Effect of Temperature Difference on the Steady State Time Using ANSYS

Ridha Hameed Majeed

Kerbala technical institute, Alfurat Al-Awsat technical university56001, kerbala, Iraq

Email: inkr.red@atu.edu.iq

Submission date:- 7/3/2018	Acceptance date:- 22/5/2018	Publication date:- 3/9/2018

Abstract

In this paper, ANSYS-14(APDL) program was used to study the effect of the temperature difference between two faces of samples (ΔT) exposed to transient heat transfer on the time required to reach to steady state (S.S.time). Four materials with different thermal properties were chosen.Sample used as a rectangular shape with dimension (1*15) cm. One face of the sample was exposed to three various temperatures (75,125 and 175ºC), while the other face was exposed to convection thermal load at 25 °C. The study showed that the real relationship between the time required to reach the steady state (S.S.time) and the temperature difference between two face of sample is an inverse exponential relationship, which was derived based on the equivalent time. And the result of the relationship between the temperature at the steady state (S.S.Temp.) and (ΔT) was a positive linear relationship. While the relationship between (S.S.time) with the thermal diffusivity (α) is an inverse exponential, and the relationship between (S.S.Temp.) and (α) was a positive logarithmic. The results of the study also indicate that the thermal diffusivity (α) effect on (S.S.time) and (S.S.Temp.) will decreased with approaching the heating source, at the same time the effect of the temperature difference (ΔT) on (S.S.time) and (S.S.Temp.) also decreases with approaching the heating source.

Keywords: Heat transfer, Thermal diffusivity (α), Temperature difference (ΔT), Time needed to reach steady state (S.S.time), Sample temperature at steady state (S.S.Temp.).

Nomenclature

ΔT	temperature difference between two faces of samples
S.S.time	steady state time (Time needed to reach steady state)
S.S.Temp.	steady state temperature (sample temperature at steady state)
α	thermal diffusivity

Introduction

It is easy to give a general view of the heat transfer during any body, whatever the complexity of this shape, the nature of its components, and the amount of temperature difference between its two faces. But the problem is how to get a precise understanding of that relationship by obtaining an equation through which accurate numerical results can be obtained depending on the state of the body and the surrounding thermal conditions. This paper is an attempt to obtain mathematical relationships showing the effect of temperature difference between the two faces of a sample on the time needed to reach the steady state as well as study the effect of other variables affecting on this relationship.

In this research was presented a several studies that dealt with the effect of some parameters on the steady and transient heat transfer through materials.

One of studies is an attempt to conceptualize the relationship between thermal diffusivity of any material and its thermal behavior when exposed to any thermal conditions in the unsteady state. The results of the study showed a positive relationship between thermal diffusivity and temperature rise. **[1].** The total heat transfer appearances of a packed bed of spheres represented by the effective thermal conductivity. This study presents a purpose-designed test that combines physical measurements with Computational Fluid Dynamics (CFD) simulations to separate the conduction heat transfer and contributions of radiation, containing the wall effects. Primary results obtained offer important insights into the trends observed in the experimental results and provide a better understanding the underlying heat transfer phenomena. **[2]**. Due to complicated derivations and formidable calculations ,transient heat conduction was solved by a new analytical method for hollow composite cylinders with two or three layers subjected to general boundary conditions. The suggested way is highly efficient in calculation, due to it only contains two-by-two matrices in the solution process **[3].**

A fractional sample of the equations of generalized magneto-thermoelasticity is assumed to have variable thermal conductivity to solve a problem of an infinitely long hollow cylinder. To derive the solution using a numerical method based on Fourier series expansions, Laplace transformation techniques were used. The results showed that the thermal conductivity and time-fractional order play a major role in all considered distributions. **[4].** To solve unstable heat transfer problem during the metal body, a metallic thermal protection system (MTPS) was used. Assuming it consists a number of layers, a new analytical approximation method based on the separation of variables with the orthogonal expansion of heat prediction through MTPS were adopted. **[5]**. Study the effect of silicon ratio on aluminum alloy - silicon by measuring thermal diffusion in laser flash analysis (LFA). This study showed that the thermal diffusivity of the alloy increases with decreasing the ratio of silicon in the alloy **[6]**.

A comparative study of the rate of heat transfer between composite MS-Hylum-Wood and composite MS-Fiber Glass- Brick was conducted experimentally and analytically by the ANSYS program. The results of the study proved that the composite material of composite MS-Hylum-Wood has better thermal insulation than the composite MS-Fiber Glass- Brick. **[7].** One of researches used Mathlab program to study the distribution of temperature across a plane wall. Results of the study showed no difference in the distribution of temperature during the wall except at high temperatures due to the high conductivity of the wall of the plane. After 0.4 m of wall, thickness the relationship between distance and temperature became curved shape after it was linear. **[8]**. By the method of Laplace transformation , a set of classical analytical solutions to heat conduction in a two-layer composite hollow cylindrical medium was derived .Two solutions were used .The first was subjected to constant-temperature boundary conditions and the other subjected to a constant flux and a constant temperature to evaluate short-time accuracy. Comparison between the two solutions indicates that the response of temperature is always delayed as a result of the line-source assumption. **[9].**

The results of the analysis of stable and unstable heat transfer during the brake drum using a finite component sample showed that the amount of deformation in aluminum composite less than the cast iron and the maximum temperature obtained for aluminum composite is less compared to cast iron brake drum**. [10]**. For solving the asymmetric heat conduction problem in a multilayer annulus with time-dependent boundary conditions and or heat sources, an alternative approach using the finite integral transform method was used .After integral transformation ,first order ordinary differential equations (ODEs) are formed for the transformed temperatures. The solution of ODEs to obtain the temperature distribution in each layer required the method of separation of variables (SOV)**[11].** In an analytical study, heat transfer was measured during high porosity objects. The shape of the cells and the shape of the transverse sections of the stents have a weaker effect on heat transfer by conduction. Thus, open-cell foams, in which a large proportion of the solid phase of the cell header is concentrated, show less effective connection to the heat, whereas the closed cell structures with the entire solid part of the cell walls are the most correlated. **[12].**

The researches above consist an experimental and analytical methods to study heat transfer and comparative between the results of this methods, as well as the effect of variables on these results. Our study is focused on the effect of the temperature difference between two faces of samples exposed to transient heat transfer on the time needed to reach to steady state at different thermal diffusivity by using the Ansys program.

Methodology of research

Temperature distribution through the nodes of the sample is governed by the unsteady one-dimensional heat conduction equation [13], therefore, the results of this equation use to evaluate the effect of the temperature difference between two face of sample on the time required to reach the steady state. There are other ways to study a temperature distribution through the nodes of the sample such as the Mathlab and ansyz, and others.

$$k_n \frac{\partial^2 T}{\partial x^2} = \rho_n c p_n \frac{\partial T}{\partial t} \qquad (1)$$

T=temperature
k= thermal conductivity
ρ=density
cp= Specific heat
n=time step
X =distance between two nodes

ANSYS-14 (APDL) was used to study the effect of ΔT exposed to transient heat transfer on the S.S.time. Four materials with different thermal properties were chosen (Cadmium, Stainless steel, Cement plaster and Hardboard (Medium)). The samples used in the study as a rectangular shapes with dimensions (length =15 cm and height=1 cm). One face of samples exposed to three different temperature degrees (50,100 and 150ºC), while the other face exposed to convection thermal load at 25°C. We assumed that the heat transfer was only through a sample length (one dimension), and no heat generation, in addition to there is no heat transfer around the sample.

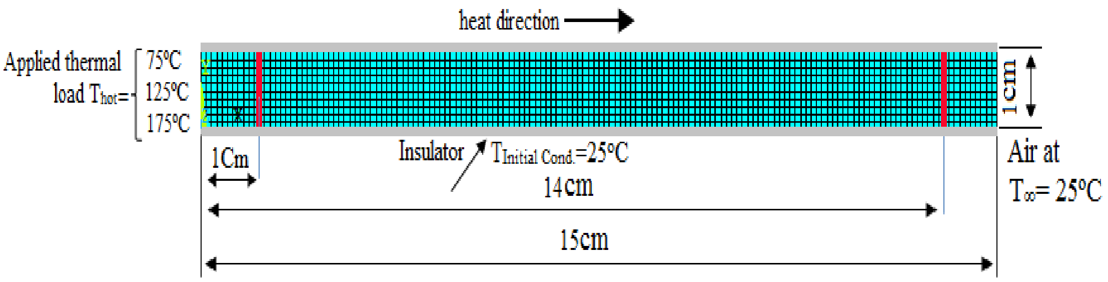

Figure (1) sample Specification

Table (1) thermal properties of materials used [14, 15].

	Cadmium	Stainless steel	Cement plaster	Hardboard (Medium)
K (W/m.ºC)	96.8	15.6	0.72	0.08
ρ (Kg/m^3)	8650	7913	1860	600
Cp (J/Kg.ºC)	231	456	840	2000
α (m^2/sec)	4.84E-5	4.32E-6	4.61E-7	6.67E-8

Table (2) boundary condition and ANSYS constant

Specimen length, m	0.15			
Specimen width, m	0.01			
Right face temperature (T_∞), º C	25			
Convection Heat transfer coefficient \ right face (h_{conv}), W/m^2.º C	10			
Left face temperature, º C	75	125	175	
Temp. difference between two face, º C	50	100	150	
Initial temperature of samples ($T_{initial\ cond.}$), º C	25			
Element edge length, m	0.01 (mesh = fine)			
No. of nodes	150			
Preferences for filtering	Thermal			
Type of analysis	Transient			
Applied time load (sec)	Cadmium	Stainless steel	Cement plaster	Hardboard (Medium)
	2000	20000	100000	200000
Time step size (sec)	1	10	50	100

Results Discussion:

Figure (2) shows that the relationship between sample temperature at steady state (S.S.Temp.) and temperature difference between two face of sample (ΔT) is a positive linear relationship, that agrees to all cases with difference in distance from the hot face and type of material, which note the following:

a. The relationship between (ΔT) of the samples and (S.S.Temp.) can be expressed in equation (2).

$$\boldsymbol{S.S.Temp.}\,(\,^{o}\boldsymbol{C}) = \boldsymbol{m} * \Delta\boldsymbol{T}(\,^{o}\boldsymbol{C}) + \boldsymbol{C} \qquad \ldots\ldots(2)$$

b- The slope value of strength line decreases when move away from the heating source especially for low thermal diffusivity materials.

Table (3) Constants of equation (2)

Distance from heating source	m	C
X=1 cm	≈1.0	24.47-24.74
X=14 cm	0.1-1.0	24.44-24.73

c- At the point (x = 1 cm), the similarity of the values of (m) to the different materials was observed in equation (2). This is due to the nearness of this point from the heating source, thus weakening the effect of other variables on the steady state temperature values (S.S.Temp.).

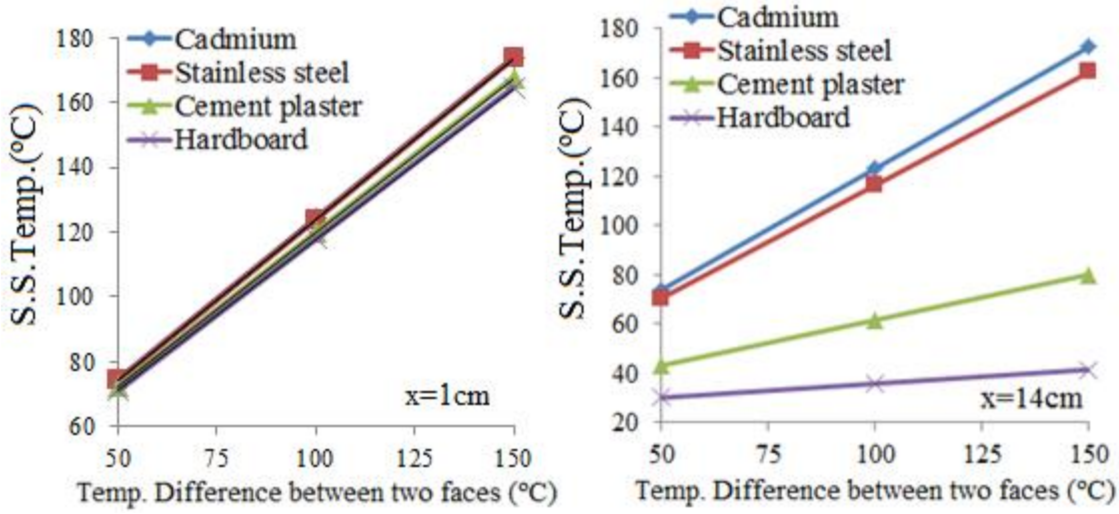

Figure (2) Effect of temperature difference between two faces of samples on steady state Temp.

Increasing the difference in temperature between the two faces means increasing the temperature of the hot face because the temperature of the other face installed at 25ºC, so the smallest difference in temperature between the face of the sample is 50ºC and the highest difference is 150ºC.

When the difference in temperature between the two sides of the sample is 50 ºC, means that the temperature of the hot face is 75 ºC, i.e. The maximum steady state temperature of sample do not exceed the temperature of the hot face 75 ºC. But when the difference in temperature between the two sides of the sample is 150 C, means that the temperature of the hot face is 175 ºC, i.e. The maximum steady state temperature of sample do not exceed the temperature of the hot face 175 ºC. So it is normal to have the time required to reach 175 ºC more than the time required to reach 75 ºC.

This is what we observe in Figure (3), which gives us an unclear perception of the real effect of the difference in temperature between the two faces of the sample on the time needed to reach a steady state of case.

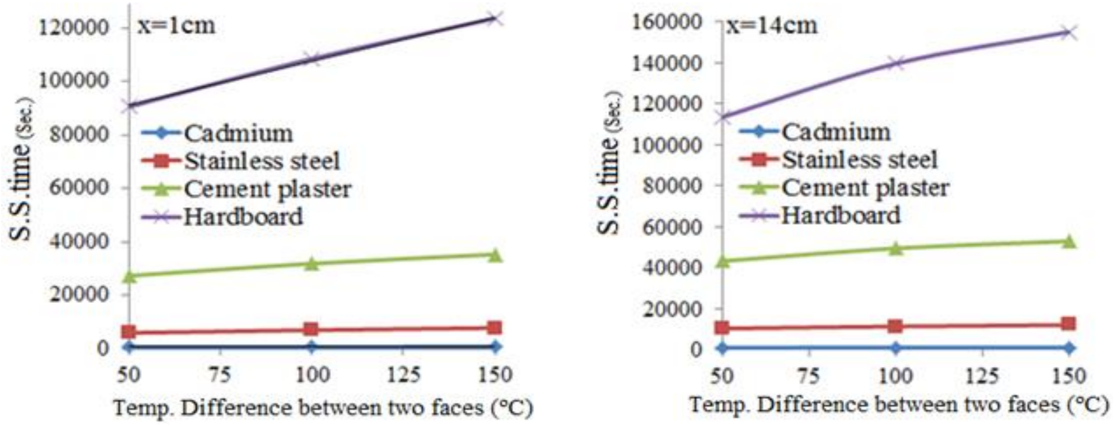

Figure (3) Effect of temperature difference between two faces of samples on steady state time

To find out the real effect of the temperature difference between the two faces of the sample on the time required to reach the steady state , the time needed to reach the steady state should be divided by the difference in temperature between the two sides of the sample for each case (steady state time / Temp. Difference between two faces), it can be called equivalent time. The results of the relationship between the equivalent time and temperature difference between the two faces of the sample are shown in Fig (4).

The results of this figure show the real effect of the difference in temperature between the two faces of the sample on the time required to reach the steady state. Which reflect the inverse power relationship between the difference in temperature between the two faces of the sample and the time required to reach the steady state for all materials except cadmium where it took the form of reverse linear relationship. Figure (4) also shows the effect of both the type of material and the amount of distance from the hot face on the equivalent time. In Figure (4), we will note that the decrease in the thermal diffusivity of the material and increase the distance from the hot face will increase the time required to reach the steady state.

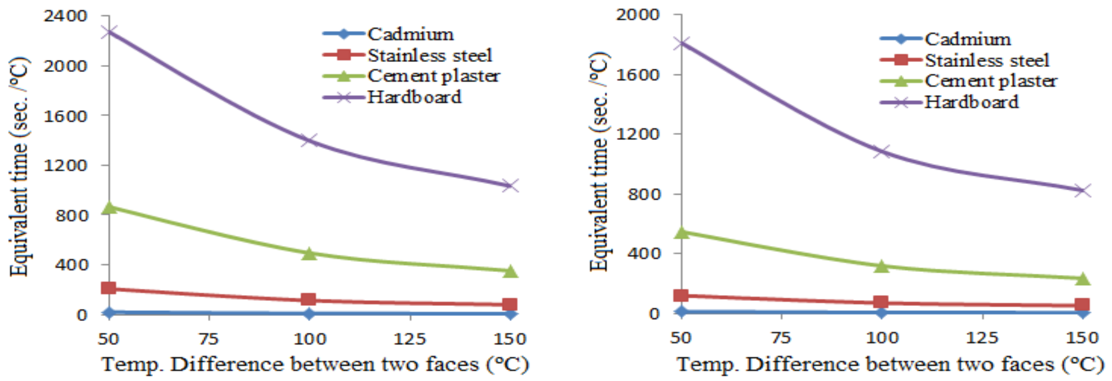

Figure (4) Effect of temperature difference between two faces of samples on equivalent time

The relationship between the thermal diffusivity (α) and (S.S.Temp.), shown in Figure (5). It can be seen the following:

a. Samples steady state temperature (S.S.Temp.) increased with increasing the thermal diffusivity especially at lowest values of thermal diffusivity, but the relationship takes a strength line parallel to the x-axis at high values of the thermal diffusivity.
b. When moving away from heating source, the effect of thermal diffusivity on (S.S.Temp.) increased with increasing of temperature difference between two faces of samples.
c. From equation (3) the relationship between the thermal diffusivity and (S.S.Temp.), can described.

$$\boldsymbol{S.S.Temp.(\,^{o}C) = m * ln(\alpha) - C} \qquad \ldots\ldots(3)$$

From Table (4) it can be noticed the values of constants of equation (4) will different based on the thermal diffusivity and (ΔT) values and, as well as the amount of distance from the heating source(x). Indeed, it can be seen a high agreement between the charts, equation and analysis.

Table (4) Constant values of equation (3)

Distance from heating source	m	C
X=1cm	0.55-1.58	80.5-191.3
X=14cm	7.2-21.4	150.2- 400.3

The relationship between (S.S.Temp.) and thermal diffusivity (α) takes the form of a logarithmic relationship, but turns into a straight line relationship parallel to the x-axis at high thermal diffusivity values, especially when approaching the heating source. We can conclude from this that the effect of thermal diffusion on (S.S.Temp.) is greatly reduced at the high values of thermal diffusivity. In this case, can be considered the temperature difference between the two face of the sample the only influential variable on the (S.S.Temp.).

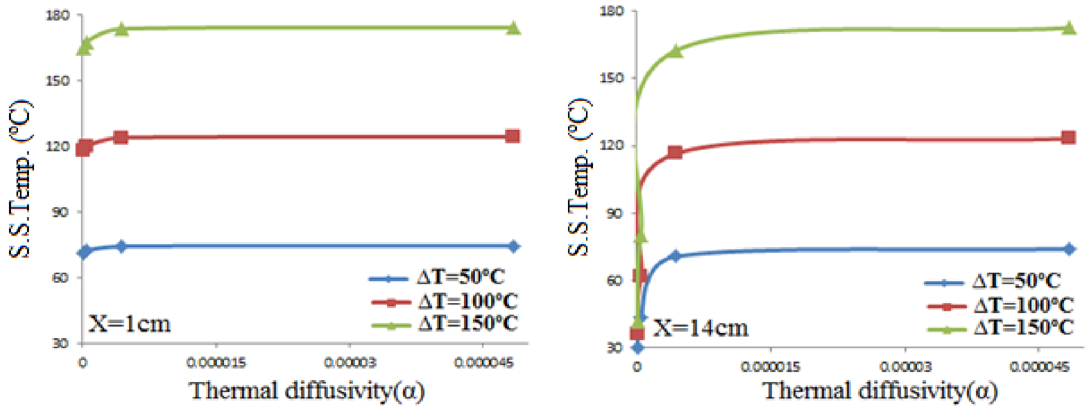

Figure (5) Effect of thermal diffusivity (α) on steady state Temp.

From the relationship between thermal diffusivity (α) and (S.S.time) can be seen in Figure (6), some observations can be seen.

a- This relationship takes as an inverse power.
b- (S.S.time) increasing significantly with decreasing the thermal diffusivity values.
c- There is no clear effect of the temperature difference between two faces on S.S.time.

Because the effect of (ΔT) on (S.S.time) which was not appears in figure (6), it possible depends on the equation (4) to show this effect.

$$\mathbf{S.S.time}_{\ (\mathbf{Sec.})} = \boldsymbol{m} * \boldsymbol{\alpha}^{-\boldsymbol{n}} \quad \dots\dots (\mathbf{4})$$

From equation (4), we detected the following:

a- It gave the highest correlation with Figure (6).
b- (S.S.time) increases with the decreasing of thermal diffusivity.

Table (5) shows the constants of equation (4), where we see the negative signal of constant (α) indicating the inverse power relationship between thermal diffusivity with (S.S.time). With regard to constant (m), we note the value of (m) at (X = 14cm) equal three times compared with the point (X = 1cm), This finding gives a clear indication that moving away from the source of heating increases the time needed to reach a steady state.

Table (5) Constant values of equation (4)

Distance from heating source	m	n	R^2
x=1cm	0.38-0.42	0.76-0.77	0.99
x=14cm	1.07-0.99	0.72-0.74	0.98

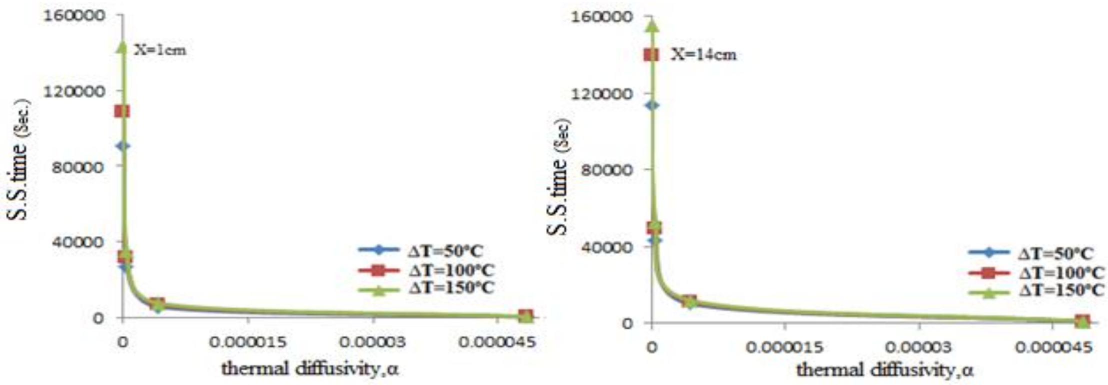

Figure (6) Effect of thermal diffusivity (α) on steady state time

Figure (7) shows the relationship between log (α) and (S.S.Temp.), which is in the form of positive nonlinear relationship where:

a. When move away from heating source (at x=14cm), the effect of log (α) on (S.S.Temp.) appears clearly, while its effect was limited when approaching the heating source (at x=1cm).
b. There is no apparent effect of the temperature difference between the two faces of samples on (S.S.Temp.).

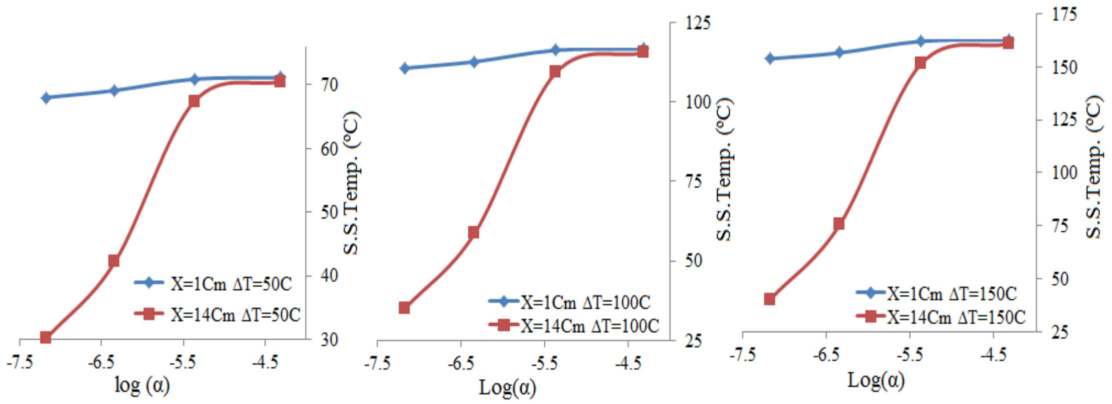

Figure (7) Effect of distance from hot face on steady state temp.

The relationship between log (α) and (S.S.time) can be seen in Figure (8), this is an inverse exponential relationship. It can be seen that the increasing of amount of temperature difference between the two faces of samples reduces the effect of moving away from the heating source on (S.S.time).

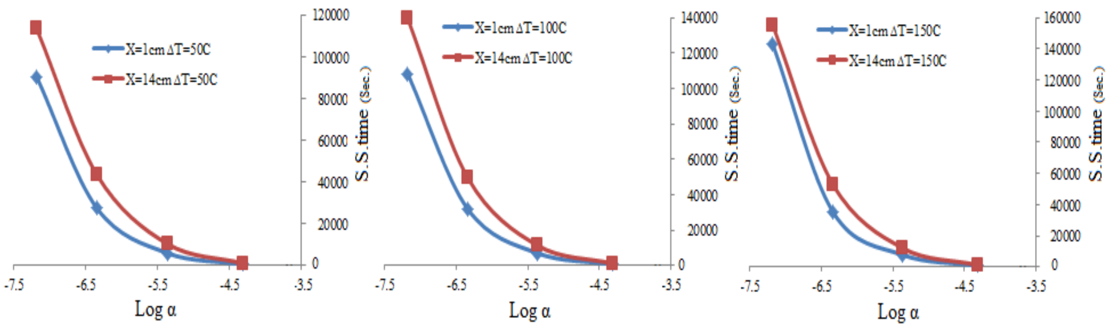

Figure (8) Effect of distance from hot face on steady state time

Conclusions

1. The relationship between the sample temperature at steady state (S.S.Temp.) and the temperature difference (ΔT) between two face of sample is a positive linear. Moving away from the heating source lead to increase the effect of thermal diffusivity on the steady state temperature value (S.S.Temp.).
2. The real effect of the difference in temperature between the two faces of the sample on the time required to reach the steady states, which reflect the inverse power relationship for all materials except cadmium where it took the form of reverse linear relationship. This fact was derived from the equivalent time (S.S.time /ΔT).
3. The relationship between the (S.S.Temp.) and the thermal diffusivity takes the form of a logarithmic relationship, but turns into a straight-line relationship parallel to the x-axis at high thermal diffusivity values, especially when approaching the heating source. We can conclude from this that the effect of thermal diffusivity on (S.S.Temp.) is greatly reduced at the high values of thermal diffusivity. In this case, we can be considered the temperature difference between the two face of sample the only influential variable on the (S.S.Temp.).
4. The relationship between the time needed to reach the steady state (S.S.time) and thermal diffusivity is an inverse power. In addition, it can be observed that there is no clear effect of the temperature difference between two face of sample on (S.S.time).
5. Approaching to the heating source lead to reducing the effect of both the thermal diffusivity and the temperature difference in raising or decreasing both the steady state time (S.S.time) and the steady state temperature (S.S.Temp.).

References

[1] R. H. Mageed, "Study of the Effect of Thermal Diffusivity on the Unstable Temperature distribution through a Low Thermal Conductivity Walls by ANSYS", Journal of university of Babylon, Vol. 26, No. 1., 2018.

[2] M. De Beer ,C. G. Du Toit and P. G. Rousseau," A methodology to investigate the contribution of conduction and radiation heat transfer to the effective thermal conductivity of packed graphite pebble beds, including the wall effect", Nuclear Engineering and Design, Volume 314, Pages (67-81)., 2017.

[3] B. Yang and S. Liu," Closed-form analytical solutions of transient heat conduction in hollow composite cylinders with any number of layers", International Journal of Heat and Mass Transfer, Volume 108, Part A, Pages (907-917), 2017.

[4] M. A. Ezzat and A. A. El-Bary , "Effects of variable thermal conductivity and fractional order of heat transfer on a perfect conducting infinitely long hollow cylinder", International Journal of Thermal Sciences, Volume 108, Pages (62-69), 2016.

[5] Liangxian Gu, Yifan Wang, Shengbo Shi and Cunxi Dai, "An approximate analytical method for nonlinear transient heat transfer through a metallic thermal protection system", International Journal of Heat and Mass Transfer. Vol.103. Pages (582-593), 2016.

[6] Yu-Mi Kim, Se-Weon Choi and Sung-Kil Hong, "The behavior of thermal diffusivity change according to the heat treatment in Al-Si binary system", Journal of Alloys and Compounds, Volume 687, Pages 54-58, 2016.

[7] R. P. Patil, A. Patil, V. H. Patil and T. A. Koli, "Analysis of Steady State Heat Conduction in Different Composite Wall", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 4, Issue 7, page(5394-5400), 2015.

[8] H. K. Jobair, "Analytical Study of Temperature Distribution of a Plane Wall Subjected to a Constant Heat Generation with Variable Thermal Conductivity Using Different Materials", International Journal of Science and Research (IJSR),. Volume 6 Issue pp (882-888), 2015.

[9] Min Li and Alvin C. K. Lai, "Analytical solution to heat conduction in finite hollow composite cylinders with a general boundary condition", International Journal of Heat and Mass Transfer, Volume 60, Pages 549-556, 2013.

[10] D. Ramesha , B. S. Kumar, Madhusudan and B. Shekar, "temperature distribution Aluminum of analysis composite and cast Iron brake drum using ANSYS", International Journal of Emerging trends in Engineering and Development ISSN 2249-6149 Issue 2,Vol.3 page(281-291), 2012.

[11] Suneet S., Prashant K. Jain and Rizwan-uddinc," Finite integral transform method to solve asymmetric heat conduction in a multilayer annulus with time-dependent boundary conditions", Nuclear Engineering and Design, Volume 241, Issue 1, Pages 144-154, 2011.

[12] R. Coquard and D. Baillis, "Numerical investigation of conductive heat transfer in high-porosity foams", Science direct, Acta Material, page (7- 44), 2009.

[13] Myers G.," Analytical Methods in Conduction Heat Transfer". Second ed., AMCHT Publication, Madison, WI. 1998.

[14] APPENDIX-1,.PROPERTY TABLES AND CHARTS (SI UNITS). http://cecs.wright.edu /~sthomas/htappendix01.pdf.

[15] Apache-Tables User Guide. IES Virtual Environment. http://www.iesve.com /downloads/ help/ VE2015/VirtualEnvironment.pdf.

تأثير الفرق في درجات الحرارة على زمن الوصول الى حالة الاستقرار باستخدام برنامج ANSYS

رضا حميد مجيد

قسم التقنيات الميكانيكية، المعهد التقني كربلاء، جامعة الفرات الأوسط التقنية، 56001، كربلاء، العراق

Email: inkr.red@atu.edu.iq

الخلاصة

في هذا البحث استخدم برنامج (ANSYS-14) لدراسة تأثير الفرق في درجات الحرارة على طرفي نموذج (ΔT) معرض لانتقال الحرارة غير المستقرة على الزمن اللازم للوصول الى حالة الاستقرار (S.S.t). تم اختيار اربعة مواد ذات خواص حرارية مختلفة. النموذج المستخدم في الدراسة على شكل مستطيل أبعاده (1*15 cm). أحد جوانب العينة عرض لثلاث درجات حرارية مختلفة هي (50,100,150) ^{o}م، أما الجانب الآخر فقد عرض لحمل حراري عند درجة حرارة 25°م. بينت الدراسة ان العلاقة الحقيقية بين كل من الزمن اللازم للوصول الى حالة الاستقرار(S.S.time) والفرق بين درجتي الحرارة على طرفي النموذج (ΔT) علاقة اسية عكسية والتي تم استنتاجها بالاعتماد على الزمن المكافئ ، بينما كانت العلاقة بين درجة حرارة النموذج عند حالة الاستقرار(S.S.Temp.) والفرق بين درجتي الحرارة على طرفي النموذج طردية خطية. اما العلاقة بين الزمن اللازم للوصول الى حالة الاستقرار والانتشارية الحرارية (α) فكانت علاقة أسية عكسية. وكانت العلاقة بين درجة الحرارة عند حالة الاستقرار والانتشارية الحرارية طردية لوغاريتمية. ومن نتائج الدراسة أيضا انخفاض تأثير الانتشارية الحرارية على الزمن اللازم للوصول الى حالة الاستقرار(S.S.time) وعلى درجة الحرارة عند حالة الاستقرار(S.S.T) بالاقتراب من مصدر التسخين، وفي نفس الوقت فان أثر الفرق بين درجتي الحرارة على طرفي النموذج (ΔT) على كل من (S.S.time) و(S.S.Temp.) ينخفض ايضا بالاقتراب من مصدر التسخين.

الكلمات الداله: انتقال الحرارة غير المستقرة، الانتشارية الحرارية (α)، الفرق بين درجتي الحرارة على جانبي النموذج (ΔT)، الزمن اللازم للوصول للحالة المستقرة (S.S.time)، درجة حرارة النموذج عند الحالة المستقرة (S.S.Temp.).