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# DIFFERENTIAL EQUATION SOLUTION OF HEAT TRANSFER OF POLYETHYLENE TEREPHTHALATE FIBER AND COMPOSITE CONCRETE AS A THERMAL NEUTRON SHIELDER

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**KEYWORDS:** Concrete, Fiber, Thermal Analysis, Heat Transfer, Composite Material.

## ABSTRACT
Heat behavior especially flowing and distribution of heat in materials are very important for considering the selection of materials to be suitable for various activities, being able to predict or explain thermal behavior can be considered very useful in engineering field. This research focused on finding general mathematical models to explain or predict heat flow phenomena in fiber reinforced concretes. The study found that heat dissipation in fiber and concrete materials can be explained by nonhomogeneous partial differential equation by setting simple appropriate initial conditions for analysis the models.

## INTRODUCTION
At the present period, concrete materials are very important to human life. Humans need to use concrete materials in many different fields, such as civil engineering work, structural engineering, etc., and new innovations that researchers today begin to pay attention to reinforce some materials into concrete materials in order to allow concrete materials to be used with some properties better, such as being able to support more compressive strength, can support higher impact strength or can be used to prevent thermal neutron radiation better than the normal one [1-5]. Neutrons are considered to be very harmful to human biological systems. Because neutrons are able to interact with hydrogen atoms that are elements of living things and result in harmful chemicals in the body of that organism. Such chemicals are substances such as free radicals caused by the process of decomposition of polymers that are important structures of that organism [6-10]. Nowadays, there is a lot of research that has begun to focus on production composite concrete material system that has the ability to reduce or absorb thermal neutron radiation to reduce such problems [11-12] but interesting issues after researchers have already produced concrete materials is how thermal properties of material be distributed or transferred and how it relates to the mathematical function. These thermal and thermodynamic problems are analyzed by material thermodynamics, engineering mathematics and thermal physics to illustrate the thermal behavior of concrete and materials in concrete especially polyethylene terephthalate (PETE) fibers and sodium borate powder. This research focused only on the heat transfer behavior of the fibers in concrete which is a 1-dimensional (1D) heat transfer and heat transfer in a concrete materials which is a 3D heat transfer with related thermal phenomena.

## EXPERIMENTAL DETAILS
### Materials and procedures
#### *Materials*
For the analysis of thermal conductivity behavior of PETE fibers in concrete, the research analyzed only the heat transfer in one dimension. Polyethylene terephthalate; PETE fibers were used in the analysis, both non-gamma irradiated and irradiated fiber. The basic properties of the fibers used in the analysis processes can be considered in the Table 1. Below. Gamma rays irradiated into the PETE fibers resulted fibers had be changed some characteristics and amount of internal crystals that varied from the original. Fibers that have been irradiated with gamma radiation also have changed in a glass transition temperature values. Researchers often use fibers to pass gamma rays before being added to concrete materials in order to make more stability of fibers. Irradiated fibers lead to difficult to decompose in the alkali condition of concrete, and in the part of analysis the behavior of heat

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transfer in three dimensions of the concrete material, it was used various reinforced concrete with PETE and sodium borate fibers because PETE has properties to help reduce the energy of thermal neutrons, but sodium borate has a good ability to absorb thermal neutrons. This research focused on analyzing the heat flow in fibers and the distribution of heat in concrete materials for establishing a general mathematical model. The basic properties of concrete materials used in the analysis can be considered from the research of Sarayut et al., 2019 [13].

***Table 1. Fundamental properties of PETE fiber [13]***

| **Property** | **Value** |
|---|---|
| Density [1] | 1.365 g/cc |
| Glass Transition Temperature ($T_g$) [2] | 67 ºC |
| Melting Temperature [3] | 254.3 ºC |
| Degree of Crystallinity [3] | 39.68 |
| Weight Average Molecular Weight (MW) [4] | 24495 ± 391 g/mol |

[1] Measurement performed at 28 ºC
[2] Operated using differential scanning calorimeter )DSC, Netzsch, DSC-204-F1( with temperature increment rate of 25 ºC/min and temperature range of -50 to 150 ºC
[3] Calculated using XRD (Bruker, D8 Advance)
[4] Measured using acetate membrane osmometry method.

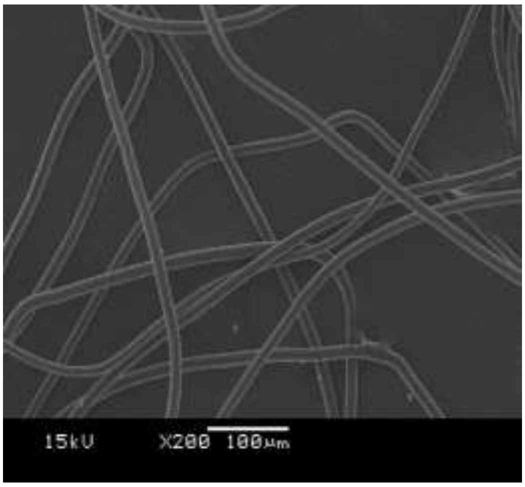

***Fig. 1. SEM picture of fibers (200X, 15 kV)***

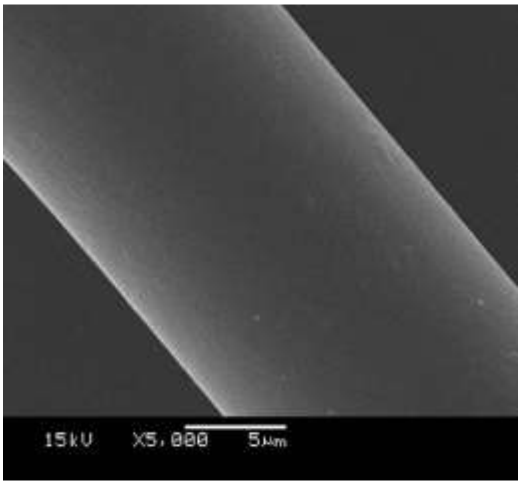

***Fig. 2. SEM picture of fibers (5,000X, 15 kV)***

Fig.1. and Fig.2 are SEM micrographs of fiber in 200 and 5,000 zooming power respectively. The sodium borate/PETE composite concrete was mixed using a pan mixer. For fiber reinforced concrete, concrete was mixed first, after which PETE fibers were mixed into the fresh concrete. Sodium borate was dry mixed with cement in the first stage, followed by the other type of ingredients that shown in the research of Sarayut et al, 2019 [13]. The prepared samples were left of curing in water for 28 days.

***Procedures***

**2.1.2 (A). Analysis heat flow in one dimensional direction of PETE fibers [14-16]**

Assume that the PETE fibers used in the analysis is classified as a homogeneous material throughout the length of the L, and has a cross-sectional area equal to A, which has the condition that the heat can flow in the same direction as the length of the fiber only. The same temperature was assumed to be occurred in any point which is in the same planar of cross-sectional area. One end of the fiber was set as the position x = 0 and the other end was at the position x = L as shown in Figure 3 below.

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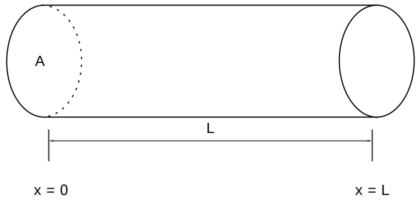


*Fig. 3. Fiber geometry which has the length L and cross sectional area A.*

Given **u** is the amount of heat stored in the fibers at the position **x** at any time **t** and if given no heat flowing through both ends of the fibers. **G(d,z)** is a multiplier function that shows the relationship between the amount of crystals (**d**) in the fiber and the amount of gamma radiation projected (**z**). Diffusivity ($\mathbf{c^2}$) was timed to the flowing of heat rate term ($\frac{\partial^2 \mathbf{u}}{\partial \mathbf{x}^2}$). The nonhomogeneous partial differential equation that shows the flow of heat within the fiber can be written as

$\frac{\partial u}{\partial t}=c^2\frac{\partial^2 u}{\partial x^2}$ with initial conditions; $0<x<L$, $t>0$, $u(0,t)=0$, $u(L,t)=t$, $u(x,0)=f(x)$

**2.1.2 (B). Analysis heat flow in three dimensional direction of PETE fibers [17-20]**

Considering the concrete materials in the spherical coordinate system in the xyz coordinate system

From Figure 4, the point **P** stored heat **u**, where **P** is at the coordinates **P (x, y, z)**. If given **ρ**; the angle that is counted with the **x** axis, **θ**; the angle is counted with the **y** axis and **∅**; the angle that is counted with the z-axis. $\mathbf{C^2}$ is thermal diffusivity and functions **F (B, j)**; a multiplier function which is a function that shows the relationship between the amount of sodium borate (**B**) and the amount of fiber inserted into the concrete (**j**)

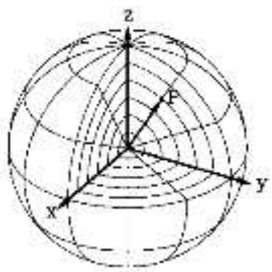


*Fig. 4. Spherical geometry of a composite concrete material*

Given **R** is a radius of assumed spherical coordinate with initial conditions; $\mathbf{0<\rho<R,\ 0<\emptyset<\pi,\ u(R,\emptyset)=f(\emptyset)}$ and according to the distribution of heat, so that

$$\frac{\partial^2 u}{\partial t^2}+\frac{2}{\rho}\frac{\partial u}{\partial \rho}+\frac{1}{\rho^2}\frac{\partial^2 u}{\partial \emptyset^2}+\frac{\cot\emptyset}{\rho^2}\frac{\partial u}{\partial \emptyset}=0$$

# RESULTS AND DISCUSSION

**Analysis heat flow in one dimensional direction of PETE fibers**

According to the equation $\frac{\partial u}{\partial t}=c^2\frac{\partial^2 u}{\partial x^2}$, when the effect of the amount of crystal in the fiber is analyzed, the general solution of partial differential equation can be written as

$$u(x,t)=\frac{2G(d,z)}{L}\sum_{n=1}^{\infty}\left(\int_0^{\infty} f(x)\sin\frac{n\pi x}{L}dx\right)e^{-\left(\frac{[cn\pi]^2}{L^2}\right)t}\sin\frac{n\pi x}{L}$$

Note that the value of multiplier function **G(d,z)** will be established by experiments. In the previous model, heat stored (**u(x,t)**) in the fiber in point **x** at time **t** will be revealed by substitution another desired values in equation.

**Analysis heat flow in three dimensional direction of PETE fibers**

According to the equation $\frac{\partial^2 u}{\partial t^2}+\frac{2}{\rho}\frac{\partial u}{\partial \rho}+\frac{1}{\rho^2}\frac{\partial^2 u}{\partial \emptyset^2}+\frac{\cot\emptyset}{\rho^2}\frac{\partial u}{\partial \emptyset}=0$, when the effect of amount of sodium borate and fiber is co-analyzed, the general solution of differential equation can be written as

$$u(\rho,\emptyset)=F(B,s)\left[\sum_{n=1}^{\infty}\left[\frac{2n+1}{2R^n}\int_0^{\pi}f(\emptyset)P_n(\cos\emptyset)\sin\emptyset d\emptyset\right]\rho^n P_n(\cos\emptyset)\right]$$

Where, $\mathbf{F}(\mathbf{B},\mathbf{s})$ is a multiplier function; a multiple variables function which was proportionally to amount of sodium borates and fibers. $\mathbf{F}(\mathbf{B},\mathbf{s})$ will be obtained by experiments. If fraction of reinforcing agents was changed, a multiplier function $\mathbf{F}(\mathbf{B},\mathbf{s})$ will be also varied. The above equation is intended to predict the flow or distribution of heat in fiber/sodium borate composite concrete. In order to evaluate the thermal behavior of the material before actually using it, in the future, research should be considered more accuracy. For example, in reality-the fibers do not have a perfect straight line. The diffusivity of the fibers is still likely to change according to the amount of gamma radiation projected. Moreover, at both ends of the fiber, it is not an insulator like the conditions set. In another view, the correctness of the distribution of heat in the concrete should be adjusted more accurately by analyzing the uneven distribution of sodium borate and fiber inside, and more importantly; both the fiber and the concrete itself can also transfer heat between objects in secondary form, heat radiation which if there is an improvement in the said movement will make this research complete and can be used to predict the thermal behavior of the material as well

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