fig. 1. Skin structure: 1 - epidermis, 2 - derma, 3 – hypodermis.

The basic assumptions [9, 10]:
1. Carbonaceous (natural scenario), steel and ceramic (technogenic scenario) particles are considered.
2. The three-layer system of human skin structure with effective thermophysical characteristics of each layer is considered.
3. It is supposed, that thermophysical characteristics of skin and particle do not depend on temperature.
4. Thermal destruction of skin tissue under the influence of the raised temperatures is neglected.
5. Cellular moisture evaporation from skin tissue also is neglected.
6. Conduction is basic mechanism of heat transfer in skin layers.
7. Monolithic structure of skin layers is considered.

Skin site which influenced by heated up to high temperatures particle of the definitive material with known thermophysical parameters is considered in present work. As a result of ideal contact there is an inert warming up of skin. The given physical phenomenon is considered as process of a heat transfer by heat conductivity. Borders of considered system are air and eternal tissues. The particle is considered in plate approach, that is one-dimensional statement of problem is used.

Heat transfer process in layered structure of skin is described by system of the non-stationary differential equations of heat conductivity with corresponding initial and boundary conditions:

$$\rho_1 c_1 \frac{\partial T_1}{\partial t} = \lambda_1 \frac{\partial^2 T_1}{\partial z^2} \, ,$$

$$\rho_2 c_2 \frac{\partial T_2}{\partial t} = \lambda_2 \frac{\partial^2 T_2}{\partial z^2} \,,$$

$$\rho_3 c_3 \frac{\partial T_3}{\partial t} = \lambda_3 \frac{\partial^2 T_3}{\partial z^2} \,,$$

$$\rho_4 c_4 \frac{\partial T_4}{\partial t} = \lambda_4 \frac{\partial^2 T_4}{\partial z^2}$$

$$T_i \big|_{t=0} = T_{i0} \,,$$

$$z=0, \ -\lambda_1 \frac{\partial T_1}{\partial z} = \alpha_1 (T_1 - T_e) \,,$$

$$z=H1, \ -\lambda_1 \frac{\partial T_1}{\partial z} = -\lambda_2 \frac{\partial T_2}{\partial z} \,,$$

$$z=H2, \ -\lambda_2 \frac{\partial T_2}{\partial z} = -\lambda_3 \frac{\partial T_3}{\partial z} \,,$$

$$z=H3, \ -\lambda_3 \frac{\partial T_3}{\partial z} = -\lambda_4 \frac{\partial T_4}{\partial z} \,,$$

$$z=Lz, \ T_4 = T_{4t} \,,$$

Where T_i, ρ_i, c_i, λ_i - temperature, density, thermal capacity and heat conductivity (1 - particle, 2 - epidermis, 3 - derma, 4 - hypodermis). z - spatial coordinate. t - time coordinate. The index 0, e, t corresponds to parameters during the initial moment, environment and internal tissues of organism. H_i – layer borders of system "particle-skin".

The problem is solved by a method of finite differences. Finite-difference analogues of the differential equations are solved by a marching method [11].

3 Results and Discussion

Temperature distributions in system "skin-particle" are presented in fig. 2-4. Numerical research of heat transfer processes in skin is carried out at influence of steel, ceramic and carbonaceous particles.
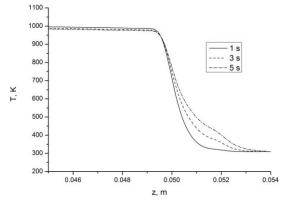

Fig. 2. Distribution of temperatures in system "skin-particle" during the various moments of time (steel particle, initial temperature T = 1000 K).
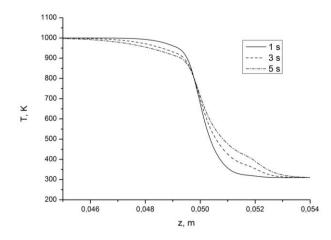
Fig. 3. Distribution of temperatures in system "skin-particle" during the various moments of time (ceramic particle, initial temperature T = 1000 K).
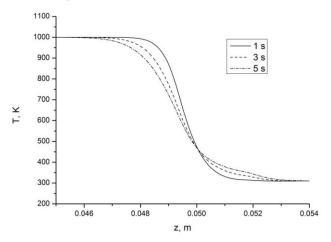

Fig. 4. Distribution of temperatures in system "skin-particle" during the various moments of time (carbonaceous particle, initial temperature T = 1000 K).

Short-term influence of heated up to high temperatures particle to skin was considered in the present work. This assumption corresponds to the scenario of human behavior which has no traumas received as a result of a fire and is capable to exclude long influence of "hot" particles on skin.

The analysis of the obtained distributions (fig. 2,3 and 4) shows., that appreciable cooling of particle occurs in the field of contact to skin and air. It is caused by the heat transfer at interaction with the environment and skin layer. Computing experiments have confirmed an obvious hypothesis that the particles having higher temperature are most dangerous to interaction with skin. So they have the greatest heat stock transferred to skin layer at contact. The top layer of investigated skin site on depth of the order of 0,5 - 2 mm is exposed to the most appreciable influence. Short-term influence of heated up to high temperatures particle mainly effect to epidermis and derma layers. Though, particle with initial temperature of the order of 1000 K cause appreciable heating of hypodermis layer.

The comparative analysis of numerical modeling results shows, that the greatest danger is represented by steel and ceramic particles which are characteristic for various

4

technogenic fires and industrial failures. The least warming up of skin is observed at influence of a carbonaceous particle that corresponds to natural fires.

4 Conclusion

It is earlier shown, that the decision in one-dimensional single-layered statement allows to obtain enough exact results at research of heat transfer processes in human skin. Results accuracy increase slightly with extension of spatial dimensions [12]. It is established, that use of three-layer statement of problem allows to reveal spatial localization of zones with the raised temperature taking into account more exact structure of skin.

The obtained results, namely program realizations of mathematical models for heat transfer in system "particle-skin", can be used for development of new generation of medical information systems [13-15]. Such systems, in turn, can find application in structures of the Ministry of Emergency Measures, medical institutions and departments of protection works or a civil defense at the industrial enterprises. Development of the complex deterministic-probabilistic approach on the basis of methods for forest fire danger forecast [16] and using information-computational technologies [17,18] taking into account the developed mathematical models of heat transfer in human skin is possible. Such system will allow prediction both forest fire danger and impact of fires on the persons.

Acknowledgments

References

1. J.T. Whitton, J.D. Everall, Br. J. Dermatol **89** (1973)
2. F. Xu, T.J. Lu, K.A. Seffen, J. Mech. Phys. Solids **56** (2007)
3. Standard D 4108-87*, Standard test method for thermal protective performance of material for clothing by open flame method, American society for testing and materials* (1994)
4. R.Sh. Enaleev, A.M. Zakirov, Yu.S. Chistov, E.Sh. Telyakov, Bulletin of the Kazan technological university **15** (2012) [In Russian]
5. A.V. Zakharevich, N.V. Baranovlskiy, Rus. J. Phys. Chem. B+ **9** (2015)
6. N.V. Baranovskiy, A.V. Zakharevich, D.S. Osotova, EPJ Web of Conf. **82** (2015)
7. S.L. Manzello, T.G. Cleary, J.R. Shields, J.C. Yang, Fire and Materials **30** (2006)
8. S.L. Manzello, T.G. Cleary, J.R. Shields, J.C. Yang, Int. J. Wildland Fire **15** (2006)
9. N.V. Baranovskiy, A.S. Solodkin, MATEC Web Conf. **23** (2015)
10. D.V. Korobkina, N.V. Baranovskiy, MATEC Web Conf. **19** (2014)
11. L. Vulkov, Lect. Notes in Comp. Sci. **9045** (2015)
12. N.V. Baranovskiy, A.S. Solodkin, A.A. Stuparenko, EPJ Web Conf. **110** (2016)
13. S. Petter, A. Fruhling, Int, J. Medical Inform. **80** (2011)
14. P.G. Goldschmidt, Communication ACM **48** (2005)
15. D.V. Korobkina, N.V. Baranovskiy, Cloud Sci. **1** (2014) [In Russian]
16. N.V. Baranovskiy, E.P. Yankovich, J. Autom. Inform. Sci. **47** (2015)
17. N.V. Baranovskiy, J. Autom. Inform. Sci. **47** (2015)
18. N. V. Baranovskiy, Cybernetics and Systems Analysis **51** (2015)