EXPERIMENTAL DESIGN TO DETERMINE THERMAL DIFFUSIVITY OF A MATERIAL: AN ANALYSIS ON TRANSIENT HEAT CONDUCTION

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Abstract

Thermal diffusivity of any object is of prime importance as it decides the amount of heat energy required to be provided or removed from an object for it to attain the required temperature on its surface at a particular instant of time. Little has been done so far in devising a way of determining the thermal diffusivity directly without having to use costlier setups or be plagued by errors being piled up by multiplication of individual parameter errors. This paper suggests a simple experimental setup which can deduce the thermal diffusivity of a material directly instead of having to calculate the thermal conductivity and specific heat capacity of the materials. The setup model can be effectively used for determining relationship between heat energy stored within and the rate of heat transfer through the outer surface of specimen when there is no heat generation. An illustrative example for the use of the model is also presented with the material in cylindrical geometry with the subsequent differential equations derived. Apart from being simple and accurate, the setup is also highly economic making it a more viable choice. This experimental model could be used for alloys, ceramics and composite materials of various combination ratios.

Keywords: *Thermal diffusivity, Experimental model.*

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1. INRODUCTION

Heat or thermal energy, like all other forms of energy, cannot be destroyed nor be created but can be converted to other forms of energy to suit our needs as in power plants, engines, etc. For this transformation, transfer of this thermal energy must take place to the required locations. This heat transfer could be by any of the three modes of heat transfer such as conduction, convection and radiation[1]. To raise the temperature of an object, one needs to be clear on the amount of energy required to bring that rise in temperature which in turn depends on the inherent property of the material whose temperature is to be risen. The fundamental quantity that enters into heat transfer situations not at steady state is known as thermal diffusivity, which gives the relationship between thermal heat conductivity and amount of heat stored in unit volume of solid[4]. Thus for the heat transfer to take place in the desired fashion, an accurate value of thermal diffusivity is very much essential.

1.1 Diffusivity and Measurement

Thermal Diffusivity is a measure of how quickly a body can change its temperature. It is the ratio of thermal conductivity to thermal capacity.[3] Hence Thermal diffusivity can be measured by determining the two thermal properties like thermal conductivity and heat capacity by experimentally establishing a heat flow boundary value problem , solving the theoretical equations , and measuring the temperatures or heat fluxes to determine thermal property by matching to the theoretical solutions. These methods are time consuming and can be susceptible to errors arising from non-realization of the assumed boundary or steady state conditions.

With the determination of thermal diffusivity of this great importance in application such as ceramics, composites alloys[3], a simple and effective way is very much of a necessity. The conventional methods, plagued with accumulation of measurement errors in individual parameters have always brought the accuracy of the calculated thermal diffusivity down. A direct method to find this could help to eliminate these errors and drastically improve the accuracy of the final value. Even then, the methods end up being way too costly making it an out of the hand option for most situations. With all of this in mind, an attempt was made to formulate a way to directly determine the thermal diffusivity of a material using a simple and cost effective method that is both feasible and usable.

2. MATHEMATICAL FORMULATION

Lumped analysis is carried out in this analysis where when temperature within a body is only a function of time. That is the body nearly remains isothermal during the process. Usually possible for smaller bodies having higher conductivity. In this study, the temperature variation of cylinder with time and position are done. When the specimen is exposed to the surroundings with an elevated temperature T_i which is greater than the surrounding temperature the entire temperature within the specimen is uniform T_i. The formulation of heat conduction problems for the determination of the one-dimensional transient temperature distribution in a cylinder results in a partial differential equation whose solution typically involves infinite series and transcendental equations, which are inconvenient to use[1]. But the analytical solution provides valuable insight to the physical problem, under the conditions of constant thermo-physical properties, no heat generation, thermal symmetry about the mid-plane, uniform initial temperature, and constant convection coefficient, the one-dimensional transient heat conduction problem of the geometry can be expressed as [1]

Differential Equation

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$

The Boundary conditions are as, A long cylinder with radius of r_0 and a uniform initial temperature of T_i is exposed to a Fluid with temperature of T_∞ (T_∞<T_i). The convective heat transfer coefficient between the fluid and cylinder is h. assuming there is no internal heat generation and constant thermo physical properties. Solving the above differential equations with these boundary conditions we get the result as $\theta=A_1\, \mathbf{e}^{-\lambda_n^2 F_0}$ [1][7][8].where $\theta = \frac{T-T_\infty}{T_i-T_\infty}$, $F_0 = \frac{\alpha t}{r_0^2}$ and A1 and $\boldsymbol{\lambda_n}$ are constants, t is the time, $r_0$is the radius, α thermal diffusivity

3. EXPERIMENTAL DEFINITION

The constants A1 and $\boldsymbol{\lambda_n}$ are the functions of Biot number [1]. Once the biot number is known using these relations temperature at any positions can be found out. The determination of the constants $A1$ and $\boldsymbol{\lambda_n}$ usually requires interpolation. For those who prefer reading charts to interpolating, these relations are plotted and the one-term approximation solutions are presented in graphical form, known as the *transient temperature charts*.[2]The transient charts associated with the spherical and cylindrical geometries were developed by Heisler , hence the name HEISLER CHARTS

From the above principle and solution of the differential equation we understood that by knowing the value of constants transient analysis can be done and easily we can obtain the value of thermal diffusivity with the help of transient temperature table. So our aim is to determine those constants experimentally. Thus we have developed an experimental arrangement to obtain these constants.

The solution for the differential equation obtained can be rewritten as $\ln\theta = \ln A_1 - \boldsymbol{\lambda_n}^2 . f_o$ (applying logarithm on both sides) and also as $\ln \theta = \ln A_1 - \boldsymbol{\lambda_n}^2 \alpha t/r^2$, which is in the form of equation of straight line where lnA1 is the intercept and $-\boldsymbol{\lambda_n}^2 \alpha/r^2$ is the slope. So determining the slopes and intercept of the straight line in a graph plotted between dimensionless temperature theta and time will help us to get the value of thermal diffusivity.

3.1 Experimental Procedure

The material to be tested (Mild steel in this experiment) has to be made into a cylindrical form in such a way that the length to radius ratio is greater than 10. Make arrangements to record the centre temperature of the specimen. Make sure not to use normal thermometers since it measures a surface temperature rather than a point temperature.

While using sensors make sure to calibrate it and find the errors. Use a vessel which can accommodate the specimen and has the arrangement to drain the water from bottom. Place the cylindrical specimen in the vessel along with the temperature measuring unit.

Pour hot water into the vessel so that uniform heating is attained for the cylinder. Once the temperature of the specimen is raised and temperature measuring unit shows a steady reading, drain off the water. Replace the water with Ice such that the ice covers the entire specimen. Make sure to use large amount of ice so that the temperature of the surroundings remains constant. Note down the temperature of ice initially. Now record the temperature drop of the specimen in every 10 seconds.

4 EXPERIMENTAL RESULTS

The Temperature drop in every 10 seconds calculated is used to find dimensionless temperature theta, and now a graph is plotted between dimensionless temperature theta and Time

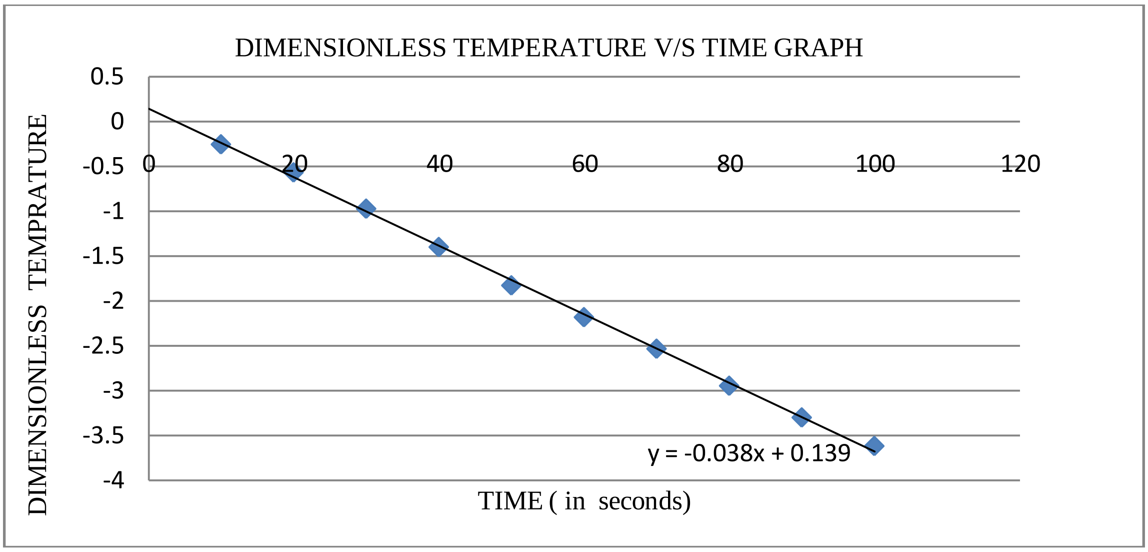

Fig – 4.1 Dimensionless temperatures V/s Time Graph

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Corresponding value of $\lambda_n$for the obtained value of $A_1$from the transient heat conduction table is 1.072.Substituting these values we get thermal diffusivity of the Mild steel Specimen as **$\alpha = 7.479 \times 10^{-6}$ m^2/s**

5. CONCLUSION

The generalized differential equation for heat transfer has been solved for this boundary condition and the solution has been obtained. From the equation it is observed that the constants can be obtained from a simple experimental setup. Accordingly an experimental setup has been created and the experiment has been conducted to obtain the constants and thus thermal Diffusivity Thermal Diffusivity obtained from the experiment carried out using a mild steel Rod and actual value of thermal diffusivity has been compared. Comparing with the actual values of thermal diffusivities there is an error of 20-25 percentages. This is mainly because of certain experimental errors. This error can be reduced to certain extent.

REFERENCES

[1]. Yunus A. Cengel. and Afshin J.Ghajar ***Heat and Mass transfer*** McGraw-Hill Publications, 2010.

[2]. R.K. Rajput, ***Heat and Mass transfer***, S Chand Publications 2012.

[3]. Ibrahim Dincer & Sadik Dost ***Thermal Ditfusivities of Geometrical Objects Subjected to Cooling*** Applied Energy 51 (1995) 111-118 © 1995 Elsevier Science Limited

[4]. Hans Dieter Baehr – Karl Stephen, ***Heat and Mass transfer,*** third edition, Springer.

[5]. Domkundwar&Domkundwar, ***Heat and Mass transfer,***DhanpatRai Publications.

[6]. Incorpera, Dewit, Bergman, ***Fundamentals ofHeat and Mass transfer,*** 2011**.**

[7]. V B Ramanna, ***Advanced Engineering Mathematics,*** McGraw-Hill.

[8]. N.P.Bali, ***Engineering Mathematics,*** Lakshmi Publications, 2011

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