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LECTURES SERIES IN PROPAGATION OF THERMOELASTIC WAVES IN SKIN TISSUE

LECTURE 3

LASER THERAPY

Section two: Laser Pulse in general surgery (Laser Scalpel)

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Vol. 8, 1–8, 2018

High-Order Effect in Two-Temperature Thermal Lagging to Thermal Responses in Biological Tissue Subjected to Laser Irradiation

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In the processes of the medical treatment of the biological skin tissue, it is essential to know the evolution of

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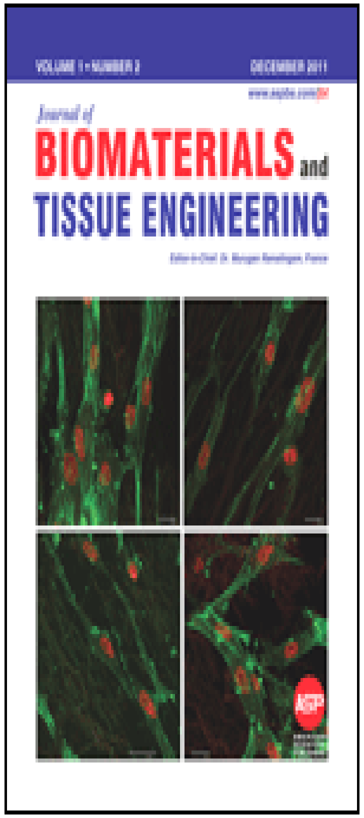

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Handbook of Nanostructured Biomaterials and Their Applications in Nanobiotechnology

Topics

1- Definition

2-Important of Laser therapy

3- Purpose

4- Relationship between Laser Therapy and Mathematic

5- Formulation of the Problem

6- The thermal damage

7- Numerical Results

8- Figures

9- Conclusion

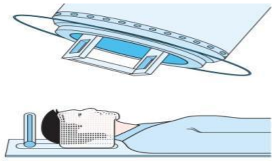
10- References

Laser Surgery has revolutionized the world of medicine

A revolution in the world of medicine was achieved through the use of laser technology for removing tumor out side skin and inside the breast human, general surgery and cosmetic or skin treatment. We do Lectures and papers in those uses:

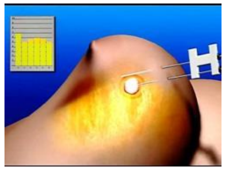
Previous and Next Lectures

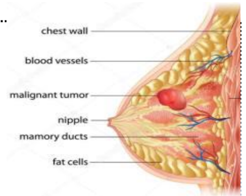
1



We Used magnetic fluid hyperthermia to remove tumor in outside human skin.

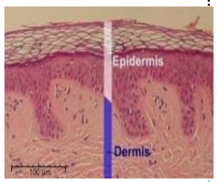
2





We Used Laser Ablation to remove cancer in breast human.

3



We Used Laser Scalpel in general surgery.

4

We Used Laser Pulse with rectangular irradiation in Cosmetic or skin treatment.

5

Used to remove cancer in brain and other parts inside human.

Important of Laser in general surgery

In medicine, lasers allow surgeons to work at high levels of accuracy by focusing on a small area, damaging less of surrounding tissue. You may feel less pain by blocking nerve endings, less swelling, less blooding. However, The laser works to evaporate the water in the soft tissue and then cut it, so it evaporates bacteria, viruses and fungi.

Purpose

By using a pulse laser, surgeons can cut very sharply without damage to the surrounding tissue.

Relationship between Laser Therapy and Mathematic

- **In 1948,** *Pennes* used mathematical model to describe temperature distribution in the living biological tissues. The model known as **the Pennes bio-heat transfer equation (PBT),** and it remains used today.
- **The Pennes bio-heat transfer equation (PBT)** is based on **the classical Fourier's law,**
- $\mathbf{q}(r,t) = -\mathrm{K}\nabla\mathrm{T}(r,t)$ (1)
- Where T is the temperature, K is the heat conductivity, q is the heat flux, and t is the time.
- **The energy conservation equation of bioheat transfer** is described as
- $\rho C \frac{\partial T}{\partial t} = -\nabla \mathrm{q} - W_b C_b \rho_b (T - T_b) + (Q_{met} + Q_{ext})$ (2)

From the two equations:

- $\rho C \frac{\partial T}{\partial t} = \mathrm{K}\, \nabla^2 T - W_b C_b \rho_b (T - T_b) + (Q_{met} + Q_{ext})$ (3)

where ρ is the density, C is the specific heat, C_b and W_b are the specific heat and perfusion rate of blood. Q_{met} is the metabolic heat generation and Q_{ext} is the heat source T_b is the blood temperature.

- **In 1958,** *Vernott and Cattaneo* modified **the classical Fourier's law** as

$$\mathrm{q}(r, t + \tau_q) = -\mathrm{K}\nabla\mathrm{T}(r, t) \tag{4}$$

- **In 1997,** *Tzou* added τ_T to become **the classical Fourier's law** as next and call **Dual Phase lag (DPL)**

$$\mathrm{q}(r, t + \tau_q) = -\mathrm{K}\nabla\mathrm{T}(r, t + \tau_T) \tag{5}$$

- **In 2006,** *Youssef* modified (5) to become **two temperatures** as

$$\mathrm{q}(r, t + \tau_q) = -\mathrm{K}\nabla T_C(r, t + \tau_T) \tag{6}$$

and

$$T_C - T_D = \beta\nabla^2 T_C \tag{7}$$

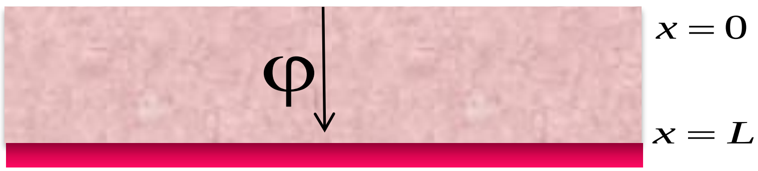
where β is a non-negative parameter which is called two-temperature parameter, T_C is the conductive temperature, T_D is the dynamical temperature.

Formulation of the Problem

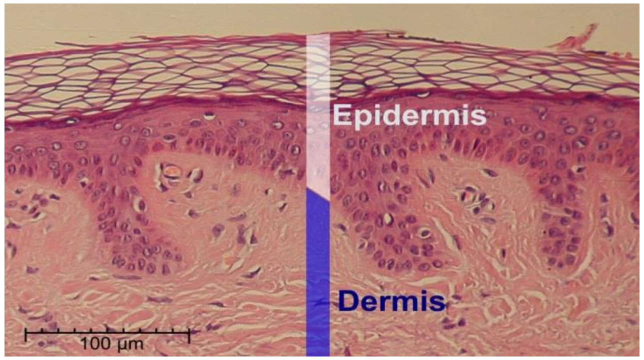
When the laser beam hits the skin surface, the laser energy is absorbed and scattered. *Lambert* expresses the laser power intensity along the tissue by using *depth–Beer's* law, as follows:

$$I(x,t) = I_0 e^{-\delta x} H(t) \tag{8}$$

$$-k\frac{\partial \varphi(x,t)}{\partial x}\bigg|_{x=0} = q_0$$



$$\frac{\partial \varphi(x,t)}{\partial x}\bigg|_{x=L} = 0$$



$$-k\frac{\partial \varphi(x,t)}{\partial x}\bigg|_{x=0} = Q_{ext}(x,t)\big|_{x=0} = \delta I_0 H(t) = q_0, \quad \frac{\partial \varphi(x,t)}{\partial x}\bigg|_{x=L} = 0 \tag{9}$$

q_0 is the maximum strength of Laser, I_0 is power density of laser irradiation, δ is the penetration depth and $H(t)$ is the Heaviside unit step function.

The energy conservation equation of bio-heat transfer is described in the context of the two-temperature model as:

$$\rho C \frac{\partial T_D}{\partial t} = -\nabla \cdot q - W_b C_b \rho_p \left(T_D - T_b\right) + \left(Q_{met} + Q_{ext}\right) \tag{10}$$

The second order DPL (Dual Phase Lag) model can be rewritten as:

$$\left(1 + \tau_q \frac{\partial}{\partial t} + \frac{\tau_q^2}{2} \frac{\partial^2}{\partial t^2}\right) \nabla \cdot q = -K \left(1 + \tau_T \frac{\partial}{\partial t} + \frac{\tau_T^2}{2} \frac{\partial^2}{\partial t^2}\right) \nabla^2 T_C \tag{11}$$

and

The two temperature model can be rewritten as:

$$T_C - T_D = \beta \nabla^2 T_C \tag{12}$$

Heat generation due to scattering is assumed to be negligible; therefore, the specific absorption rate in the target zone can be expressed as follows [24, 29]:

$$Q_{ext}(x,t) = -\frac{\partial I}{\partial x} = \delta I_0 e^{-\delta x} H(t) = \delta I_0 e^{-\delta L} H(t) \tag{13}$$

Where $I_0\left(W/m^2\right)$ represents the power density of laser irradiation, δ represents the penetration depth which gives the value of how deep the laser heat wave can penetrate through the given material, H (t) is the unit step function, and L is the thickness of the skin layer.

Because of the chemical reactions taking place within the tissues, the metabolic heat source is valid, and it is assumed to be a constant

$$Q_{met} = 368.1\ W/m^3 \tag{14}$$

Consider the following functions:

$$\varphi = \left(T_C - T_b\right),\ \ \theta = \left(T_D - T_b\right) \tag{15}$$

Hence, we have

$$K\left(1+\tau_T\frac{\partial}{\partial t}+\frac{\tau_T^2}{2}\frac{\partial^2}{\partial t^2}\right)\frac{\partial^2\varphi}{\partial x^2} = \rho C\left(1+\tau_q\frac{\partial}{\partial t}+\frac{\tau_q^2}{2}\frac{\partial^2}{\partial t^2}\right)\frac{\partial\theta}{\partial t} +$$

$$W_b C_b \rho_p\left(1+\tau_q\frac{\partial}{\partial t}+\frac{\tau_q^2}{2}\frac{\partial^2}{\partial t^2}\right)\theta - \left(1+\tau_q\frac{\partial}{\partial t}+\frac{\tau_q^2}{2}\frac{\partial^2}{\partial t^2}\right)\left(Q_{met}+Q_{ext}\right), \tag{16}$$

$$\theta = \varphi - \beta\frac{\partial^2\varphi}{\partial x^2} \tag{17}$$

Applying Laplace transform $\bar{f}(s) = \int_0^\infty f(t)e^{-st}dt$

Thus, we get

$$\frac{\partial^2\bar{\varphi}(x,s)}{\partial x^2} - \lambda^2(s)\bar{\varphi}(x,s) = -f(s), \quad 0 \le x \le L \tag{18}$$

where

$$\lambda^2(s) = \frac{h_q\left(\rho C s + W_b C_b \rho_p\right)}{\left[K h_T + \beta h_q\left(\rho C s + W_b C_b \rho_p\right)\right]}, \quad f(s) = \frac{\left(\delta I_0 e^{-\delta L} + 368.1\right)}{s\left[K h_T + \beta h_q\left(\rho C s + W_b C_b \rho_p\right)\right]}$$

$$h_T = \left(1 + s\tau_T - \frac{s^2\tau_T^2}{2}\right), \quad h_q = \left(1 + s\tau_q - \frac{s^2\tau_q^2}{2}\right)$$

The general solution

$$\bar{\varphi}(x,s) = c_1(s)e^{\lambda x} + c_2(s)e^{-\lambda x} + \frac{f(s)}{\lambda^2(s)}, \quad 0 \le x \le L \tag{19}$$

Apply the boundary conditions

$$\left.\frac{\partial\bar{\varphi}(x,s)}{\partial x}\right|_{x=0} = \left.\bar{Q}_{ext}(x,s)\right|_{x=0} = \frac{\delta I_0}{s} = q_0, \quad \left.\frac{\partial\bar{\varphi}(x,s)}{\partial x}\right|_{x=L} = 0 \tag{20}$$

Hence we obtain

$$\overline{\varphi}(x,s)=\left(\frac{-q_0}{\lambda\sinh(\lambda L)}\right)\cosh\lambda(L-x)+\frac{f}{\lambda^2} \tag{21}$$

and

$$\overline{\theta}(x,s)=\left(\frac{-q_0\left(1-\lambda^2\beta\right)}{\lambda\sinh(\lambda L)}\right)\cosh\lambda(L-x)+\frac{f}{\lambda^2} \tag{22}$$

Numerical Results

To determine the temperature distribution of each layer $\varphi(x,t)$ and $\theta(x,t)$, we will use a Riemann-sum approximation method to obtain the numerical results in which, any function in Laplace domain can be inverted to the time domain as

$$Z(t) = \frac{e^{\kappa t}}{t}\left[\frac{1}{2}\bar{Z}(\kappa) + \mathrm{Re}\sum_{n=1}^{N}(-1)^{n}\,\bar{Z}\left(\kappa + \frac{i\,n\pi}{t}\right)\right] \tag{23}$$

For faster convergence $\kappa t \approx 4.7$

The thermal damage

Moritz and *Henriques* proposed that skin damage could be represented as a chemical rate process, which is calculated by using a first order *Arrhenius* rate equation as

$$\Omega = A\int_{0}^{t} e^{\frac{-E_a/R}{T_D(x,\xi)}} d\xi \qquad (24)$$

A is a material parameter (frequency factor)

E_a is the activation energy

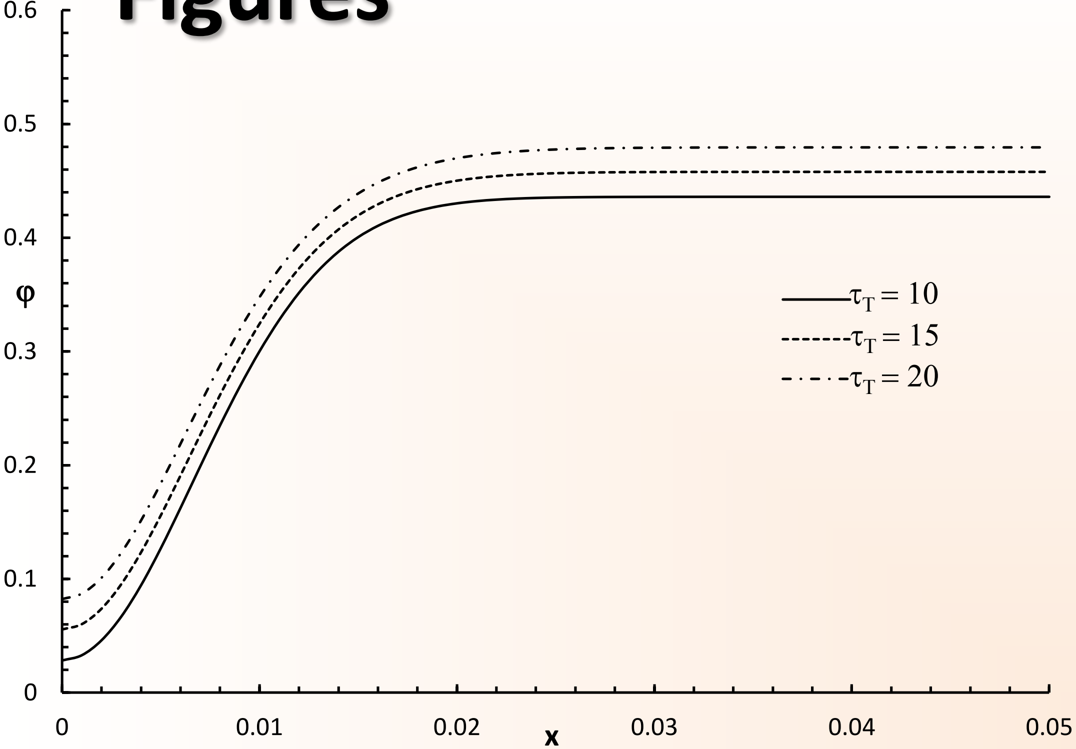
ξ is the universal gas parameter

$$T_D = (\theta + 37.0 + 273.0)\,\mathrm{Kelven}$$

Table I. The material properties of the skin tissue.[1, 3, 4, 19, 24, 25, 30]

Parameter	Unit	Skin tissue
K	W/m°C	0.628
ρ	kg/m^3	1000
ρ_b	kg/m^3	1060
C	J/kg°C	4187
C_b	J/kg°C	3860
W_b	ml/Cm	0.00187
T_b	°C	37
τ_T	s	10
τ_q	s	15
L	m	0.05

Figures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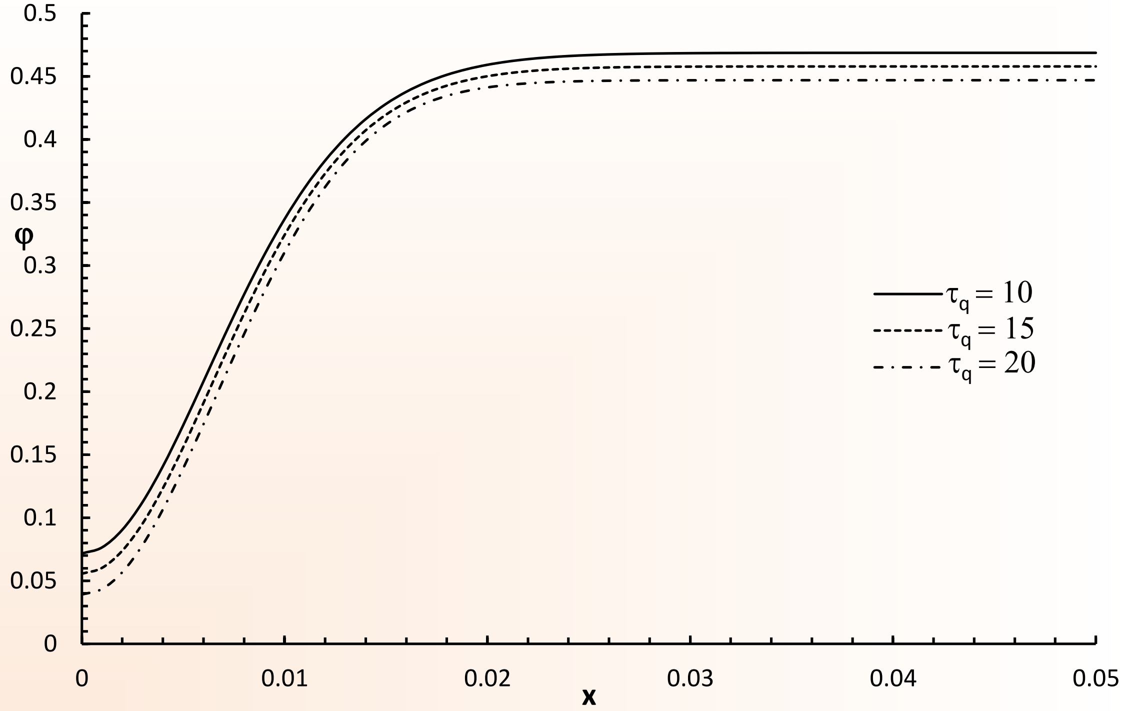
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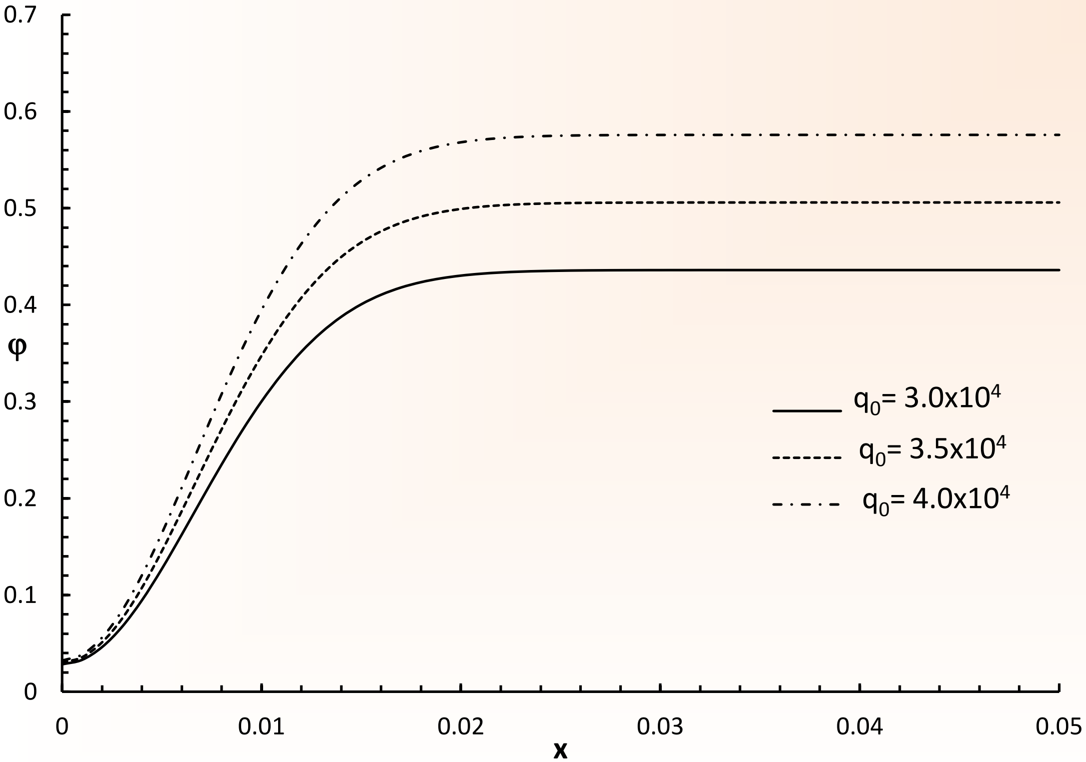
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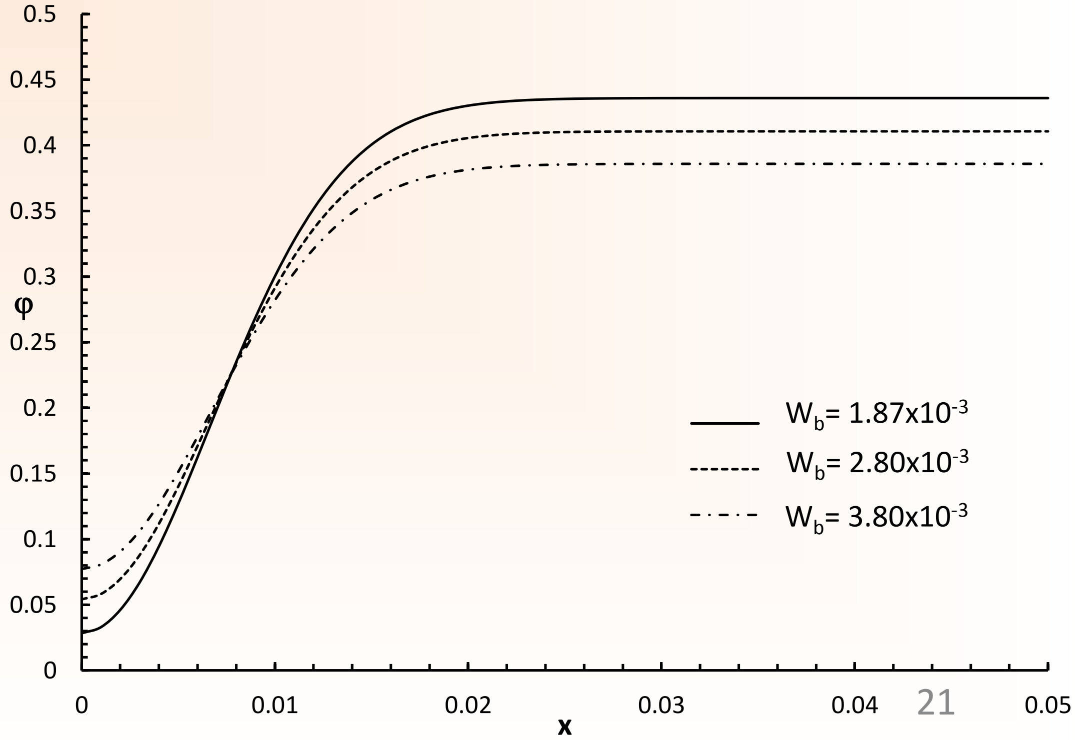
$q_0 = 3.0 \times 10^4$
$q_0 = 3.5 \times 10^4$
$q_0 = 4.0 \times 10^4$


φ
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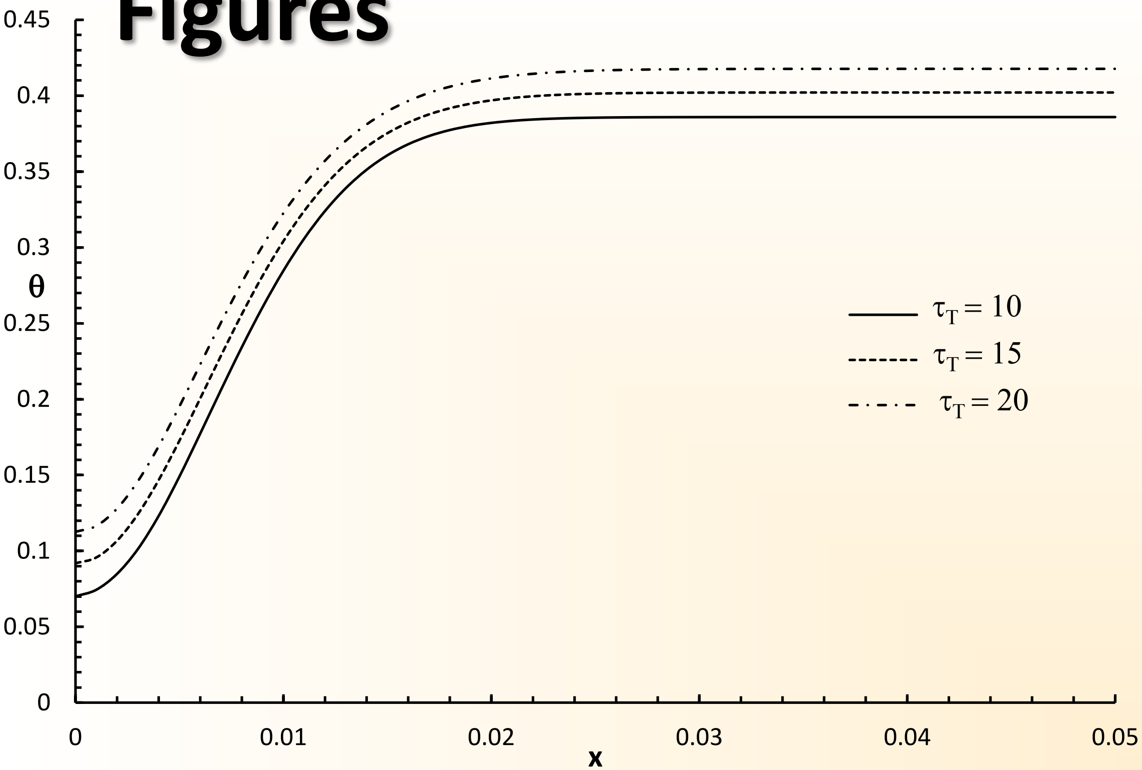
$W_b = 1.87 \times 10^{-3}$
$W_b = 2.80 \times 10^{-3}$
$W_b = 3.80 \times 10^{-3}$

Figures



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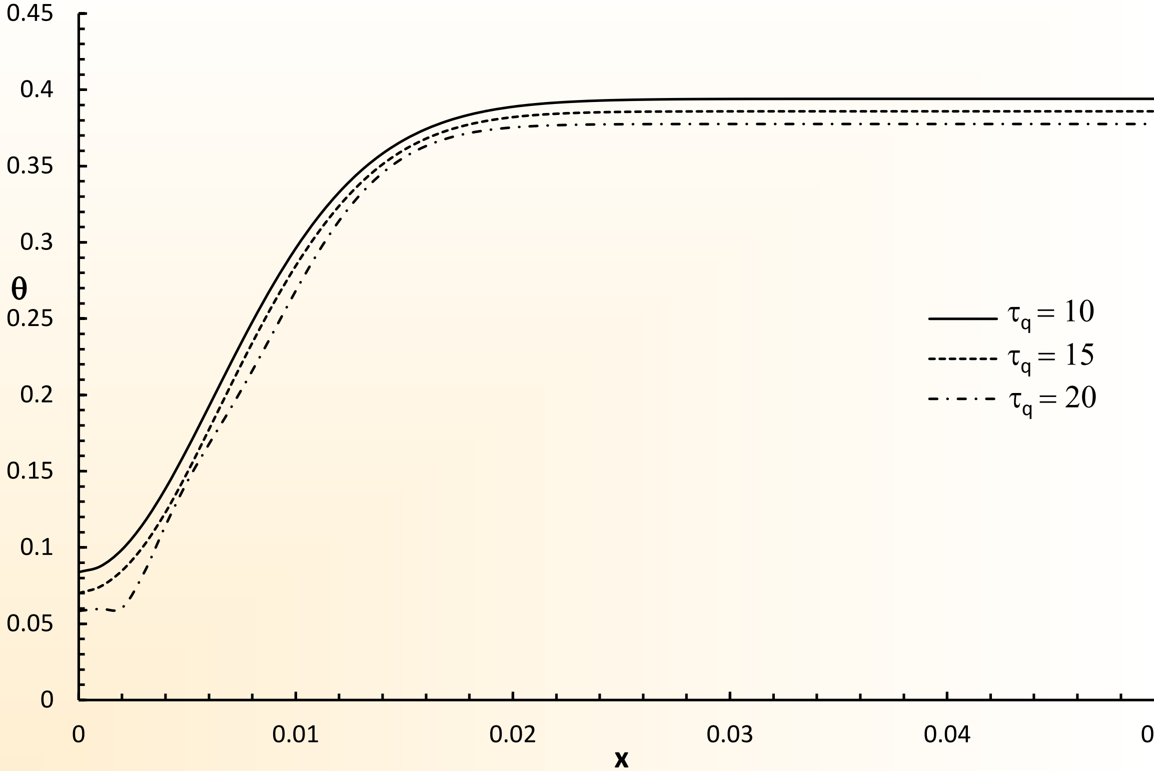

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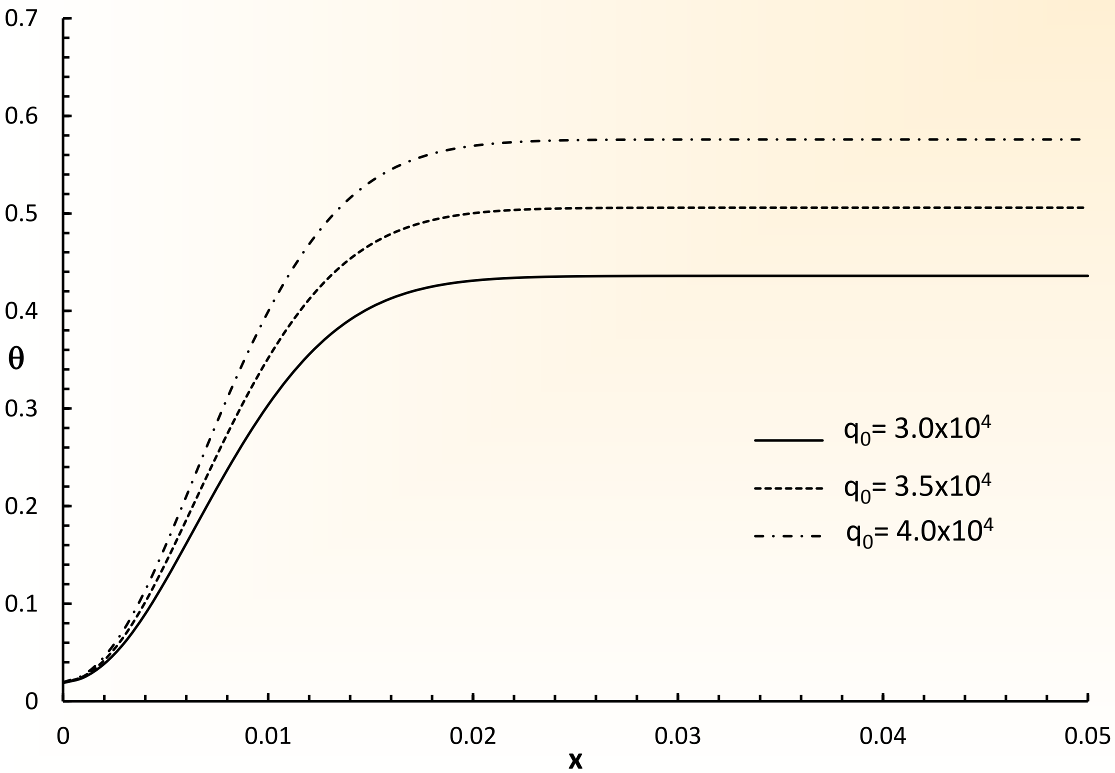

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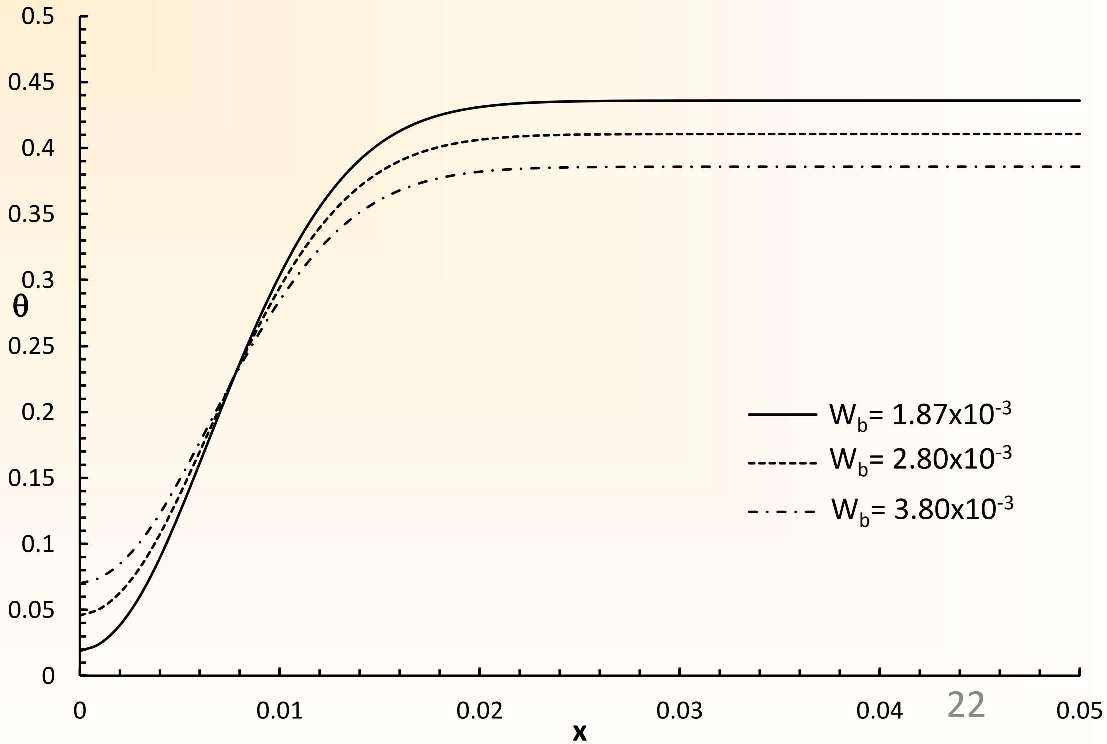

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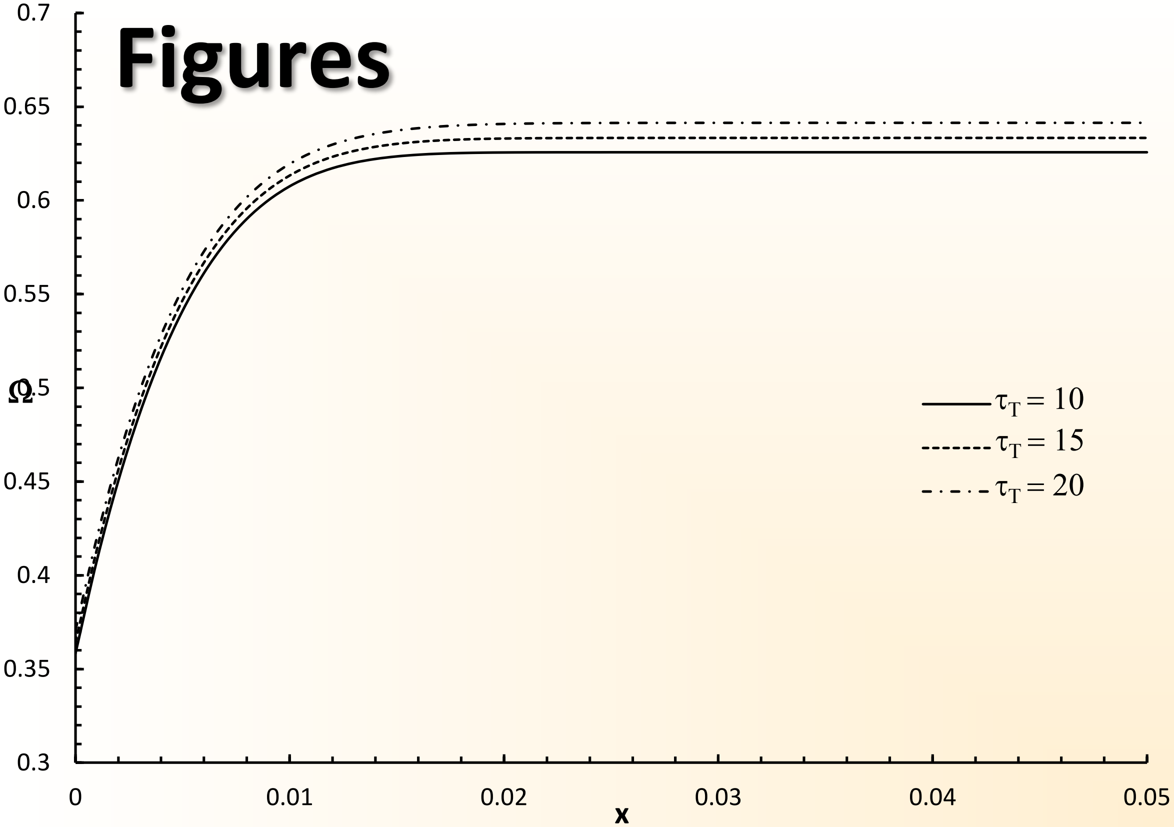
Figures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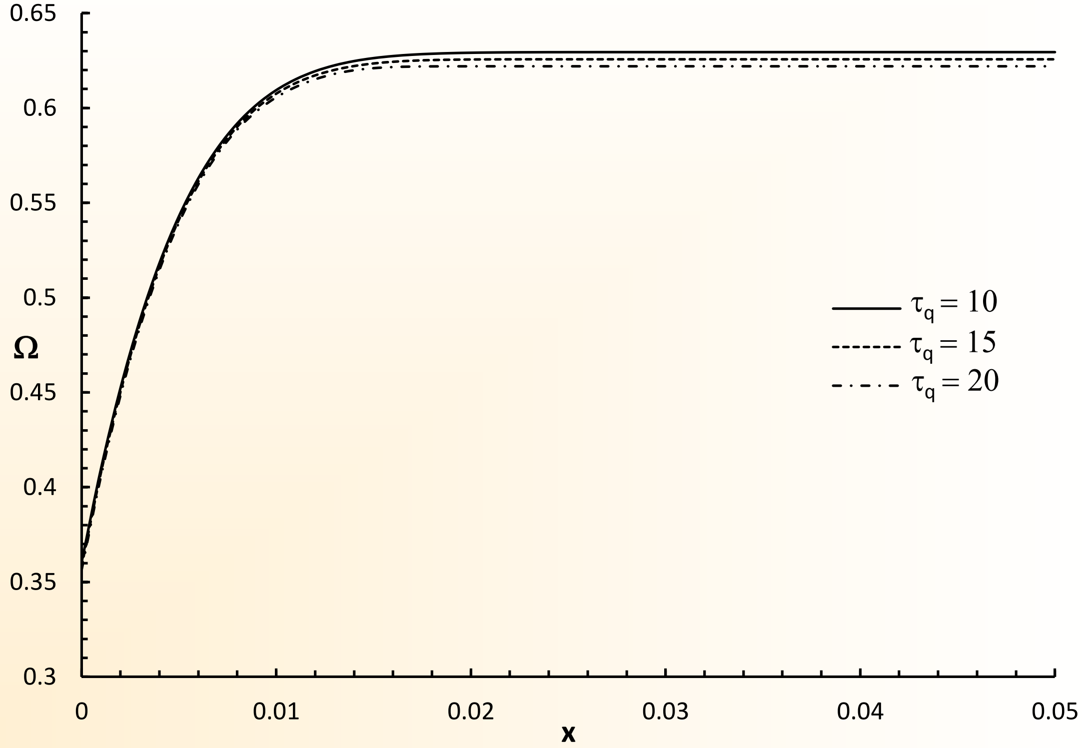
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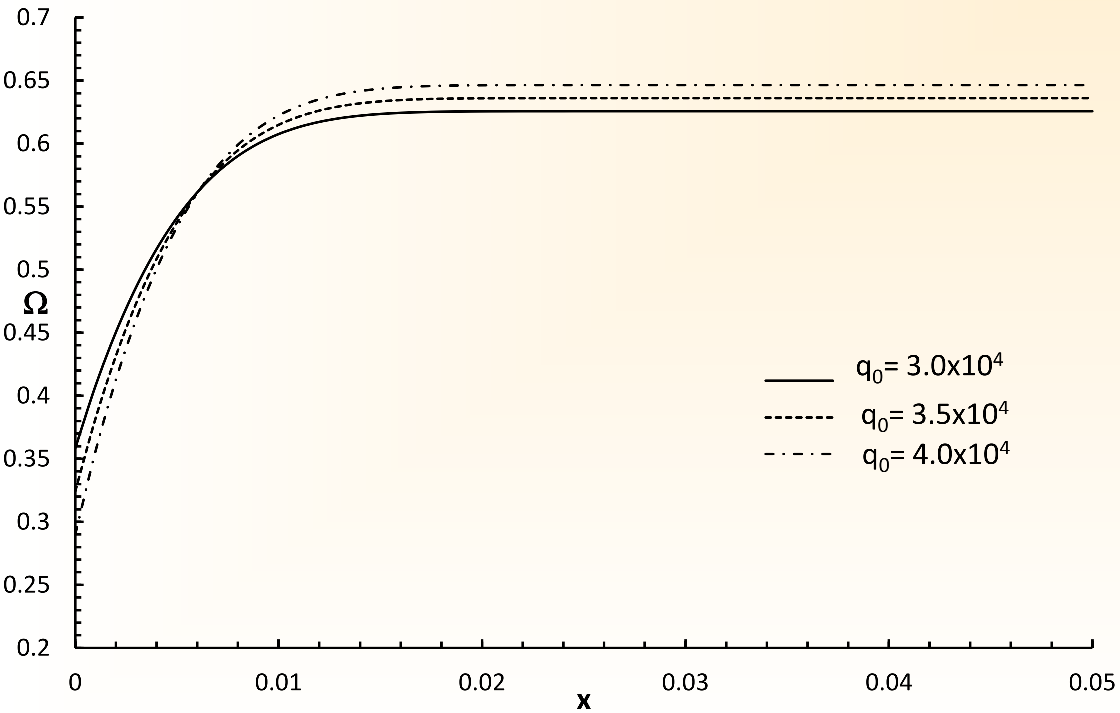
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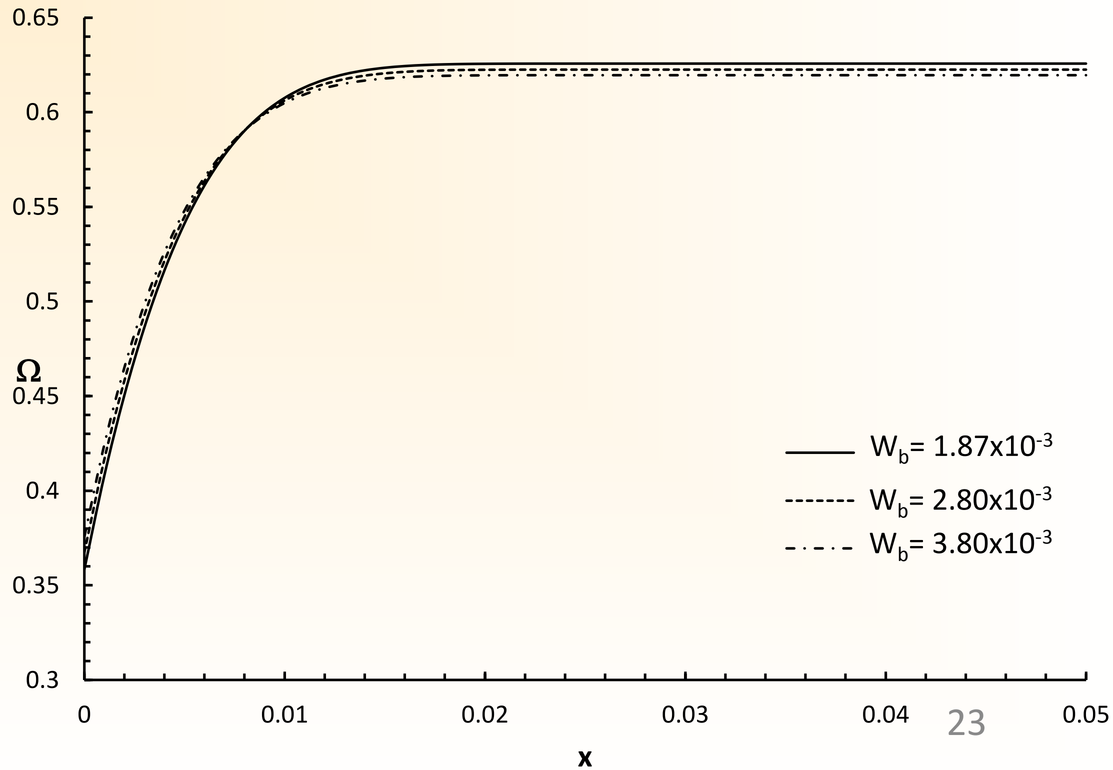
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W_b= 1.87x10^{-3}
W_b= 2.80x10^{-3}
W_b= 3.80x10^{-3}

Conclusion

A mathematical model of two-temperature bio-heat transfer equations was constructed. Thermal damage quantity in the tissue was calculated by using Arrhenius integral. The phase lag of the temperature gradient parameter, the phase lag of the heat flux parameter, power density of laser irradiation value, perfusion rate of blood value, and two-temperature parameter have significant effects on the conductive temperature increment, the dynamical temperature increment, and the thermal damage quantity of the skin tissue.

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Thank you